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RADIATION PROTECTION

PROGRAMME

1990-91

Final report

Volume 2

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Relación de actividades
Programa
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Beretning
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STRÅLINGSBESKYTTELSE

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STRAHLENSCHUTZ

Έκθεση πεπραγμένων
Πρόγραμμα
ΠΡΟΣΤΑΣΙΑ ΑΠΟ ΑΚΤΙΝΟΒΟΛΙΕΣ

Progress report
RADIATION PROTECTION
Programme

Rapport d'activité
Programme
«RADIOPROTECTION»

Rapporto d'attività
Programma
RADIOPROTEZIONE

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RESEARCH IN RADIATION PROTECTION

VOLUME II

Radiation Protection Programme 1990-1991 - Final Report
Volume 2
Summary

The final report of the 1990-1991 period of the radiation protection programme outlines the research work carried out during the whole contractual period under all contracts between the Commission of the European Communities and research groups in the Member States. More than 450 scientists collaborated on this programme.

Results of more than 350 projects are reported. They are grouped into three sectors:

1 Human Exposure to Radiation and Radioactivity, which includes:

1.1 Measurement of Radiation Dose and its Interpretation
1.2 Transfer and Behaviour of Radionuclides in the Environment

2 Consequences of Radiation Exposure to Man; Assessment, Prevention and Treatment, which includes:

2.1 Stochastic Effects of Radiation
2.2 Non-Stochastic Effects of Radiation
2.3 Radiation Effects on the Developing Organism

3 Risks and Management of Exposure, which includes:

3.1 Assessment of Human Exposure and Risks
3.2 Optimization and Management of Radiation Protection

Within the framework programme, the aim of this scientific research is to improve the conditions of life with respect to work and protection of man and his environment and to assure safe production of energy, i.e.:

(i) to improve methods necessary to protect workers and the population by updating the scientific basis for appropriate standards;
(ii) to prevent and counteract harmful effects of radiation;
(iii) to assess radiation risks and provide methods to cope with the consequences of radiation accidents.

CONTENTS OF VOLUME II

DYSFUNCTION AND NEOPLASIAS OF HAEMOPOIETIC AND OSTEOGENIC TISSUE FOLLOWING EXTERNAL IRRADIATION OR BONE-SEEKING RADIONUCLIDE CONTAMINATION *IN UTERO* OR DURING NEONATAL DEVELOPMENT

THE DOSIMETRY AND EFFECTS OF FETAL IRRADIATION FROM INCORPORATED RADIONUCLIDES (NRPB ASSOCIATION)

II

CONSEQUENCES OF RADIATION EXPOSURE TO MAN; THEIR ASSESSMENT, PREVENTION AND TREATMENT

Non-stochastic effects of radiation

IMPAIRMENT OF THE HEMO-LYMPHOPOIETIC CELL SYSTEM AND ITS MICROENVIRONMENT BY IONIZING RADIATION. PATHOGENESIS OF NON-STOCHASTIC AND NEOPLASTIC EFFECTS AND CONDITIONS FOR A LONG TERM RESTORATION

Contract Bi6-061 - Sector B21

1) *Fliedner*, Univ. Ulm

Summary of project global objectives and achievements

The Ulm group contributing to the CEC Radiation Protection Programme is located in the Department of Clinical Physiology and Social Medicine of the University of Ulm, directed by Prof. Dr. Dr.h.c. Theodor M. Fliedner, and is recognized by WHO as a Collaborating Center for Radiation Accident Preparedness and Assistance. The Global Objectives of its research programme are to broaden and deepen the scientific basis for the medical management of persons accidentally exposed to ionizing radiation. The radiation accident situation around the world has shown that such accidents may occur any day and may involve a few persons (such as in Israel 1990, in Moscow (1991), but also hundreds or many thousands of persons (such as in Mexico (1983/84), Goiania (1987) or Tschernobyl (1986)). The experience has also shown, that the medical response to the accidental exposure of persons is still unsatisfactory and requires improvement. The deficits in knowledge are centred around two major questions: 1. What possibilities exist to evaluate the type and extent of radiation injury in order to come to prospective conclusions and to develop therapeutic strategies recognizing research advances made. 2. What possibilities exist to treat radiation induced damages on the basis of an answer to the question, whether the damage caused in organ systems, such as hematopoiesis, is reversible in principle or is irreversible.

The research work performed in 1990, 1991 and 1992 (January through April) concentrated on two problem areas:

1. Improvement of existing and development of new hematological indicators to predict the radiation exposure consequences in man as a basis for clinical management.

2. Improvement of existing and development of new knowledge regarding the pathophysiological mechanisms that govern the hematological consequences of radiation exposure as a prerequisite for therapeutic improvements.

The extent of work that could be performed during the period of reporting, was limited by the resources available.

Nevertheless, important achievements could be obtained and are summarized as follows:

1. Radiation response indicators

During 1990 - April 1992 the emphasis of the research work performed in this area was in the systematic analysis of radiation accident case reports in order to collect suitable information on the signs and symptoms of response to total body exposure. In close collaboration with the Institute of Biophysics (with the hospital No. 6) in Moscow, a "precomputer case report (PCR)"(with 199 pages) was developed. This will provide for the first time an international approach to single out those indicators that are of predictive value for developing suitable therapeutic approaches. The group in Moscow and our own group has access to several hundred radiation accident case reports and it could be clearly shown, using the first 30 case histories, that this PCR is suitable to record in a systematic way those signs and symptoms, that develop during the first 60 days after exposure. This PCR will now be used to record as many case histories as possible and to develop a computerbased data collection in order to be able to correlate early signs and symptoms with later clinical developments and subsequently to develop a computer aided system for radiation accident management assistance.

Using a limited number of case histories, a systems engineering model of human granulocytopoiesis was developed further in collaboration with the Department of Measurement, Control and Microtechnology of Ulm University (Director: Prof. Dr. Hofer) to calculate from the pattern of granulocyte changes in accident situations the number of stem cells that remained after total body radiation exposure and from which recovery could commence. It was found that a clinical course "reversible damage to hemopoiesis" could clearly be distinguished from a category "irreversible damage to hemopoiesis". If more than 6 per 10^6 calculated stem cell units were available, then a recovery is possible without stem cell transplantation. If the number is less, then an irreversible course is most likely. Thus, it became clear that systems modeling can be of assistance in developing "systems indicators" to evaluate the extent of damage to the hemopoietic system after exposure.

As far as "biological indicators" are concerned, our group concentrated on studies following radiation induced chromosomal aberrations as a function of time after high dose total body irradiation and bone marrow transplantation. This study is performed to analyse the predictive value of such aberrations in the months following exposure. It was found that there is a characteristic disappearance pattern of radiation induced chromosomal aberrations after high dose irradiations. The results obtained will permit us to calculate the details of the disappearance rate as a basis for an improved calculation of the extent of exposure received.

2. Pathophysiology of radiation exposure as a basis for improvement of therapeutic approaches

The work performed during the reporting period may be characterized by two approaches: Systems research and case studies. As far as systems research is concerned, a further improvement of the granulocyte renewal model was obtained. The granulocyte renewal system can now adequately be described by 37 differential equations (in collaboration with Prof. Hofer and Dr. Tibken from Ulm University). This model is able to simulate the course of granulocyte changes after total body exposure in a large number of observed cases. It is crucial to assume an "injured stem cell compartment" with cells that are injured by not destroyed and therefore still capable of a limited number of cell division. This systems approach allows us to test the site of therapeutic actions. For instance, it will now be possible to analyse the pathophysiology of the use of recombinant regulation factors in radiation accident management and to improve it in cases of reversible damage to hemopoiesis.

As far as the megakaryocytic system is concerned, we were able to develop a new biomathematical model of the megakaryocytic cell renewal system as a basis for trying to understand better the responses of this system to total body irradiation.

Finally, in cooperation with Dr. M. Körbling from Heidelberg University, it has been possible to study more than 30 patients that received total body irradiation to an extend of 1000 - 1400 cGy, were treated with autologous bone marrow transplantation, and received blood stem cells (autologous). These data were analysed with respect to treatment results (comparison of bone marrow versus blood derived stem cells). It was shown, that the use of blood derived stem cells results in an earlier recovery of hemopoiesis as compared to bone marrow derived stem cells. It was also of interest to compare the pattern of hematopoietic recovery with the computer simulation model of granulocytes. This study confirmed the value of the computer simulation approach for trying to understand the pathophysioloy of hemolymphopoietic recovery after total body irradiation and stem cell transplantation.

Project 1

Head of project: *Prof. Fliedner*

Objectives for the reporting period

The objectives for the reporting period (1.1.1990 - 30.4.1992) were to obtain answers to the following questions:

1. In what way is it possible to improve existing and develop new knowledge on hematological indicators to predict the radiation exposure consequences in man as a basis for the clinical management of persons, accidentally exposed to penetrating ionizing radiation? Which advances can be made using "biomathematical indicators" as a result of cell systems engineering research and by "biological indicators" such as chromosomal aberrations?
2. In what way is it feasible to improve existing or develop new knowledge on the pathophysiological mechanisms that govern the hematological consequences of radiation exposure in the critical hematopoietic cell renewal systems as a basis for the improvement of treating radiation exposed persons?
3. Which are the options to improve existing or develop new methods to modify the response of hemopoietic tissues to radiation exposure utilizing means and ways to establish stem cell banks for persons at risk and to influence and enhance regeneration of radiation injured hematopoiesis.

Progress achieved including publications

1. Computer Data Base of Radiation Accident Case Histories

In collaboration with Prof. Baranov (Institute of Biophysics and Hospital No. VI of the Ministry of Health, Moscow) a "pre-computer case report" (PCR) was developed. It consists of all possible signs and symptoms that have been and can be recorded during the first 60 days after accidental total body radiation exposure. It has been successfully tested in more than 40 case histories collected in Moscow and in Ulm and found to be excellently suited to record signs and symptoms as a function of time after exposure as a basis for developing a computer data base to be able to compare "new cases" to cases successfully or unsuccessfully managed previously. This PCR will now be presented to an international expert group in order for it to be approved and recommended at a global level within the framework of the WHO collaborating centers on radiation accident management.

2. Computer Simulation of Radiation Accident induced Blood Cell Changes

In cooperation with Prof. Hofer and Dr. Tibken from the Department of Measurement, Control and Microtechnology of our University, a granulocyte renewal system was developed on the basis of systems engineering approaches to be able to simulate granulocytic blood cell changes after accidental exposure. The system (Fig. 1) consists of 7 cellular and 2

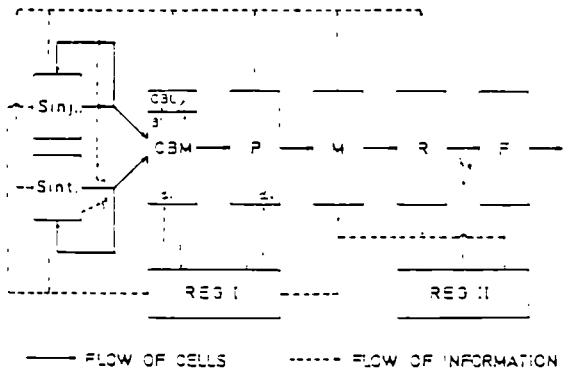


FIG. 1 - MODEL OF GRANULOCYTOPOIESIS

regulator compartments. Of crucial importance is a compartment of "injured stem cells" that have lost their unlimited replicative capacity, but are still capable of a limited number of divisions. Using this model - described by 37 differential equations, we were able to simulate the granulocyte changes in 4 patients with reversible injury (Fig. 2). Thus, we could calculate the number of "stem cell units" that must have been present to allow or not allow regeneration (Fig. 3). In one case (accident Israel 1990, Fig. 4) the regeneration observed beyond 10 days was induced by bone marrow cell transplantation on day 5 after accidental exposure. The calculation of the number of stem cells indicates that more than 6 per 10^6 calculated stem cell units must remain intact if a spontaneous regeneration of hemopoiesis is to occur after exposure. This calculation can be made within 5-6 days after accidental exposure, early enough to institute appropriate therapeutic regimens.

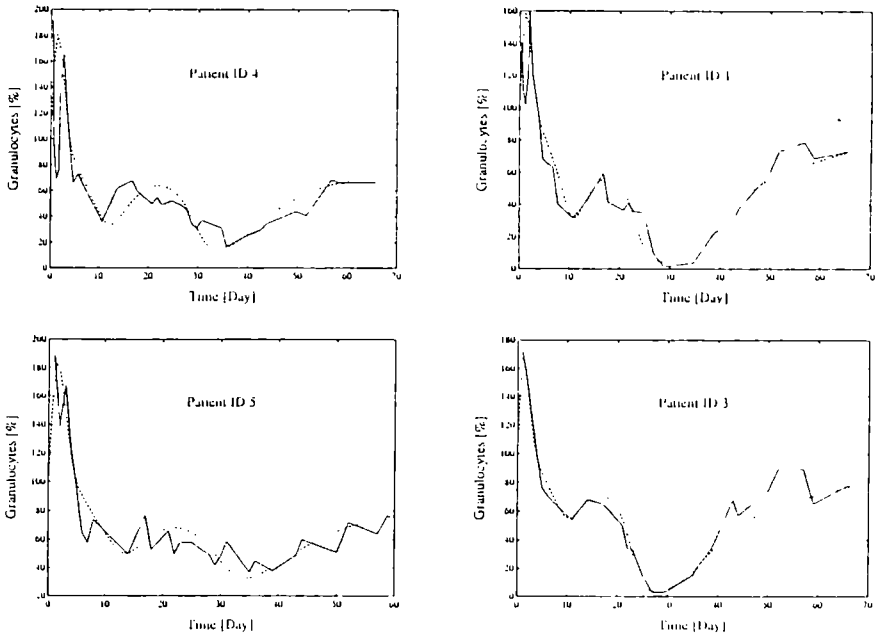


FIG. 2 - COMPARISON OF MODEL OUTPUT AND PATIENT DATA FOR IRRADIATION

	Remaining Intact Stem Cells % (Cell Number)	Remaining Injured Stem Cells % (Cell Number)	Destroyed Stem Cells % (Cell Number)
Patient ID: 4	0.06 ($7.5*10^5$)	5.6 ($7.0*10^{10}$)	94.34
Patient ID: 5	0.26 ($3.25*10^6$)	8.0 ($1.0*10^8$)	91.74
Patient ID: 1	0.0004 ($5.0*10^3$)	5.28 ($6.6*10^7$)	94.72
Patient ID: 3	0.0006 ($7.5*10^3$)	9.12 ($1.14*10^8$)	90.88
Brescia Case	0.0 (0)	0.0 (0)	100.0
Norway Case	0.0 (0)	0.0 (0)	100.0
Sor-Van Case	0.0 (0)	0.0 (0)	100.0
Moscow Case	0.0 (0)	0.001 ($1.25*10^4$)	99.999

FIG. 3 - COMPUTER DERIVED CALCULATIONS OF STEM CELL POOL SIZES

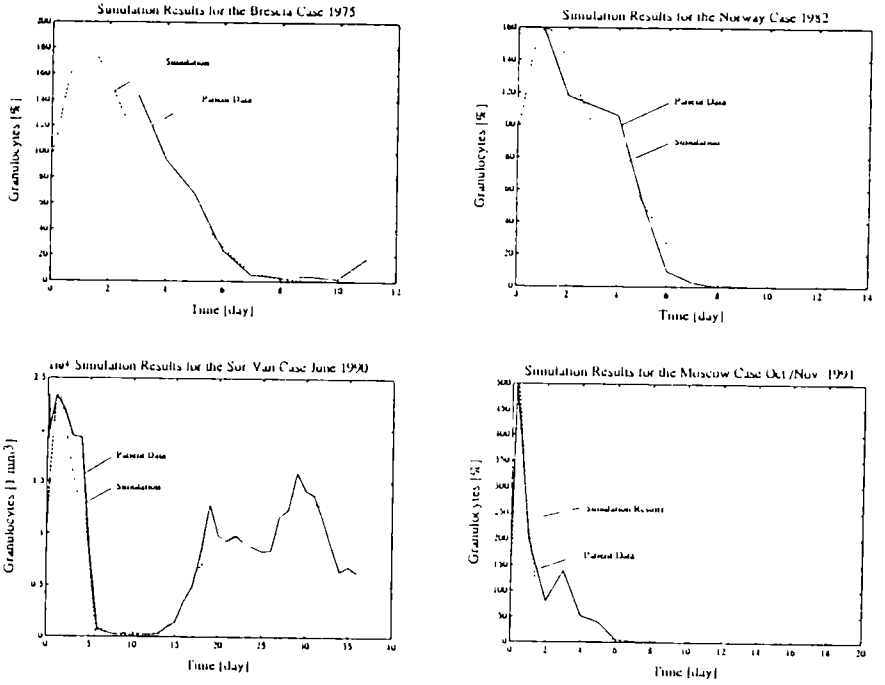


FIG. 4

In order to test, whether the "calculated stem cell units", that are the result of computer simulation approaches of clinical observations can be seen in relation to the "biological stem cells" actually transfused, we used the blood granulocyte regeneration curves of several patients with hematopoietic neoplasms who received total body irradiation and subsequently an infusion of autologous (cryopreserved) blood derived stem cells. 3 granulocyte recovery patterns are shown in fig. 5 after the transfusion of 71, 296 and 505 x 10^4 CFU-GM. These curves can be simulated if one assumes that the stem cell pool is restored to 4, 10 or 20% of normal by the transfusate. If one correlates these data, it is evident, that there appears to be a strong correlation between the number of CFU-GM transfused and the calculated fraction of stem cells from which recovery may commence. This gives strong evidence, that the biomathematical model used (see fig. 6) is valid and should be developed further to increase its conceptual power.

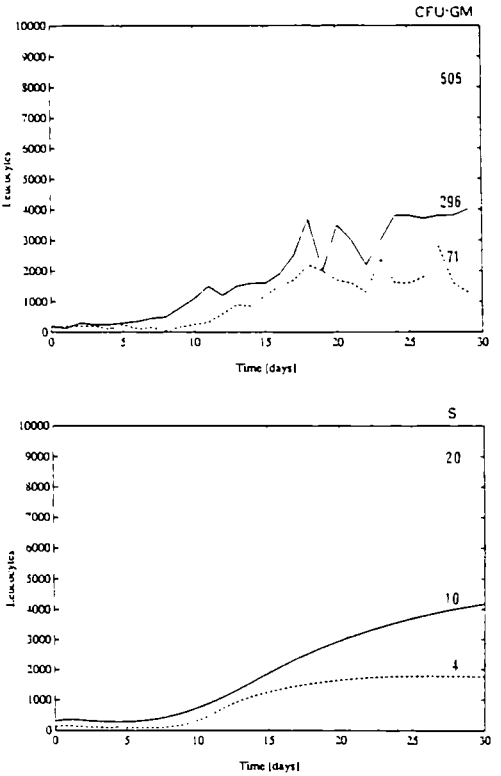

CFU-GM
505
296
71
Time (days)
S
20
10
4
Time (days)

FIG. 5

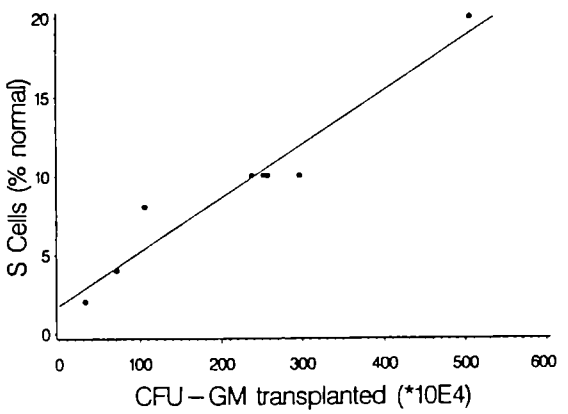

S Cells (% normal)
CFU – GM transplanted (*10E4)
0
5
10
15
20
0
100
200
300
400
500
600

FIG. 6

3. Development of a Computer-based Assistence System for Radiation Accident Management

The data base (see point 1) for radiation accident case histories is an important element for the development of a computer based radiation accident management assistance system. It has been the purpose of the studies during the reporting period to develop and evaluate software programmes necessary to develop a full scale system.

A knowledge-based assistance system is a computer-based advisor to guide pysicians to deal with medical problems. The management of the acute radiation syndrome is a seldom occuring medical problem. Elder experts still have the knowledge how to tackle this problem but young physicians have almost no possibility to gain experience in how to manage an accidentially irradiated person. To ensure the optimal management of the acute radiation syndrome in the future physicians should have at hand a computerized guidance to deal with radiation injuries.

After switching on the guidance it must be capable to "discuss" with the physician in charge the problems of the acutely irradiated person and to adivse him in how to optimally make a medical management plan. For the easy communication with in general unexperienced computer users the patient card metaphor is applied. A physician knows very well how to browse through, how to insert data into, and how to retrieve information from a patient card. The simulation of a patient card on the computer screen, which is easily usable by the physician and which can be used by the advisor to display its advice, has been implemented. A control blackboard architecture has been applied to plan the management according to the established medical strategy sequential diagnosis. The management plan which is composed of diagnostical, prognostical, and therapeutical tasks can be visualized on the patient card to give the physician in charge a good overview.

Basic knowledge about the management, the diagnosis, the prognosis, and the therapy of the acute radiation syndrome has been compiled to be used by the knowledge-based assistance system. The sources of the knowledge have been both elder experts and the literature. Wet data of real cases are used to evaluate the behaviour of the prototypically implemented advisor.

4. Chromosomal Aberrations as an Indicator after High Dose Total Body Irradiation

29 patients (CML; AML; AML) were cytogenetically examined after total body irradiation (1200 cGy) and chemotherapy and bone marrow transplantation with respect to the fate of host lymphocyte or bone marrow cell aberrations as a function of time after irradiation. A total of 37.985 mitotic figures

were examined. The course of dicentric chromosomal aberrations per 100 metaphases is given as a function of time in Fig. 7.

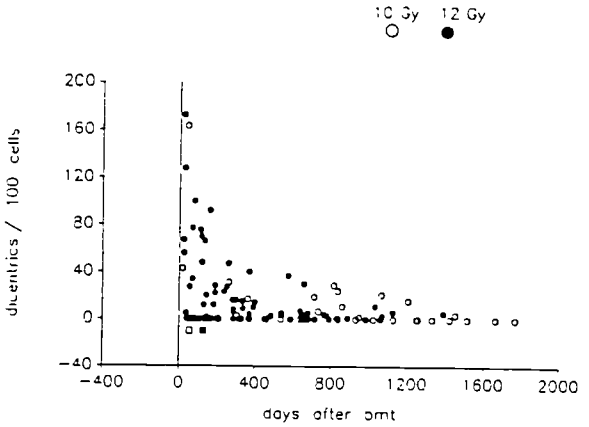


FIG. 7

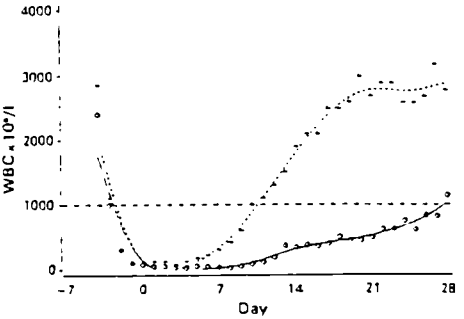
This shows that the number of such aberrations persists for several years after such an excessive exposure. Up to 10 multicentric aberrations can be observed and cells with such aberration numbers can persist for many years. These studies are of importance if one wants to use chromosomal aberrations as indicators to extrapolate back to exposure levels and to predict risks for the induction of radiation induced late effects.

5. Pathophysiology of total body exposure and results of stem cell therapy

In order to answer the question whether stem cell banks can be established to cryopreserve pluripotent hemopoietic cells and to have them available in case of whole body overexposure (for persons at risk, such as rescue team workers) a study was performed (in collaboration with Dr. M. Körbling from the Department of Internal Medicine, University of Heidelberg (Director: Prof. Hunstein)) to study patients with hemopoietic malignancies that were subjected to total body irradiation. Their stem cells were isolated from either bone marrow or blood, cryopreserved and reinfused after total body irradiation.

Complete and sustained hemopoietic function following myeloablative therapy can be successfully achieved by autologous transfusion of blood derived hemopoietic stem cells.

It was the purpose of this study to compare autologous blood stem cell transplantation (ABSCT) in 20 patients with autologous transplantation of a mafosfamide purged marrow (pABMT) in 23 patients; all were transplanted in first complete remission (CR) of acute myelogenous leukemia (AML) using the same pretransplant regimen (14.4 Gy total body irradiation and 200 mg/kg cyclophosphamide). The autografts, mostly differing in source of hemopoietic stem cells, cell composition and CFU-GM number, were evaluated for their ability to reconstitute hemopoiesis and induce long-term disease-free survival (DFS). Prior to harvest, hemopoietic stem cells were mobilized by inducing transient myelosuppression (ara-C 100 mg/m² every 12h s.c. days 1 - 5 and daunorubicin 45 mg/m², days 3 and 4) followed by an overshooting of peripheral stem cell concentration (Fig. 8).



Course of peripheral white blood cell concentration following myeloablative therapy and autologous transplantation of blood derived (----) or bone marrow derived (——) stem cells on a daily blood count basis. Day 0 = day of transplantation. + = individual, daily values after autologous blood stem cell transplantation. ◇ = individual, daily values after autologous bone marrow transplantation.

FIG. 8

The major differences of both transplant approaches were the following: (1) the blood stem cell autograft contained 17-fold more mononuclear cells (MNC) than the bone marrow autograft;(2) white blood cell (WBC) reconstitution following myeloablative therapy and ABSCT was initiated significantly earlier; the median time to reach 1000 x 10^6/I WBC was 10 days (ABSCT) versus 28 days (pABMT); (3) platelet reconstitution occured faster following ABSCT compared with pABMT, although the significance was borderline; (4) the patients' hospital stay was significantly shorter following ABSCT (45 days) versus pABMT (73 days); (5) of 20 ABSCT patients, 14 have relapsed compared with 11 out of 23 patients autografted with bone marrow; (6) the probablity of DFS 2 years after transplantation as higher in the pABMT group (51%) compared with the ABSCT group (35%). Due to the small sample size and thus limited statistical power the difference was not statistically significant. This is a first report comparing the characteristics of ABSCT with pABMT, where fast hemopoietic reconstitution and easy access to the peripheral

stem cell source are the obvious advantages of the ABSCT approach. The timing of blood stem cell harvest, prior consolidation treatment and stem cell mobilization procedures seem to be crucial for the clinical outcome of ABSCT.

In addition, these data provide important evidence, that stem cell banks are feasible in man and that the collection of blood derived stem cells is most likely more efficient for later use than are bone marrow derived stem cells.

6. Studies on the Collection and Use of Blood derived Stem Cells

In order to obtain a sufficient number of stem cells from the peripheral blood to be cryopreserved for reinfusion after a myeloablative dose of total body irradiation, studies were performed to increase the number of stem cells in the blood. These studies were performed in close collaboration with the Department of Internal Medicine V of the University of Heidelberg (Director: Prof. Dr. W. Hunstein).

We investigated the effect of recombinant human granulocyte-macrophage colony-stimulating factor (rhuGM-CSF) on the pool of circulating hemopoietic progenitor cells in 11 patients with hematclogical malignancies of nonmyeloid origin and one patient with sarcoma. These patients were eligible for autologous blood stem cell transplantation rather than autologous bone marrow transplantation because sufficient marrow aspirates could not be performed due to damage at the usual sites of bone marrow harvest by previous chemo- and/or radiotherapy. Recombinant human GM-CSF was given as continuous i.v. infusion via central venous line for a median time of 11.5 days (range 5-22 days), during which a median number of six aphereses were performed. In comparison to the pretreatment level the median increase in the number of granulocyte-macrophage colony-forming units (CFU-GM)/ml of peripheral blood was 8.5-fold. In all 12 patients a median decrease of the platelet count of 21% (range 7% - 67%) was observed during rhuGM-CSF treatment prior to the start of the apheresis procedures. Six patients were treated with a myeloablative conditioning therapy consisting of total body irradiation and/or high-dose polychemotherapy followed by autografting with blood stem cells. Five of them achieved a sustained engraftment. Recombinant human GM-CSF proved to be highly efficient in increasing the number of circulating progenitor cells in these patients with severely compromised hemopoiesis. Blood stem cells harvested under a rhuGM-CSF treatment are capable of restoring hemopoiesis in man after a myeloablative pretransplant therapy.

In addition, another clinical study was performed to test different approaches to mobilize stem cells to be collected from the peripheral blood: Patients with relapsed Hodgkin's disease who respond to salvage therapy are successfully treated with cyclophosphamide, carmustine (BCNU), and etopo-

side (VP-16) (CBV) followed by autologous bone marrow transplantation (ABMT). Because of heavy pretreatment including radiation to the pelvic site, marrow harvest was not feasible in those patients. We therefore used blood-derived hemopoietic precursor cells as an alternative stem-cell source to rescue them after superdose chemotherapy hemopoietic precursor cells were mobilized into the peripheral blood either by chemotherapeutic induction of transient myelosuppression followed by an overshooting of blood stem-cell concentration, or by continuous intravenous (IV) granulocyte-macrophage colony-stimulating factor (GM-CSF)administration. The median time to reach 1,000 WBC per microliter, 500 polymorphonucelar cells (PMN) per microliter, or 20,000 platelets per microliter was 10, 20.5, and 38 days, respectively, for 50% of all patients. The platelet counts of two patients never dropped below 20,000/ul following autologous blood stem-cell transplantation (ABSCT), whereas two other patients had to be supported with platelets for 75 and 86 days posttransplant until a stable peripheral platelet count of 20,000/ul was attained. Among the 11 assessable patients, seven are in unaintained complete remission (CR) at a median follow-up of 318 days. This is a first report on a series of ABSCTs in patients with advanced Hodgkin's disease proving that,despite prior damage to the marrow site, the circulating stem-cell pool is still a sufficient source of hemopoietic precursor cells for stem-cell rescue.

7. Megakaryocyte Model of Hemopoiesis

To incorporate recent experimental results we developed a new mathematical model of the thrombopoietic system.

The model is a compartment model, implemented with a system of differential equations. The stochasticy of the process is described by using subcompartments. The model includes 8 main compartments: the undetermined stem-cells, the clonogenic cells committed to megakaryopoiesis, the endomitotic compartment, 4 compartments for the maturing megakaryocytes of ploidy 8, 16, 32 and 64n and the compartment of thrombocytes.

Simulations have been done for the kinetics of nearly all kinds of perturbations from the steady state of the system. The results of these simulations were compared with experimental data from the literature, including acute and chronic thrombopenia and thrombocytosis, hydroxyurea treatment and total body irradiation. The model is capable of simulating most of these experimental data. To simulate the compensated megakaryocytopenic state after irradation the influence of the other hematopoietic linages has to be considered.

The simulations showed,that a good correlation between model results and most of the experimental data can be achieved. In experiments, where the correlation is bad, it has been found, that the experimental data cannot be explained with the current concept of thrombopoiesis.

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NON-STOCHASTIC EFFECTS OF IRRADIATION IN MAN: DIAGNOSIS, PROGNOSIS AND TREATMENT OF ACUTE RADIATION INJURY

Contract Bi6-065F - Sector B21

1) *Jammet*, CIR

Summary of project global objectives and achievements

The global objective of the research programme is an increased knowledge of the pathophysiology of total-body irradiation (TBI) in different conditions of dose rates and fractionation, in order to derive diagnostic and therapeutic attitudes in the eventuality of accidental acute irradiation of large parts of the body.

It is based on the analysis of clinical protocols of TBI comparing various modalities of dose delivery, on the measurement and evaluation of biological parameters after TBI, either as biological dosimeters or as pathophysiological markers for diagnosis or prognosis and on experimental data.

Total- or large-part-of-the-body-irradiation induce not only profound alterations to the haematopoietic system with, according to the absorbed dose, short term implications in the vital prognosis, but also immediate or evolutive alterations of various organs (lens, lung,...). These dose-delivery related effects have been analyzed in a randomized protocol comparing single versus fractionated TBI, and low versus high dose rate (Pr A Laugier, Hopital Tenon, Paris).

Bone marrow transplantation, as a therapy for radiation induced myeloid aplasia, still poses a number of clinical problems, mainly related to the tolerance of allogenic bone marrow.

Dosimetry is essential in accidental situations in order to avoid graft rejection. Biological dosimetry based on chromosome aberrations does not provide alone accurate dose estimations in many situations (varying dose rates, energy, fractionation, protraction,...). Complementary biological indicators would be very usefull to reduce the range width of dose estimations. Among several serological parameters investigated, amylasemia appears as an early indicator (24 h) of acute irradiation (above 2 Gy) including parotid glands. Of the serum interleukines investigated after TBI, only IL6 diclosed an early, dose related, spike above 2 Gy, the biological significance of which is still unclear (Pr JM Cosset, H Magdelenat, Institut Gustave Roussy,Villejuif, and Institut Curie, Paris).

The success of bone marrow transplantation depending upon MHC compatibility between the donor and the receiver, HLA typing is a prerequisite to transplantation. As accidentally irradiated patients may present with few circulating lymphocytes, new methods requiring very few nucleated cells, such as DNA amplification by PCR (Polymerase Chain Reaction) will help overcome this situation (Pr JM Cosset, Villejuif and Paris)

GVHD (graft vsersus host disease) has not been yet eradicated as a complication of allogenic bone transplantation and, in some instances may render allogenic transplantation more deleterious than beneficial. It is of high theoretical and practical priority that experimental and clinical immunopharmacology help reduce GVHD in accidental TBI. Specific depletion of human alloreactive T cells has been achieved by the group of A Fischer (Hopital Necker, Paris) as well as encouraging results in the tolerance of MHC-mismatched allografts in an animal model.

The molecular mechanisms of interphasic, programmed cell death (apoptosis) were investigated in irradiated human lymphocytes. Induction of Ubiquitin gene transcription and nuclear protein ubiquitination were shown to be involved in radiation induced apoptosis and delay in lymphocyte death could be obtained in vitro with anti-sens oligonucleotides.(Institut Curie, Paris)

Project 1

Head of project: *Prof. Jammet*

Objectives for the reporting period (Reporting period : 1990 - 1991 - 1992.)

Clinical investigations

• Toal-body irradiation and transplantation

Biological investigations

• HLA phenotyping after total body irradiation.

• Serological dosimetry

• Cytokines after total body irradiation.

• Growth factors in fibrotic process

Experimental investigations

• Physiopathology of the irradiated human lymphocyte

- Analysis of chromatine structure
- Mechanisms of interphasic cell death

• Tolerance to HLA-mismatched allogenic bone marrow transplantation

Progress achieved including publications

1. Clinical investigations

Total-body irradiation before bone marrow transplantation (Pr A Laugier):

The data obtained concern the survey of 157 patients referred to the Department of Radiation Oncology of the Hospital Tenon (Paris) between 1987 and 1989 for total-body irradiation (TBI). They were treated accordin to the following two techniques: (1) either in one fraction (1000 cGy to the midplane at L4 and 800 cGy to the lungs) or six fractions (1200 cGy on 3 consecutive days to the midplane at L4 and 900 cGy to the lungs). The patients were randomized according to two instantaneous dose rates (LOW or HIGH) in single-dose (6 *vs* 15 cGy/min) and fractionated (3 *vs* 6 cGy/min) TBI groups. There were 77 patients in the LOW group and 80 in the HIGH group, with 57 patients receiving single-dose TBI (28 LOW and 29 HIGH) and 100 patients receiving fractionated-dose TBI (49 LOW and 51 HIGH). At 4 years (March 1991), relapse-free survival and survival rates were 54.9 % and 50.7 % in the LOW group; 61.9 % and 53 % in the HIGH group (p = 0.69 and 0.82, respectively). There was no difference in the incidence of graft *vs* host disease (GVHD), interstitial pneumonitis (IP), or venoocclusive disease either between the LOW and the HIGH groups or between the single- and fractionated-dose groups. The 4-year estimated cataract incidence was significantly higher

in the single-dose HIGH than in the LOW instantaneous dose rate TBI group ($p = 0.049$). Multivariate analysis showed that instantaneous dose rate and fractionation do not influence the relapse-free and overall survival rates or the incidence of interstitial pneumonitis. In addition, athough acute GVHD appeared to be the most important risk factor in the occurrence of IP, no different IP incidence rates were observed between allogenic and autologous BMT groups.

2. Biological investigations

Serological dosimetry (Pr JM Cosset-Institut Gustave Roussy-Institut Curie)

Post-irradiation hyperamylasemia as a biological dosimeter

Serum alpha-amylase was measured before and 24 h after either total-body (31 patients) or localized irradiation including the salivary glands (40 patients) or tthe pancreatic area (22 patients). A significant increase in amylasemia was observed for doses larger than 0.5 Gy to the parotid glands. A sigmoid function of dose was fitted to the data and predicted a maximum amylasemia level larger than 4 Gy and smaller than 10 Gy. The raw data from other published series were adequately described by the same model. However, the confidence limits of predicted dose reamined large because of a considerable interindividual variabilit. Post irradiation hyperamylasemia appears to provide a good criterion for sorting accidentally irradiated patients: 24 hours after a dose larger than 2 Gy to the parotid glands, 91 % (sensitivity) of the patients had an amylasemia level higher than 2.5-fold the upper normal value. Conversely, 96 % (specificity) had their serum amylasemia lower than 2.5-fold the upper normal value when the dose was lower than 2 Gy. However, a retrospective estimation of the absorbed dose (dosimetry) is not likely to be very accurate because of large interindividual variability.

Serum cytokines after total body irradiation (TBI)

An early spike of serum IL6 was observed during and/or after TBI, but no variation in IL1 or TNFα serum levels. The spike was generally observed at the end of irradiation or within 8 hours following irradiation.
The spike intensity of serum IL6 was dose related between 0 and 10 Gy, the detection threshold being ≈ 2 Gy. Variations between assay methods were observed. Large inter-individual variations were observed but the lag time of occurrence of the peak and its intensity were not related to clinical parameters (fever, etc...).

Growth factors (GF) in fibrotic process.(H.Magdelénat-Institut Curie)

The intraplatelet concentrations of PDGF and TGFβ were determined by bio- and radioimmuno-assays. An increased concentration of both GFs was observed in myelofibrosis-associated pathologies (e.g. myeloid splenomegaly). Although such myelofibroses are idiopathic, this observation support the role of these growth factors in the pathogenesis of intramedullary fibrotic process. In addition, treatment with gamma-Interferon was able to reverse the increased platelet levels of PDGF and TGFß.

3. Experimental investigations

Physiopathology of the irradiated lymphocyte.(H. Magdelénat-Institut Curie)

Interphasic programmed cell death (apoptosis) of peripheral blood lymphocytes was induced in vitro by γ irradiation. Doses in the range of 5 Gy allowed the study of apoptosis at the morphological level by video intensified fluorescence microscopy of chromatin structures, and at the molecular level (apoptosis endonuclease assay, gene activation,...). In situ hybridization and run-on transcription assay showed the selective degradation of 28S RNA in apoptotic cells.

We have demonstrated that ubiquitin gene expression and nuclear protein ubiquitination are specifically increased in apoptotic cells and that ubiquitin mRNA targetted antisens oligos interfere with protein ubiquitination and delay radiation induced apoptosis.
We are now transferring these experimental approach to the study of lymphocytes from total - body irradiated patients.

Tolerance induction in HLA-mismatched allogenic bone marrow transplantation
(Collaborative programme of INSERM U 132-Pr A. Fischer. Hopital Necker, Paris France)

The specificic elimination of human alloreactive T cells had previously be obtained with an anti-interleukine-2 receptor immunotoxin (ricin A-chain) (Cavazzana-Calvo et al.,1990). In a mouse experimental model, it was further demonstrated that the treatment of the graft with the immunotoxin prevents the rejection of a MHC-mismatched transplantation, prevents acute and chronic GVH, increases long term survival of host animals, and allows complete and stable chimerism (Cavazzana-Calvo et al., in preparation).

Recently,tolerance to MHC-mismatched transplantation could also be induced in an animal model (mouse) with anti-LFA1 mAb. The degree of chimerism which could be obtained was related to the total dose of mAb. The induced tolerance is donor-specific (rejection of another untreated donor).

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DEVELOPMENT OF CONDITIONS ALLOWING RESTORATION OF HAEMOPOIESIS BY ALLOGENIC PURIFIED AND *IN VITRO* MULTIPLIED - PLURIPOTENT HAEMOPOIETIC STEM CELLS

Contract Bi6-079 - Sector B21

1) *van Bekkum* , TNO-ITRI

Summary of project global objectives and achievements

The project aims at the following research objectives:
1/ to study the effect of haemopoietic growth factors in vivo and in vitro;
2/ to investigate non-toxic conditioning regimens for bone marrow transplantation;
3/ to develop methods to identify and isolate hemopoietic stem cells.
Briefly, preclinical studies will be carried out in total body exposed rhesus monkeys to study whether treatment with haemopoietic growth factors can shorten the period of profound pancytopenia and/or immunodeficiency after transplantation of a limited number of bone marrow cells, or without bone marrow transplantation. In the latter situation, it is also investigated as to whether the response to administration of growth factors can be used as a prognostic indicator of haemopoietic damage.
Following a radiation accident resulting in exposure to high, but inhomogeneous doses of ionizing radiation, non-toxic conditioning treatment by immunosuppression could be decisive when optimal bone marrow transplants are not available and allogeneic transplants would be considered, which, although resulting ultimately in partial chimeras or rejection, could be of temporary benefit to ensure survival. Earlier work in mice showed that treatment with monoclonal antibodies against T lymphocytes may be useful. A large spectrum of antibodies is therefore currently tested in mice ultimately selecting such antibodies for which equivalents in humans are available and which could be tested by preclinical studies in rhesus monkeys.
Concentration of haemopoietic stem cells and removal of T lymphocytes which are responsible for graft vs host disease would be of considerable benefit for imperfectly matched bone marrow transplantation. Considerable stem cell enrichment (40-140-fold) with less than 1% contamination of T lymphocytes has already been achieved using a method by which stem cells are selected on the basis of binding to the CD34 monoclonal antibody ICH3, which is in turn conjugated to Protein-A coated immunomagnetic beads. The stem cells can be safely eluted from the beads by competition with excess immunoglobulin and recovered. This method will be improved and used for allogeneic MHC matched, sex-mismatched grafts in rhesus monkeys with sustained chimerism (recognized from karyotyping) as an endpoint parameter. Chimerism will be studied as a function of the radiation dose and the number of T lymphocytes present. The method will be adapted to human treatment modalities.

The experiments performed demonstrated the validity and reproducibility of the proposed stem cell purification method, established the usefulness of the CD34 positive cells for allogeneic bone marrow transplantation, showed that CD34 positive cells can be used to achieve bone marrow as well as T-lymphocytes chimerism, indicated that CD34 positive cells require more intensive conditioning of the recipients than conventional grafts and showed in a prospective way the number of T-lymphocytes that is acceptable in an MHC-identical bone marrow graft.
In addition, we have initiated a number of experiments that aim for in vivo treatment with combinations of hemopoietic growth factors. The GM-CSF studies provided base line data for endogenous hemopoietic recovery in the 4 - 9 Gy TBI range and demonstrated that granulopenia can be completely prevented up to 5 Gy TBI doses and considerably mitigated in the 6-7 Gy dose range. IL-3 has been extensively studied, but in spite of its large effects in unirradiated monkeys, it was less effective than GM-CSF in stimulating endogenous recovery in irradiated monkeys. Studies with other growth factors have been started to yield base line data for therapeutic intervention in irradiated subjects with an optimal combination of hemopoietic growth factors, which has yet still to be defined.

Project 1

Head of project: *Prof. van Bekkum*

Objectives for the reporting period

In the reporting period, much emphasis has been laid on the preparative method used to isolate stem cells by positive selection based on binding to CD34 antibodies and the use of the resulting fractions for preclinical autologous as well as allogeneic bone marrow transplantation in rhesus monkeys, for the purposes outlined before. We further aimed to have completed the studies on non-toxic conditioning regimens that are currently underway in mice and to report on the ongoing studies on mitigation of radiation induced pancytopenia in rhesus monkeys by treatment with hemopoietic growth factors as well as on the in vitro effects of haemopoietic growth factors on stem cells.

Progress achieved including publications

We proposed to develop a simple, rapid, safe and generally applicable method to positively select for and purify hemopoietic stem cells for routine use in autologous as well as allogeneic BMT. The method is based on recognition of the stem cells by the anti-human CD34 monoclonal antibody ICH3. ICH3 is a high avidity mouse IgG2a that neither modulates nor has any effector functions such as cytotoxicity. In pilot experiments, sorted ICH3 positive cells were shown to effectively reconstitute hemopoiesis in autologous lethally irradiated rhesus monkeys. To develop a method suitable for the large-scale preparation of BM stem cells, Protein A was covalently bound to immunomagnetic beads and ICH3 was conjugated to Protein A. Cells bound to the antibodies can then be eluted from the protein A beads by competitive elution using excess soluble IgG. The present project envisages the further development and tests for the practical feasibility of this method, using standardized experimental conditions for autologous as well as allogeneic BMT in rhesus monkeys, thereby focussing on the immunosuppression required to prevent rejection of allogeneic highly purified stem cell concentrates and the use of cytokines to accelerate immunohemopoietic reconstitution in vivo.

Quality control and reproducibility of the ICH3/Protein A/immunomagnetic beads method and allogeneic transplantation in MHC-matched, sex mismatched rhesus monkey donor/recipient pairs was undertaken to assess the potential of these stem cell concentrates, to establish the radiation dose required for acceptance of such highly purified cells and to establish the number of T-lymphocytes that can be allowed in a bone marrow graft without causing unacceptable GvHD.

A large number of experiments was done to ascertain reproducibility and quality control of the CD34-positive bone marrow fractions to be used for transplantation purposes. Using an optimal cells/beads ratio, the method appeared to be equally efficient for prefractionated stem cell concentrates, obtained by density centrifugation and E-rosette sedimentation to remove residual T-lymphocytes, and for unfractionated bone marrow subjected to Ficoll-centrifugation to remove granulocytes and red cells. In both cases, about 1% of CD34-positive cells were obtained, which contained on the average 60 - 70 % of progenitor cells as measured by colony-formation in response to GM-CSF. Since we established earlier by an assay based on measuring regeneration rate after autologous transplantation, that the number of regenerating stem cells in vivo in FACS-sorted CD34-positive cell fractions runs closely parallel to the content of in vitro colony-forming cells, it may be safely assumed that this result is also indicative for the number of regenerating stem cells in the isolated CD34-positive cells. The

CD34-positive cell fractions can be easily depleted of a small fractions of monocytes/ macrophages by a similar procedure using a CD11b monoclonal. The quality control of the fractions obtained was further done by measuring the forward and perpendicular light scatter, showing that the majority of the cells have light scatter properties compatible with those of stem cells as identified in the window set in the light scatter plot of unfractionated bone marrow. In addition we routinely measured content of T-lymphocytes by CD4/CD8 monoclonal antibodies and showed that in any case the CD34-positive cell fractions are depleted for 2 to 3 logs of T-lymphocytes. By these experiments we set a standard for CD34-positive fractions suitable for allogeneic bone marrow transplantation, using a method that equally well handles 10^6 as well as 10^{10} bone marrow cells.

Because of the availability of suitable MHC-matched, sex-mismatched sibling donors for monkeys selected for allogeneic bone marrow transplantation, we started with pilot experiments on the use of these fractions for allogeneic transplantation. For these purposes, we studied regeneration rate of peripheral blood cells in comparison to conventional T-lymphocyte depleted bone marrow grafts and monitored chimerism as a function of time after transplantation. Chimerism was determined in bone marrow by measuring the number of donor-type karyotypes in IL-3 and GM-CSF stimulated bone marrow samples, as well as in T-lymphocytes stimulated with IL-2 and PHA. In addition, in 2 monkeys, we deliberately added 5×10^5 per kg body weight peripheral blood T-lymphocytes to the bone marrow grafts in an attempt to establish an upper limit for the number of T-lymphocytes.
Conventional T-lymphocyte depleted control grafts following a relative low TBI dose of 7.4 Gy (orthovolt X-rays) will result in sustained partial bone marrow and peripheral blood T-lymphocyte chimerism without causing GvHD. The 2 monkeys treated in this way were used as standards. The CD34 positive cell engrafted as rapidly as the controls. Karyotyping 3 weeks after transplantation showed that this rapid engraftment was donor derived. However, after more prolonged periods of time, monkeys conditioned with 8.3 Gy TBI showed only 2-5 % donor type karyotypes in their reconstituted bone marrow, suggesting that either the endogenous residual stem cells had taken over, or that the graft had been partially rejected. Surprisingly, however, donor type peripheral blood T-lymphocytes in these monkeys have been very high during the entire observation period, which is a result comparable to a successful bone marrow transplantation for SCID in humans. To date, a suitable explanation for this peculiar type of split chimerism is not available. To exclude that this result was attributable to a limited capacity of CD34 positive cells to supply sustained bone marrow progeny, we raised the conditioning TBI dose to 9 Gy. In 3 of 3 evaluable monkeys transplanted following 9 Gy TBI, bone marrow chimerism remained as high as in the conventional controls. These results demonstrate that CD34-positive cells are very well capable to produce myeloid as well as T-lymphocyte progeny for sustained periods of time, a feature that was hitherto unexplored. In addition, the CD34-positive grafts apparently require a more intensive conditioning regimen than the conventional control grafts.
The same data demonstrated that graft-versus-host disease did not occur from grafts that contained 10^5 T-lymphocytes 3per kg or less, but did occur, and lethally so, in 1 of 2 recipients of grafts to which 5×10^5 peripheral blood T lymphocytes were deliberately added. This result indicates that the upper limit of T lymphocytes allowable in an MHC-matched bone marrow graft, a situation in which GvHD is entirely determined by minor histocompatibility disparities, is in between 1 and 5×10^5 per kg body weight.

As regards the development of non-toxic conditioning regimens we tested in mice all possible permutations of five monoclonal antibodies, which included anti-Thy-1, anti-CD4 and anti-CD8 monoclonals, and the anti LFA-1 antibodies anti-CD11a and anti-CD18. As a model system we used chimerism at the level of red blood cells, white blood cells as well as immature bone marrow cells (day-12 CFU-S) in sublethally irradiated alpha- or beta-thalassemic mice. The results demonstrated clearly and reproducibly that the anti-CD4/CD8/CD11a combination of monoclonal antibodies, given before as well as after irradiation, was equivalent to the immunosuppressive action of at least 3 Gy total body irradiation, allowing chimerism at radiation doses as low as 4 Gy TBI. It is our intention to treat rhesus monkeys with the same

regimen, but unfortunately the humanized antibodies that would preferentially be used for such studies are currently not available.

Extensive data are available now on the radiosensitivity of the hemopoietic system of rhesus monkeys, including the relationship between peripheral blood cell regeneration time and radiation dose in the 4 to 10 Gy range and calculations on the radiosensitivity of hemopoietic stem cells as well as the LD50. In addition, sophisticated protocols of supportive care, including gastrointestinal decontamination and reverse barrier nursing in laminar air flow containment, have been developed and made available to match supportive care for human patients. Continuous intravenous infusion is routinely done by Porth-a-Cath implantation, connected to a small electronic pump hidden in an especially designed jacket.
This set up has been used for studies on GM-CSF and Interleukin-3. The GM-CSF data essentially demonstrated that monotherapy with a hemopoietic growth factor is restricted by the number of available target cells in that complete prevention of neutropenia could be achieved up to doses of 5 Gy total body irradiation (TBI), whereas GM-CSF was totally ineffective at a dose of 8 Gy TBI. These results were in accordance with those obtained by GM-CSF treatment of irradiated rhesus monkeys that received limited numbers of autologous bone marrow cells. Although a excellent correlation was obtained between GM-CSF response and radiation dose given, the GM-CSF response could not be used as an indicator for radiation damage before about a week after irradiation.
IL-3 stimulates *in vitro* a bone marrow cell population ancestral to most, if not all, of the bone marrow derived blood cells, in addition to pre-B cells, mast cells, natural cytotoxic cells, the formation of osteoclasts, blast cells in acute myeloid leukemia, but not prothymocytes or natural killer cells. Contrasting its broad range of action in vitro, recombinant human IL-3, administered to rhesus monkeys (Macaca mulatta) and cynomolgus monkeys (Macaca fasicularis), exerted limited and in part inconsistent effects on blood cell production. Somewhat larger effects of human IL-3 on peripheral blood numbers in these species were noted by sequential administration of another, more pathway-restricted hemopoietic growth factor, granulocyte/macrophage colony-stimulating factor (GM-CSF). Based on such evidence it is generally held, that IL-3 expands an early cell population that subsequently requires the action of a later acting factor such as GM-CSF to complete its development. Alternatively, we proposed the hypothesis that the limited effects of human IL-3 in Macaca species should in part be attributed to its species specificity. Therefore, we decided to produce rhesus monkey IL-3. The gene encoding rhesus monkey IL-3 (Rh-IL-3) was isolated from a M. mulatta genomic DNA library by hybridization with a human IL-3 cDNA probe. The Rh-IL-3 gene encodes a deduced mature protein of 124 amino acids with 1 potential N-linked glycosylation site and 2 conserved cysteine residues. It lacks 9 C-terminal amino acids of human IL-3 and differs in 23 amino acids from the remaining mature human IL-3 sequence. Construction of Rh-IL-3 cDNA and expression in Bacillus licheniformis yielded a functional protein that was purified to homogeneity. The purified Rh-IL-3 was approximately 100-fold more active than human IL-3 in stimulating hemopoietic colony formation in vitro by purified Rhesus monkey bone marrow progenitor cells. Comparison of the coding DNA sequences of Rhesus monkey IL-3 to those of mouse, rat, gibbon and human revealed a high evolutionary rate of nucleotide substitutions that give rise to amino acid changes. Although the cause of this high rate of amino acid replacement has not been resolved, it provides an explanation for the species specificity pattern encountered for IL-3.
We administered Rh-IL-3 to Rhesus monkeys in doses ranging from 3 to 30 microgram/kg/day subcutaneously during 30 consecutive days to test its in vivo effects. One monkey received a continuous intravenous infusion at the highest dose used for 16 consecutive days. After a lag phase of one week, a strong dose-dependent effect on the numbers of circulating nucleated blood cells, including normoblasts, was noted. Analysis of white blood cells revealed substantial increases in numbers of eosinophilic and neutrophilic granulocytes and the appearance of large numbers of cells designated as atypical basophilic granulocytes. Intracellular histamine levels of peripheral blood cells rose to levels directly proportional to the numbers of these atypical basophils. Also monocytes and lymphocytes increased in number. Highest white cell counts (up to 75 x 10^9/l) were observed in the recipient of 30

microgram/kg/day Rh-IL-3 as a continuous infusion. Neither absolute cell numbers nor the variety of cell types produced are precedented in studies with human IL-3 in Macaca species.
The peripheral blood cells were also monitored by measuring the frequency of cells with the myeloid differentiation antigen CD11b versus the number of T lymphocytes as characterized by CD4/CD8 antigens. Together these markers identify the vast majority of the white cells. CD11b positive cells, including atypical basophilic granulocytes, showed an IL-3 dose dependent rise, whereas the T lymphocyte numbers were not appreciably influenced by IL-3. In two monkeys which received 3 or 10 microgram/kg/day, respectively, T lymphocytes were measured every three days during IL-3 treatment. Peripheral blood T cells in these monkeys remained stable at a mean value of $3.3 \pm 1.5 \times 10^9$/l, not different from normal values.
The red cell lineage was strongly stimulated by the administration of IL-3. After a lag phase of about one week, more than 6-fold rises of reticulocyte numbers were observed in the monkeys which received 10 or 30 microgram/kg/day. Normoblast numbers rose to 10^9/l in the recipient of 30 microgram/kg/day subcutaneously and up to 18×10^9/l in the monkey that received a continuous infusion of 30 microgram/kg/day. The reticulocytosis did not translate into a rise in red cell numbers, most likely due to the frequent blood and bone marrow punctures for analyses. In addition, vast numbers of circulating normoblasts may also point to ineffective erythropoiesis, suggesting a possible lack of erythropoietin in levels proportional to those of IL-3.
Bone marrow was punctured weekly to determine cellularity, progenitor cell numbers and morphologic changes. Total punctate cellularity during treatment showed dose-dependent increases after one week of IL-3 administration. Dose-dependence was lost after two weeks when values of $3.8 \pm 2.4 \times 10^8$ (mean$\pm$s.d.) nucleated cells per ml punctate were reached as opposed to $0.7 \pm 0.6 \times 10^8$ cells/ml for pre-treatment punctates combined with those of the control monkey. The peripheral blood nucleated cell numbers, though high in absolute numbers, were in all cases low compared to the marked bone marrow cellularity, which demonstrates that the large numbers of bone marrow cells obtained are not attributable to blood contamination. IL-3 stimulated bone marrow cellularity was maintained during the third ($1.6 \pm 0.5 \times 10^8$/ml) and fourth week ($3.3 \pm 2.2 \times 10^8$/ml). It dropped to low numbers in the first week after cessation of IL-3 administration ($0.2 \pm 0.1 \times 10^8$/ml), but returned to more normal numbers ($0.4 \pm 0.2 \times 10^8$/ml) in the second week post-treatment. Prominent features of bone marrow morphology were dose-dependent increases of undifferentiated cells, atypical basophilic granulocytes, megakaryocytes and eosinophilic precursors. Juvenile neutrophils as well as erythroid precursor cells in all stages of development were most numerous. The frequency of in vitro detected immature colony-forming hemopoietic progenitor cells GM-CFU [granulocyte/macrophage colony-forming units as detected in methyl cellulose cultures stimulated with GM-CSF] and BFU-E [erythroid burst-forming units in response to IL-3 and erythropoietin] increased as well throughout the treatment with IL-3. An illustrative example was provided by the monkey which received Rh-IL-3 intravenously. In this animal the progenitor cell numbers had increased on the seventh day of IL-3 treatment to 2.5×10^6 GM-CFU per ml punctate from a pretreatment number of 16×10^3 GM-CFU/ml and to 2×10^5 BFU-E/ml from 8×10^2 BFU-E/ml. Since peripheral blood counts during the first week of IL-3 administration do not show major changes, it was concluded that IL-3 initiated production of blood cells is preceded by amplification of immature bone marrow hemopoietic progenitor cells.
The thrombocyte response to administration of Rh-IL-3 showed a peculiar dose dependence. At lower doses, a clear thrombocytosis was observed, which lasted for two weeks after discontinuation. The monkeys which received 3 microgram/kg/day had mean peak thrombocyte counts of 618×10^9/l, starting from a mean pretreatment value of 377×10^9/l, while those receiving 10 microgram/kg/day rose from a mean of 285×10^9/l pretreatment to a maximum level of 580×10^9/l. The monkeys which received IL-3 in a dose of 30 microgram/kg/day developed profound thrombopenia. Since all bone marrow preparations showed active megakaryocytopoiesis and shift platelets were abundant, it was concluded that the thrombopenia reflected an increased consumption rather than decreased production, probably

on the basis of hypersplenism. Withdrawal of IL-3 prompted resolution of skin lesions and of thrombocytopenia.
In spite of these dramatic effects in unirradiated monkeys, administration of IL-3 before or after irradiation in the 4-5 Gy TBI dose range had only marginal effects on the recovery of peripheral blood white cells, red cells or thrombocytes. The effects in general were less impressive than was earlier observed for monotherapy by GM-CSF, although a broader range of action was observed. Side effects were completely absent in irradiated monkeys. Based on these observations, we proposed the hypothesis, that many of the effects of IL-3 may be indirect, which was supported by a low abundance of IL-3 receptors on immature CD34 positive bone marrow cells.
Similar studies have been initiated with SCF (also termed MGF or kit-ligand), IL-6 and combinations of various growth factors, including GM-CSF and erythropoietin, but these studies have not been completed yet. The monotherapy experiments provide a basis for combinations of growth factors to treat radiation induced pancytopenia.

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RADIATION DAMAGE AND RECOVERY OF THE IMMUNE SYSTEM

Contract Bi6-059 - Sector B21

1) *Doria* , ENEA

Summary of project global objectives and achievements

The project is part of the European Network of Experimental and Clinical Research and is focussed on radiation damage and recovery of the immune system, with the main objective of designing appropriate strategies for medical intervention in radiation accidents and radiotherapy.

Following our previous studies on the effects of human recombinant (hu r) IL-1 beta and its synthetic nonapeptide VQGEESNDK, position 163-171 of human Il-1 beta, on the restoration of T helper cell activity and IL-2 production in sublethally irradiated mice, we compared the protective and restorative activities of these molecules on the 30 day-survival of lethally irradiated mice. We found that the nonapeptide is able to protect from lethal radiation injury and to restore viability. The nonapeptide is less effective than hu r IL-1 beta but, as it does not exhibit the IL-1-like side effects of the whole molecule, it appears as an interesting compound for medical intervention in radiation accidents.

IL-3 is a colony-stimulating factor that regulates hemopoiesis. We have investigated whether murine recombinant (mu r) IL-3 injected into mice exposed to sublethal irradiation can accelerate the recovery of thymocytes and splenic T and B cells. We found that the injection of mu r IL-3 may induce complete recovery of T and B cells, and responsiveness to mitogens and antigens in sublethally irradiated mice. Thus, IL-3 appears as a powerful molecule that can be successfully used in radiation accidents.

Cell typing for bone marrow transplantation in irradiated persons requires rapid and precise techniques. In collaboration with Prof. G.B. Ferrara from the Cancer Institute in Genoa, human mAb and recombinant DNA techniques have been applied to the identification of HLA allelic specificities. A new series of mAb specific for HLA class I and II molecules has been produced while the use of digoxegenin has allowed a very rapid DNA typing with no need for radioactive probes. It has also been possible, by host and donor DNA typing, to detect bone marrow take as soon as 10 days after transplantation.

Project 1

Head of project: *Prof. Doria*

Objectives for the reporting period

1. Effects of IL-1 and its nonapeptide 163-171 on protection and restoration in lethally irradiated mice.

2. Effect of IL-3 on the recovery of T and B lymphocytes in sublethally irradiated mice.

3. Improvement of serological and recombinant DNA techniques for rapid and precise HLA typing in humans.

Progress achieved including publications

Studies on mice. We have previously reported that the synthetic nonapeptide VQGEESNDK, position 163-171 of human IL-1 beta, when injected in mice immunodepressed by sublethal irradiation, induces restoration of T helper cell activity and IL-2 production. The immunorestorative activity of the nonapeptide is similar to that of the human recombinant (hu r) IL-1 beta, but with no IL-1-like inflammatory effects which hamper the use of the whole protein as immunomodulator. Based on these findings we compared the protective and restorative activities of the 163-171 nonapeptide and hu r IL-1 beta on the 30 day-survival of lethally irradiated mice. When mice were given a single injection of different doses of the nonapeptide or hu r IL-1 20 hrs before total-body irradiation, both molecules were found able to increase the percent survival of mice exposed to 750 or 850, but not to 950 cGy. The nonapeptide, however, was less effective than hu r IL-1 beta and displayed a different dose-response relationship, suggesting that the two molecules act through different radioprotective pathways. When mice were injected with the nonapeptide or hu r IL-1 beta immediately after exposure to 850 cGy, the percent survival was also increased but restoration was lower than protection in both cases. The nonapeptide was less effective than hu r IL-1 beta also in restoration but the two molecules displayed a comparable dose-response relationship as if they shared similar mechanisms. These findings altogether indicate that the 163-171 nonapeptide is

able to protect from lethal radiation injury and to restore viability. The nonapeptide is less effective than hu r IL-1 beta but, as it does not exhibit the IL-1-like side effects of the whole molecule, it appears as an interesting compound for medical intervention in radiation accidents and radiotherapy.

IL-3 is a colony-stimulating factor that regulates hemopoiesis. This cytokine, indeed, is involved in the differentiation of pluripotent stem cells to mature cells of several lineages, such as neutrophils, macrophages, erythrocytes, eosinophils, megakaryocytes and mast cells. IL-3 also promotes limited self-renewal of the multipotent stem cells which give rise to splenic colonies. We have investigated whether murine recombinant (mu r) IL-3 injected into mice exposed to sublethal irradiation can accelerate the recovery of thymocytes and splenic T and B cells. In a first series of experiments, mice were given 300 cGy and daily injections of mu r IL-3 starting immediately after irradiation for 5 consecutive days. Seven days after irradiation, thymuses and spleens were assayed for cellularity, thymocyte mitotic response to Con A, splenocyte mitotic responses to Con A and LPS, splenocyte antibody response to the hapten trinitrophenyl (TNP) and helper activity to the carrier horse red blood cells (HRBC) in cultures with the conjugate TNP-HRBC. Irradiated mice of other groups were similarly treated with mu r IL-3 for 10, 15, or 20 days and sacrificed 14, 21, or 28 days after irradiation, respectively. Under these conditions, IL-3 treatment did not accelerate the recovery from radiation damage in the thymus and spleen. In a second series of experiments, mice were given 100, 200, 300, or 400 Gcy and daily injections of mu r IL-3 starting immediately after irradiation for 5 consecutive days. Mice were sacrificed 7 days after irradiation, and thymuses and spleens were assayed as indicated above. Results indicate that daily injections of 5 µg mu r IL-3 induced complete recovery of thymocyte cellularity and mitotic responsiveness to Con A in mice exposed to 200 but not to 300 or 400 cGy. Lower doses than 5 µg were not efficient in mice exposed to 200 cGy., whereas I µg was very effective after 100 cGy. Similar results were obtained for splenocyte count and mitotic responses. Fluorimetric analysis performed on thymocytes indicates that 5 µg mu r Il-3 completely reversed to normal values the CD4 and CD8 cell distribution altered by 200 cGy. Also the antibody response and helper activity of spleen cells were depressed by 200 cGy but could be recovered up to the level of unirradiated controls if mice were treated with 5 µg, but not 0.5 µg, mu r IL-3. In conclusion, these findings indicate that injection of mu r IL-3 may induce complete recovery of T and B cellularity, and responsiveness to mitogens and antigens in sublethally

irradiated mice provided larger amounts are injected after higher radiation doses. Thus, IL-3 regulates the generation and growth of mature T and B cells and appears as a powerful molecule that can be successfully used in radiation accidents and radiotherapy.

Studies on humans. Treatment of irradiated persons by bone marrow transplantation may be successful if host and donor are HLA compatible. Cell typing techniques must be rapid and very precise in the fine recognition of antigenic specificities. The reagents now routinely used, such as alloantisera from multiparous women or from volunteers subjected to planned immunization and mouse monoclonal antibodies (mAb) to HLA class I and II molecules, are not easily available and do not always distinguish between alloantigens. Conversely, human mAb produced by human B cells from immunized volunteers, after EBV transformation and repeated subcultures, are much more powerful than mouse mAb in the fine typing of the HLA antigenic repertoire. Also DNA amplification by plymerase chain reaction (PCR) and subsequent hybridization by allele or sequence specific oligonucleotide probes is a valid approach to cell typing. Prof. G.B. Ferrara, Head of the Immunogenetics Laboratory at the Istituto Nazionale per la Ricerca sul Cancro in Genoa, is collaborating with our laboratory in the application of human mAb and recombinant DNA techniques to the identification of HLA allelic specificities. Fourteen cell lines (MPI-14) secreting cytotoxic human IgM alloantibodies of restricted HLA specificities have been established. By use of mAb MP8 the HLA-DP polymorphism was analyzed and a supertypic determinant encoded by 7 DPB genes was detected. Furthermore, the HLA-DP typing was also performed using dot-blot analysis with 14 synthetic oligonucleotide probes. Each probe was tested against genomic DNA amplified by PCR using DP beta-specific primers. A total of 45 HLA homozygous B cell lines of known DPw specificities was analysed and different hybridization patterns were found for each DPw specificity. The oligonucleotide hybridization performed on DPw negative B cell lines exhibited a pattern distinct from those of known DPw specificities, indicating the presence of novel DP allelic sequences. Thus, the use of these technologies has allowed reliable typing of HLA-DP antigens, which may play an important role in allogeneic bone marrow transplantation and in susceptibility to autoimmune diseases. Further improvements of these techniques have allowed, by use of digoxegenin, very rapid DNA typing with no need for radioactive probes. It has also been possible, by host and donor DNA typing, to detect bone marrow take as soon as 10 days after transplantation. Finally, a new series of human mAb specific for HLA class I and II molecules has been produced.

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THE REDUCTION OF THE RISKS OF LATE EFFECTS FROM INCORPORATED RADIONUCLIDES (NRPB ASSOCIATION)

Contract Bi6-347e - Sector B22

1) *Stradling* , NRPB - 2) *Volf*, KfK Karsruhe - 3) *Métivier* , CEA-FAR
4) *Burgada* , ADFAC (Univ. Pierre et M. Curie) - 5) *Archimbaud* , CEA-Pierrelatte

Summary of project global objectives and achievements

The overall objectives of the project are one, to evaluate the reduction in risk of late effects from incorporated radionuclides by the administration of chelating agents and two, to provide practical guidance to those responsible for the treatment of accidental exposures.

In detail, the aims for 1990-92 were as follows:

a) To investigate the efficacy of the siderophore analogues code named DFO-HOPO and DTPA-DX for enhancing the removal of Pu and Am from the body.

b) To synthesise and test the efficacy of the siderophore analogue 3,4,3-LIHOPO for Pu, Am.

c) To investigate treatment regimens for the decorporation of transportable forms of thorium and uranium.

d) To assess the effects of orally administered DTPA on the induction of bone tumours by Pu and on the removal of Pu and Am from the body after their inhalation as nitrate.

All studies were conducted using rats.

The substance of choice for enhancing the excretion of Pu and Am from the body is DTPA. However, the development of siderophore analogues by Professor K. Raymond at the University of California, and subsequent short term screening experiments in mice after the intravenous injection of Pu by Dr. P.W. Durbin at the Lawrence Berkeley Laboratory, showed that they were likely to be more effective decorporating agents than DTPA. Much of the work carried out in 1990-92 has been devoted to the more detailed testing of these analogues using different chemical forms and modes of intake of the actinides, and different treatment regimens.

1. Efficacy of siderophore analogues for plutonium and americium

The first studies with siderophore analogues used a hydroxypyridinone derivative of desferrioxamine (DFO-HOPO) and a dihydroxamic acid derivative of DTPA (DTPA-DX). Both substances were provided by Professor Raymond.

After inhalation of the actinides as nitrates, DFO-HOPO and DTPA-DX were less effective than DTPA for removing Pu from the body but DTPA-DX and DTPA were equally effective for Am (NRPB). It was concluded however that DTPA should remain the agent of choice after this mode of intake.

After intravenous injection of Pu as citrate, DFO-HOPO was appreciably more effective than DTPA after both intraperitoneal (NRPB) and subcutaneous injection (KfK). The most effective regimen involved the simultaneous administration of DFO-HOPO and DTPA (KfK).

DFO-HOPO was also more effective than DTPA when administered orally (KfK). Continuous infusion of DFO-HOPO over an interval of 14 days using implanted minipumps was no more effective than a single injection for mobilising Pu from the skeleton and liver (KfK).

After subcutaneous or oral administration, DTPA-DX was less effective than DTPA for reducing the skeletal content of Am injected as citrate (KfK). Whilst the retention of Am in the liver was appreciably less after a single injection of DTPA-DX (KfK), this initial advantage over DTPA was lost after repeated administration of the chelates (NRPB).

The screening experiments in the USA referred to previously had suggested that 3,4,3-LIHOPO was likely to be the most effective siderophore analogue. However, the substance was not available to the partners until 1991 when it was synthesised at the University Pierre et Marie Curie (ADFAC) in sufficient amounts for it to be tested after the inhalation and intravenous injection of Pu and Am as nitrate (NRPB), the inhalation of Pu as the tributylphosphate complex (CEA) and the intravenous injection of Pu and Am as citrate (KfK). For Pu inhaled as nitrate, the repeated administration of 30 μmol kg^{-1} 3,4,3-LIHOPO (30 min, 6h, 1, 2, 3d) reduced the content of the lungs and total body to respectively 2% and 4% of those in untreated animals by 7d post exposure. These values were respectively 6 and 4 times less than when DTPA was administered using the same treatment protocol. The ligand was also at least as effective as DTPA for Am. No histological damage to the kidneys and liver was observed after the repeated administration of 3,4,3-LIHOPO (NRPB).

The ligand was also much more effective than DTPA after the inhalation of Pu-TBP (CEA). Of particular importance was the observation that after an intake which simulated human exposure to several orders of magnitude the ALI for ^{239}Pu, the amounts of Pu retained by the liver and skeleton (1.7% and 7.1% controls) were 4 times less with 3,4,3-LIHOPO than with DTPA when administered at 1h, 24h and 48h.

The efficacy of 3,4,3-LIHOPO was also greater than that of DTPA after the intravenous injection of Pu (NRPB and KfK). For example, after the single administration of 3 μmol kg^{-1} 3,4,3-LIHOPO at 30 min, the body content of Pu at 7d, 7% controls, was three times less than after the repeated administration of DTPA, 30 μmol kg^{-1} at 30 min, 6h, 1, 2, 3d (NRPB). With these treatment regimens, 3,4,3-LIHOPO and DTPA were equally effective for Am, the body contents being reduced to 30% controls at 7d; the repeated administration of 30 μmol kg^{-1} reduced the body content to 16% of controls.

Other studies (KfK) demonstrated that the efficacies of 3,4,3-LIHOPO for Pu after single administration of 3 and 30 μmol kg^{-1} were virtually identical whilst that for Am increased only marginally with dosage. Of particular note were studies which showed that 3,4,3-LIHOPO was extremely effective for the decorporation of Pu and Am when either infused at a dosage of 3 μmol $kg^{-1}d^{-1}$ or administered orally at 100 μmol kg^{-1} (KfK).

Together the above observations suggest that 3,4,3-LIHOPO could represent a most significant development for reducing the reduction of risk from intakes of Pu and Am. However, further work is necessary to investigate its full potential and evaluate its toxicity.

2. Removal of thorium from the body

It is often assumed that DTPA will be as effective for Th as it is for Pu when the nitrates are inhaled. Studies conducted at NRPB show that this is not so. When the initial mass concentration of Th in the rat lung simulated human exposures to either 4 or 1.7 x 10^{-3} times the ALI for ^{232}Th, the retention of Th in the body could not be reduced to less than one-half of that in

untreated animals, even when dosages about 30 fold in excess of those recommended for humans were used.

Studies undertaken at the Shanghai Medical University have indicated that certain substituted phenol-aminocarboxylic acid derivatives may be of value for Th decorporation. A pilot study conducted at NRPB investigated the comparative efficacies of two phenolaminocarboxylic acids (code named here as SM1 and SM2), 3,4,3-LIHOPO and DTPA for thorium after its intratracheal instillation as nitrate (4ng). The substances were administered intraperitoneally either at 30 min (SM1, SM2 300 μmol kg^{-1}, 3,4,3-LIHOPO 30 μmol kg^{-1} or at 30 min, 6h, 1, 2, 3d (3,4,3-LIHOPO and DTPA 30 μmol kg^{-1}). The average body contents of Th at 6d were respectively 64%, 29%, 29%, 17% and 78% of those in untreated animals. These results demonstrate the potential usefulness of 3,4,3-LIHOPO for removing thorium from the body and further work will be undertaken to optimise its efficacy after different modes of administration of the ligand and mode of intake of thorium (NRPB, KfK).

3. Removal of uranium from the body

In the past decade, several phenolic compounds have been tested for their ability to prevent fatal uranium poisoning. The most promising compound appears to be Tiron (sodium 4,5-dihydroxybenzene-1,3-disulphonate). Studies conducted at NRPB have shown that this compound would be only moderately successful for treating overexposures to uranium by inhalation; the body content was reduced to only about two-thirds of that in untreated animals even with repeated administration. The efficacies of certain polyaminopolyalkylphosphonic acids (CEA, NRPB), bisphosphonates, phosphonoalkylphosphinates (NRPB) and calixarine (CEA) have been examined. The substances were either synthesised at ADFAC or CEA Pierrelatte, or were obtained as gifts from Albright and Wilson Ltd., UK, or Norwich Eaton Pharmaceuticals Inc., USA. The best results so far have been obtained with diethylenetriaminepentamethylenephosphonic acid. After the intravenous injection of uranium and the prompt administration of 300 μmol kg^{-1}, the uranium contents of the kidneys and total body were reduced to 8% and 31% of control values by 4d. However, the efficacy of the substance reduces rapidly with the delay in administration and after 30 min was largely ineffective. The examination of other treatment regimens and the development of new chelating agents is considered a priority in view of the number of workers potentially exposed to transportable uranium compounds.

4. The efficacy of DTPA in drinking water

In principle, the administration of DTPA in drinking water could also be of value for the treatment of inhaled transportable forms of Pu and Am. This route of intake would be more advantageous than intravenous injection since DTPA can be self administered, it is more likely to be accepted by the patient should prolonged administration be deemed necessary, and it may be more appropriate for accidents involving large numbers of people. Experiments conducted at NRPB have shown that the continuous administration of 95 μmol $kg^{-1}d^{-1}$ of ZnDTPA in drinking water is as effective as twice weekly injections of 30 μmol kg^{-1}. However, further work is required to evaluate the optimal treatment regimen and the toxicity of the ligand under these conditions.

A study on the effects of continuous oral administration of ZnDTPA on bone tumour induction in rats injected with ^{239}Pu has been undertaken by KfK. Preliminary analysis of the results indicates that when treatment began after 4 days, the bone tumour incidence was only reduced marginally, although the survival time of the rats increased compared with untreated animals. When treatment commenced after 30d, the tumour incidence was reduced further but the survival time only increased marginally. All the results on bone tumour incidence must be considered as preliminary until confirmed histologically.

Summary

The data obtained after the administration of the siderophore analogues supports the partners' judgement concerning the potential usefulness of these substances for Pu and Am. In particular 3,4,3-LIHOPO has been shown to be substantially more effective than DTPA for enhancing the excretion of these actinides after their inhalation and injection and the substance is effective after oral administration. It is also noteworthy that 3,4,3-LIHOPO also appreciably enhances the excretion of thorium from the body compared with DTPA. However, further work is needed to optimise the various treatment regimens and most importantly to evaluate its toxicity. Data obtained very recently have also shown that it is also substantially superior to DTPA for removing Pu and Am from simulated wound sites.

At present no substances are available which appreciably increase the elimination of U from the body and this remains a potentially serious problem in radiological protection. It is hoped that with the synthetic and technical expertise available within the participating organisations and the willing cooperation of others, significant progress can be made in future.

Finally, it has been shown that a reduction in bone tumour incidence, and an increase in survival time, can be achieved by means of DTPA administered in drinking water. This method of treatment is also effective for inhaled transportable forms of Pu and Am though the optimal treatment regimen has yet to be established.

Project 1

Head of project: *Dr. Stradling*

Objectives for the reporting period

(a) To examine the efficacy of the siderophore analogues code named DFO-HOPO, DTPA-DX and 3,4,3-LIHOPO for enhancing the removal of plutonium and americium from the body after their inhalation and injection.

(b) To investigate treatment regimens for the decorporation of thorium.

(c) To investigate treatment regimens for the decorporation of uranium.

(d) To examine the efficacy of orally administered DTPA for removing plutonium and americium from the body after their inhalation as nitrate.

Progress achieved including publications

1. DFO-HOPO and DTPA-DX and 3,4,3-LIHOPO for Pu and Am

A hydroxypyridinone derivative of desferrioxamine (DFO-HOPO), a dihydroxamic derivative of DTPA (DTPA-DX), and DTPA were tested at dosages of 30 μmol kg^{-1} for their ability to remove ^{238}Pu and ^{241}Am from rats after their intravenous injection as citrate or inhalation as nitrate. The siderophore analogues were provided by Professor K. Raymond, Dept. of Chemistry, Univ. of California, Berkeley.

The most effective treatment regimen for injected Pu was the repeated administration of DFO-HOPO. By 7d the body content was reduced to 8% of that in untreated animals; the value after DTPA treatment was 15%. Repeated dosages of 3 μmol kg^{-1} DFO-HOPO were as effective as those of 30 μmol kg^{-1} DTPA. After inhalation of Pu, repeated treatment with DTPA, DTPA-DX or DFO-HOPO reduced the body contents by 7d to respectively 10, 15 and 31% of controls. After inhalation of Am, DTPA-DX and DTPA were equally effective, the body contents being reduced to 7% of control values with repeated treatment. Injection of DFO-HOPO was ineffective for enhancing the elimination of inhaled or injected Am.

These results confirm the strategy of examining the use of siderophore analogues for the decorporation of Pu and Am. However, on the basis of these results DTPA should remain the agent of choice.

The 3,4,3-LIHOPO was synthesised by Dr. Burgada, University Pierre et Marie Curie.

The repeated administration of 30 μmol kg^{-1} 3,4,3-LIHOPO at 30 min, 6h, 1, 2 and 3d after exposure has been shown to be an extremely effective treatment regimen for enhancing the excretion of ^{238}Pu inhaled as nitrate. By 7d, the Pu contents of the lungs and total body were reduced respectively to 2% and 4% of those in untreated rats. These values were 6 and 3 times less than when DTPA was administered using the same protocol. For inhaled Am, the ligands were equally effective, the lung and total body contents being reduced respectively to 13% and 10% of those in controls.

Histological examination of the liver and kidneys after repeated administration of 3.4.3-LIHOPO showed slight degenerative changes. These changes would probably have no effect on liver and kidney function and after a time the cells would be expected to return to normal. Interestingly the changes were more marked after the repeated administration of DTPA. Clearly, further work is required to evaluate the toxicity of 3,4,3-LIHOPO but the results so far are extremely encouraging.

The ligand 3.4.3-LIHOPO was also substantially more effective than DTPA after intravenous injection of ^{238}Pu nitrate. With a single administration of 3 μmol kg^{-1} 30 min after exposure, the body content was reduced to 7% of that in controls by 7d. The repeated administration of DTPA at dosages of 30 μmol kg^{-1} at 30 min, 6h, 1, 2 and 3d reduced the body content to 19% of controls. After the repeated administration of 30 μmol kg^{-1} 3.4.3-LIHOPO and DTPA, the body contents at 7d were respectively 16% and 31% of controls.

Further studies designed to optimise treatment with 3.4.3-LIHOPO together with a more detailed evaluation of its toxicity will be undertaken but the evidence available so far suggests that the use of this substance could represent a most significant development in the reduction of risk from plutonium exposure.

2. Decorporation of thorium

It is usually assumed that DTPA will be as effective for Th as for Pu.

The efficacy of Ca DTPA and Zn DTPA were evaluated for removing thorium from the rat after its deposition as nitrate in the lungs. When the initial mass concentration in the lungs simulated human exposure to four times the ALI for ^{232}Th, the prompt (300 or 1000 μmol kg^{-1} body weight at 30 min) or repeated (30 or 300 μmol kg^{-1} body weight at 30 min, 6h, 1,2,3d) administration of Ca DTPA were at best only moderately effective. By 7d after exposure, the body contents of Th were respectively 74%, 65%, 90% and 74% of those present in untreated animals. When the mass concentration in the lungs simulated acute exposure to 1.7 x 10^{-3} times the ALI for ^{232}Th, the efficacy of treatment was not increased appreciably despite the substantial reduction in mass. After the repeated administration of Ca DTPA at dosages of 30 and 300 μmol kg^{-1} using the protocol above, the body contents of thorium by 7d were respectively 69% and 51% of those in untreated animals. Under comparable conditions, the efficacy of Zn DTPA was less than Ca DTPA.

In contrast, the ligand 3,4,3-LIHOPO has been shown to be effective for thorium. In a pilot experiment, ^{234}Th nitrate was instilled into the lungs of rats and the animals administered with 30 μmol kg^{-1} LIHOPO at 30 min, 6h, 1, 2 and 3d. By 7d, the Th contents of the lungs and total body were both reduced to 17% of controls; the values using DTPA were respectively 73% and 78% of controls. It is probable that treatment would be much more effective after the inhalation of Th nitrate and if the administration of LIHOPO was extended.

3. Decorporation of uranium

In the past decade, several phenolic compounds have been investigated in animals for their ability to prevent fatal uranium poisoning. The most promising derivative appears to be Tiron (sodium 4,5-dihydroxybenzene-1,3-disulphonate). In experiments conducted at NRPB, the compound was administered to rats in dosages of 30, 300 or 1000 μmol kg^{-1} at 20, 60 and 180 min after the intratracheal instillation of uranyl nitrate. The amounts of uranium deposited in the lungs of rats were equivalent to intakes by workers of about 12 times the permitted daily limit of 2.5 mg. The average body contents of uranium 5d after exposure using the treatment regimens above were respectively about 100%, 78% and 65% of those in untreated animals.

These results suggest that the administration of Tiron is of limited practical value for enhancing the elimination of uranium from the bodies of overexposed workers.

Phosphonic acid derivatives obtained from Albright and Wilson plc and Norwich Eaton Pharmaceuticals Inc have been screened for their ability to enhance the excretion of uranium from the rat. After prompt administration, two polyaminopolyalkylphosphonic acids, diethylenetriamine-pentamethylenephosphonic acid and hexamethylenediaminetetramethylenephosphonic acid, reduced the uranium contents of the kidneys and total body to 8% and 30% of those in controls. However, treatment was much less effective at later times and hence the substances appear to have limited practical application. The bisphosphonates and phosphonoalkylphosphonates examined were less effective than the above polyaminopolyalkylphosphonates. However, a definite correlation was found between the lack of affinity of the compounds for bone mineral and the reduced skeletal deposit of uranium; this should aid the design of more effective substances. The development of suitable agents for reducing the risk after uranium incorporation remains an important aspect of radiological protection for workers in the nuclear industries.

4. Efficacy of orally administered DTPA

The oral administration of ZnDTPA in drinking water has long been suggested as a treatment regimen for plutonium. However, no experiments appear to have been conducted after the inhalation of this actinide. Studies at NRPB have shown that the continuous administration of 10^{-3}M solutions of DTPA, reduced the Pu contents of the lungs and total body to about 3% and 15% of those in controls. This method of treatment was as effective as twice weekly injections of 30 μmol kg^{-1} of DTPA. Histological examination of the gastrointestinal tract showed that some damage was sustained after oral administration but was considered to be reparable. This observation was unexpected in view of the data available from other studies with rats. Further work is required to evaluate the toxicity of DTPA and to optimise the treatment regimen.

Publications

1. Stradling GN, Gray SA, Moody JC, Hodgson A, Raymond KN, Durbin PW, Rodgers SJ, White DL and Turowski PN. The comparative efficacy of DFO-HOPO, DTPA-DX and DTPA for enhancing the elimination of plutonium(IV) and americium(III) from the rat. Proc. 3rd International Symposium on Chelating Agents in Pharmacology, Toxicology and Therapeutics, Plzen, July 10-12th 1990. Plzen.lék. Sborn: Suppl. 62, 87-88, 1990 (published Autumn 1991).

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6. Stradling GN, Gray SA, Moody JC, Hodgson A, Ellender M, Pearce MJ, Wilson I, Burgada R, Bailly T, Leroux Y, Manouni DE and Raymond KN. The efficacies of 3.4.3-LIHOPO and DTPA for enhancing the excretion of plutonium and americium from the rat: comparison with other siderophore analogues. Int. J. Radiat. Biol. (in press).

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Work planned for 1992-94

The work will focus on optimising treatment regimens for Pu, Am and Th after inhalation and wound contamination using 3,4,3-LIHOPO and on the toxicity of the ligand after different methods of administration. The studies with Th will take account of the widely different mass concentrations in the lungs that can occur after industrial accidents, eg. ^{228}Th and ^{232}Th. The potential for treating contaminated wounds with 3,4,3-LIHOPO has been recognised by the nuclear industry. The decorporation of uranium remains a priority and any significant progress will result in the extension of the work to inhaled transportable forms of the metal, eg. UO_3 and UF_4. Further work is required to optimise the efficacy of orally administered DTPA.

Project 2

Head of project: *Prof. Volf*

Objectives for the reporting period

1. To investigate the efficacy of the siderophore analogues code named DFO-HOPO, DTPA-DX and LIHOPO for enhancing the removal of Pu and Am from the body of rat after intravenous injection of the actinides.

2. To establish the relative effectiveness of these new chelators compared to DTPA, the present chelator of choice for treatment in man after incorporation of actinides.

3. To carry out more detailed investigation on the most promising new agent(s).

4. To attempt to reduce the incidence of bone tumours due to deposited Pu-239 using continuous chelation treatment.

Progress achieved

1. Pilot experiments

The effects of three siderophore analogues and DTPA were compared in female Sprague Dawley rats.

1.1 Injection treatment

Chelators were admistered subcutaneously as a single human equivalent dose (30 umoles. kg^{-1}) at 1 hour after a single intravenous injection of Pu-238 and Am-241 and the tissue distribution was measured at 7 days post radionuclide injection. The Pu-238 content of the organs decreased in the order LIHOPO > DFO-HOPO > DTPA > DTPA-DX. LIHOPO reduced plutonium retention in the skeleton and liver to 8% and 2%, respectively, of that in untreated controls. With Am-241, LIHOPO also proved to be the most effective agent, reducing the radioactivity in the skeleton and liver to 30% and 5%, respectively. DTPA-DX was equally or more effective than DTPA, DFO-HOPO had no effect on Am-241 retention.

1.2 Oral treatment

Immediately after injection of the actinides a single chelate dose of 100 umoles.kg^{-1} was administered by stomach tube and the rats were sacrificed 7 days later. The contents of Pu-238 in bone, liver and kidneys were reduced by LIHOPO to about 10% of control values; DFO-HOPO was nearly equally effective but DTPA and DTPA-DX were substantially less effective. The organ contents of Am-241 were reduced by LIHOPO to about 20% of control values and by DTPA to only about 50% of control values; DTPA-DX was less effective and DFO-HOPO ineffective.

1.3 Continuous chelate administration

A continuous infusion for 14 days after actinide injection was achieved by subcutaneously implanted diffusion "mini-pumps". In general, tissue retention of the actinides was reduced to a greater extent than by single chelate injection. Best results were again obtained with LIHOPO, even though it was administered at an extreme low dose-rate (3 umoles.kg^{-1}. d^{-1}).

2. Detailed studies with DFO-HOPO and LIHOPO

2.1 Dose-effect relationship.

The greatest differences in mobilizing efficacy were observed with the lowest chelator doses. At the dose level of 3 umoles.kg^{-1} LIHOPO removed 1.5 times more Pu-238 from bone and liver than DFO-HOPO, while at a 10 times higher dose level the removal effectiveness of both chelators was virtually equal.

Furthermore, the effect of injected and orally administered chelators was compared. At the dose level of 3 umoles.kg^{-1}, injected LIHOPO removed 4 times more Pu-238 from the bone and nearly 6 times more from liver than after prompt oral administration. About equal effect was achieved when administering LIHOPO orally in a dose exceeding 3 times that of injected chelator. Similarly, the effect of LIHOPO on Pu-238 exceeded that on Am-241 only at the lowest chelate dose level. DFO-HOPO was ineffective in mobilizing Am-241.

2.2 Time-effect relationship

The effectiveness of DFO-HOPO decreased exponentially with time after injection of Pu-238. Approximate half-times for the fraction of Pu-238 which can be mobilized from the bone and liver are about 6 hours and 12 hours, respectively. The effectiveness of LIHOPO, however, decreased much more slowly, so that even after a single injection of the chelator at 5 days post administration of the actinides about 40% and 60% of injected Pu-238 were mobilized from the bone and liver, respectively. In these animals, somewhat smaller but still considerable fractions on injected Am-241 were removed (30% and 40% from the bone and liver respectively).

In conclusion, LIHOPO proved to be most effective among the chelators tested until now for chelation of plutonium and americium. It is also effective when given orally, immediately after injection of the actinides. Even small doses of this chelate, when administered in a continuous infusion, effectively remove the actinides deposited in body tissues.

3. Reduction of bone tumour risk.

Male Sprague-Dawley rats were given a single intravenous injection of Pu-239 and treated by ZnDTPA added to drinking water; treatment started either at 4 days or at 30 days after injection of Pu-239; another group of rats injected only with Pu-239 served as control. The data obtained indicate a reduction of tumour incidence in treated animals. However, increased survival seems not necessarily to be due to a lower bone tumour incidence. All the results obtained until now must be considered as preliminary since the tumour incidence both in treated and untreated groups was not yet confirmed histologically.

Project 3

Head of project: *J.L. Poncy (initially H. Métivier)*

Objectives for the reporting period

The objective of the reporting period is the investigation of the efficacy of the sideropohore analog 3,4,3-LIHOPO in comparison with the diethylene-triamine pentaacetic acid (DTPA) for enhancing the excretion of ^{238}Pu from Sprague Dawley rats after inhalation as tributylphosphate complex (^{238}Pu-TBP). To evaluate the reduction of risk of late effects from incorporated radionuclides by administration of chelating agents we have to provide the more effective schedule treatment after accidental contamination.

Progress achieved including publications

The 3,4,3-LIHOPO ligand, containing four hydroxypyridinone groups, was compared to the reference molecule, DTPA, for the ability to remove plutonium from the rats after inhalation as N-tributylphosphate - ^{238}Pu complex. The 3,4,3-LIHOPO has been synthetised by Dr R. Burgada (P. & M. Curie University, Paris).

Three groups of Sprague Dawley rats (untreated by ligand, DTPA or 3,4,3 LIHOPO treated) were used in each experiment performed during this study. The average lung activities (LA) 7 days after the inhalation, registered in the different experiments, were 869±74 Bq (1.3 ng Pu), 4.5±0.8 KBq (6.7 ng Pu), 15±2 KBq (22.4 ng Pu) and 37±3 KBq (55.3 ng Pu).

Three different treatments for the chelating agents, at dosages of 30 µmol kg-1, were administered : 1) one intravenous injection, one hour after the end of inhalation, 2) one intravenous followed by two intramusculary injections, one and two days latter 3) one intraperitoneal injection one day after the contamination.

The siderophore analog, 3,4,3-LIHOPO, is shown to be more effective than DTPA for increasing the elimination of ^{238}Pu from the lung and reducing the retention in the other organs. Only one intravenous injection of LIHOPO at one hour after the radionuclide inhalation, reduced plutonium amount in lung, liver and skeleton, at 7 days post contamination with the lowest initial amount (869 KBq), to 27.4, 6 and 11.7%, respectively, of that in untreated rats. With a large amount of contamination (37 KBq), the values are 57.4, 8.2 and 17.8% respectively (table 1). The LIHOPO is most effective than DTPA, for removal of Pu, specially after a large amount of internal contamination. The percentages of retention in lungs, livers and skeletons, of DTPA treated rats were reduced from 31, 26 and 36% respectively, after one single intravenous injection of LIHOPO. These results confirm the interest of the 3,4,3-LIHOPO for the decorporation of plutonium after an inhalation amount which correspond to human intakes in excess of the ALI, especially after a contamination by plutonium introduced as TBP complex. This complex is known to reduce the efficiency of the DTPA treatment compared to other soluble or diffusible forms of Pu.

The best therapy was repeated treatment of ligand with a first injection administred early after the contamination. Delayed treatments reduced largely the efficacy of LIHOPO, this observation was very effective after a high level of contamination (table 1).

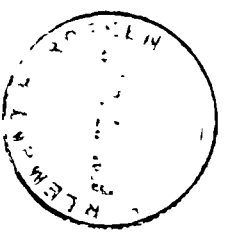

Table 1 : Effect of LIHOPO and DTPA on tissue retention of ^{238}Pu after inhalation of Pu-TBP in rats.

Treatment	LA (a)	Percentage of control rats at 7 days (standard error)				
		lung	liver	spleen	kidneys	skeleton
- Intravenous :						
DTPA	869 Bq	30.0 (1.2)	17.5 (3.4)	ND	ND	21.6 (1.4)
LIHOPO	869 Bq	27.4 (1.8)	6.0 (0.7)	ND	ND	11.7 (3.6)
DTPA	37 KBq	88.5 (6.3)	34.8 (5.7)	41.8 (6.5)	69.0 (5.5)	53.8 (12.4)
LIHOPO	37 KBq	57.4 (7.5)	8.2 (0.9)	22.6 (2.1)	46.1 (8.1)	17.8 (3.1)
- Intravenous + Intramuscular :						
DTPA	4.5 KBq	44.5 (1.8)	6.4 (1.2)	15.3 (*)	66.0 (*)	13.6 (1,5)
LIHOPO	4.5 KBq	28.2 (1.8)	6.5 (1.2)	7.7 (*)	18.9 (*)	2.92 (0.9)
DTPA	37 KBq	60.2 (2.5)	8.1 (2.2)	23.0 (5.7)	75.5 (6.3)	27.7 (4.1)
LIHOPO	37 KBq	49.5 (5.7)	1.7 (0.2)	8.4 (1.0)	19.9 (1.2)	7.1 (0.5)
- Intraperitoneal :						
DTPA	4.5 KBq	62.8 (4.2)	32.4 (10.6)	61.5 (*)	111 (*)	55.3 (9.2)
LIHOPO	4.5 KBq	62.1 (14.1)	44.4 (17.9)	69.2 (*)	69.8 (*)	45.7 (12.1)
DTPA	15 KBq	54.6 (5.6)	29.1 (3.1)	41.8 (*)	86.2 (*)	53.9 (5.1)
LIHOPO	15 KBq	59.8 (11.7)	42.8 (13.1)	79.1 (*)	52.6 (*)	55.2 (9.9)

(a) LA : mean of the activities in untreated rat lungs 7 days after inhalation.
(*) Organs from the different animals have been counted together (activities very low) and the results are expressed as (measured values/ number of organs).
ND : not different to background value.

The efficacy of LIHOPO to remove the Pu inhaled as Pu-TBP was mainly due to the decrease of the retention in the lung (1.5 times less than after repeated DTPA treatment) and in the skeleton (about 4 times less).
Table 2 confirms that the LIHOPO treatment was very effective for enhancing the excretion of Pu from the rat. The deposition of Pu in the organs other than lung, were reduced by the LIHOPO administration. This fact was specially true for the bone and liver depositions.

Table 2 : Distribution of ^{238}Pu at death after inhalation of Pu-TBP.

Treatment	LA (b)	Percentage of body burden at death (a) (standard error) lung	liver	spleen	kidneys	skeleton
- Intravenous :						
CONTROL	869 Bq	67.8 (5.8)	7.5 (0.6)	ND	ND	24.6 (0.2)
DTPA	869 Bq	75.0 (3.0)	5.3 (0.8)	ND	ND	19.6 (1.2)
LIHOPO	869 Bq	84.7 (5.7)	1.7 (0.2)	ND	ND	13.1 (2.5)
CONTROL	37 KBq	54.9 (5.3)	7.2 (2.3)	0.07 (0.01)	0.2 (0.1)	37.5 (10.2)
DTPA	37 KBq	62.1 (4.3)	3.2 (0.5)	0.04 (0.01)	0.2 (0.1)	34.4 (9.3)
LIHOPO	37 KBq	80.9 (10.6)	1.5 (0.1)	0.04 (0.01)	0.2 (0.1)	17.2 (2.7)
- Intravenous + Intramuscular :						
CONTROL	4,5 KBq	75.5 (1.8)	5.3 (0.6)	0.08 (0.01)	0.33 (0.03)	18.7 (2.3)
DTPA	4,5 KBq	91.4 (0.8)	1.05 (0.04)	0.03 (0.01)	0.59 (0.02)	6.9 (0.7)
LIHOPO	4,5 KBq	95.7 (0.8)	1.5 (0.3)	0.04 (0.01)	0.27 (0.02)	2.4 (0.8)
CONTROL	37 KBq	54.9 (5.3)	7.2 (2.3)	0.07 (0.01)	0.2 (0.1)	37.5 (10.2)
DTPA	37 KBq	68.2 (3.1)	1.2 (0.3)	0.04 (0.01)	0.4 (0.1)	30.0 (8.9)
LIHOPO	37 KBq	90.4 (10.3)	0.36 (0.05)	0.02 (0.01)	0.14 (0.07)	8.9 (1.9)
- Intraperitoneal						
CONTROL	4,5 KBq	75.5 (1.8)	5.3 (0.6)	0.08 (0.01)	0.33 (0.03)	18.7 (2.3)
DTPA	4,5 KBq	79.1 (2.9)	2.9 (0.7)	0.08 (0.01)	0.62 (0.04)	17.3 (2.7)
LIHOPO	4,5 KBq	80.7 (1.4)	4.1 (0.8)	0.09 (0.03)	0.39 (0.11)	14.7 (0.8)
CONTROL	15 KBq	71.0 (0.9)	6.83 (0,6)	0.11 (0,006)	0.40 (0.02)	21.6 (0.7)
DTPA	15 KBq	73.4 (1.9)	3.76 (0.3)	0.09 (0.01)	0.64 (0.05)	22.0 (2.0)
LIHOPO	15 KBq	73.7 (2.6)	5.07 (0.8)	0.16 (0.03)	0.36 (0.08)	20.7 (2.5)

(a) Body burden at death is the sum of radioactivity recovered in the measured organs. 4 animals for treated groups and 6 animals for control groups.
(b) LA : mean of the activities in untreated rat lungs, 7 days after inhalation.
ND : not different to background.

After inhalation, the activity found in the faeces, was higher than in urines as shown in table 3. It still appears that administration of LIHOPO to the contaminated rats increased predominantly the faecal excretion. After DTPA, the urinary excretion was predominant.

Table 3 : Effect of DTPA and LIHOPO on cumulative excretion of plutonium after inhalation of Pu-TBP in rats.

Treatment	LA (b)	Percentage of initial activity (a) (standard error) faeces 2 days	faeces 7 days	urine 2 days	urine 7 days
- Intravenous + Intramuscular :					
control	0	76.7 (3.1)	81.3 (2.7)	0.23 (0.05)	0.33 (0.03)
DTPA	4.5 KBq	70.8 (3.2)	79.8 (1.4)	6.05 (0.75)	11.3 (0.3)
LIHOPO	4.5 KBq	82.7 (1.9)	93.4 (0.5)	1.55 (0.05)	2.35 (0.05)
- Intraperitoneal					
control	0	76.7 (3.1)	81.3 (2.7)	0.23 (0.05)	0.33 (0.03)
DTPA	4.5 KBq	56.9 (16.0)	82.1 (7.4)	3.03 (0.26)	5.52 (0.50)
LIHOPO	4.5 KBq	60.0 (3.1)	87.1 (0.9)	1.17 (0.19)	1.73 (0.20)
control	0	70.6 (0.4)	80.6 (1.9)	0.17 (0.02)	0.26 (0.03)
DTPA	15 KBq	71.8 (0.3)	87.6 (1.4)	3.75 (0.01)	5.40 (0.30)
LIHOPO	15 KBq	74.5 (0.5)	88.5 (1.2)	1.02 (0.14)	1.38 (0.22)

(a) : initial activity correspond to the sum of radioactivity recovered in the measured organs and excreta.
(b) : LA is the mean of the activities in untreated rat lungs 7 days after inhalation.

The importance of the ligand 3,4,3-LIHOPO in the development of treatment in the decorporation of plutonium has induced preliminary studies to estimate the toxic effects of this compound. The inhalation route seems to be less traumatic than intravenous injection and can be administered very soon after contamination without requiring medical assistance. To test this way of administration, preliminary results were obtained on the early toxic effect of a lung administration of 3,4,3-LIHOPO in comparison with DTPA or LICAM(c). Rats were treated by intratracheal administration of the different chelates (at a dosage of 30 µmol/kg) and the fluids of pulmonary lavage by saline solution, one day after the treatment, were analysed. It appears that an inflammatory response is detected after the DTPA or LICAM(c) instillation, with a presence of more than 80% and 55% of polymorphonucleates respectively, in the lung lavage. The LIHOPO instillation do not produced a significant effect in comparison with a saline solution administred by the trachea, 26% versus 20% of polymorphonucleates.

Publication

Poncy JL., Rateau G., Burgada R., T. Bailly, Y. Leroux, Raymond KN. and R. Masse.
The efficacy of 3,4,3-LIHOPO for reducing the retention of 238Pu in rats after inhalation as the I phosphate complex. (to be submitted in Int. J. Radiat. Biol.)

Project 4

Head of project: *Dr. Burgada*

Objectives for the reporting period

(a) To synthesise the siderophore analogue 3,4,3-LIHOPO so that its efficacy for removing Pu,Am and Th from experimental animals could be investigated by CEA, Kfk and NRPB.

(b) To investigate procedures for improving the yield of 3,4,3-LIHOPO.

(c) To synthesise phosphonic acid derivatives for use by the CEA and NRPB in studies designed to remove uranium from the body.

Progress achieved including publications

The following substances were synthesised. The experimental data concerning their efficacy for decorporating the actinides are described elsewhere in the report.

Programme LIHOPO

The synthesis of 3,4,3-LIHOPO was based on that described by White et al. (Journal of Medicinal Chemistry 31, 11-18, 1988). Alternative methods of synthesis were examined but without success. However, in the yield from 15% to 50% during the purification of the product were achieved by replacing the ion exchange procedure by chromatographic separation on a silica column using a mixture of butanol, acetic acid and water as the eluant.

The purity of 3,4,3-LIHOPO was demonstrated by ^{1}H NMR spectrometry and HPLC using 3,4,3-LIHOPO obtained from Prof. K.N. Raymond as the reference substance.

During 1990-92 4,15 g of 3,4,3- LIHOPO was synthesised and distributed amongst the partners as follows.

March	1990	150 mg.	Dr. J.L.Poncy	CEA
Nov.	1990	lg.	Pr. V.Volf	KfK
Feb.	1991	lg.	Dr.G.N.Stradling	NRPB
Apr.	1992	500 mg.	Dr.G.N.Stradling	NRPB
Apr.	1992	500 mg.	Pr.V.Volf	KfK
Apr.	1992	lg.	Dr.J.L.Poncy	CEA

Programme PHOSPHONATES

Aug. 1990

DPTPP		lg.
Diethylene triamine pentamethane phosphonic acid	DETPP	lg.
EDTPA		3 g.
Nitrilo tris phosphonic acid	NTP	3g.
Piperazino methylene diphosphonic acid	PMPA	3g.
Samples prepared for Dr. M.Archimbaud	CEA	

Dec. 1991

Octamethylene bis hydroxydiphosphonic acid	OBHDP	500mg.
Aminopentamethylene hydroxydiphosphonic acid	APHDP	500mg.
Octamethylene bis hydroxyphosphonic acid	OBHP	500mg.
Aminotrimethylene hydroxydiphosphonic acid	ATHDP	500mg.
Dipropylene triamino pentamethylene phosphonic acid	DPTPP	500mg.

Samples prepared for Dr. G.N.Stradling NRPB

Publications

1. Poncy J-L, Rateau G., Burgada R., Raymond K.N. and Masse R.: The efficacy of 3,4,3-LIHOPO for reducing the retention of ^{238}Pu in Sprague-Dawley rats after inhalation as the N-tributylphosphate complex (in preparation).

2. Stradling GN, Gray SA., Moody JC., Hodgson A., Ellender M., Pearce MJ., Wilson I., Burgada R., Bailly T., Leroux Y., Manouni D.El. and Raymond KN.: The efficacies of 3,4,3-LIHOPO and DTPA for enhancing the excretion of plutonium and americium from the rat; comparison with other siderophore analogues.. Int J.Radial.Biol. (in press).

Project 5

Head of project: *Dr. Archimbaud*

Objectives for the reporting period

- To find a decorporating molecule which avoid the holding of uranium in the bone
- To try to define a methodology to characterize the more adequat decorporating molecule.
- To test the efficacies of products synthesised by Burgada's Laboratory for the decorporation of uranium, and to compare the results to those obtained with NaHCO3.
- To test in the same way products synthesised at Pierrelatte, the Calixarene 6 and Calixarene 8.
- To study the toxicity of this two compounds.

Progress achieved including publications

1. Chemical studies

We have synthesised the p-sulfonic calixarene 6 and 8 because of their hydrosoluble properties.
The purity of the molecules was checked with RMN ^{1}H et ^{13}C and also with micro analysis. We have synthesised :
The hexamere $C_{42}\ H_{36}\ O_{24}\ S_6\ 16H_2O$ M = 1405,3 g.

The octamere $C_{56}\ H_{48}\ O_{32}\ S_8\ 1/2\ C_4H_{10}O,\ 22H_2O$ M = 1922,8 g.

The stoechiometric ratio of the complex has been determined using the Job diagramm: the complex calixarene 6 - UO_2^{++} is 1 - 1
calixarene 8 - UO_2^{++} is 1 - 2

In order to determine the chelating constants, we have used the displacement method : at pH = 10.4 the uranyl ion chelating constant with carbonate is $10^{21.5}$, with Calixarene 6 is $10^{19.2}$, with Calixarene 8 is $10^{40.8}$.

2. Decorporation of uranium

We have tested the efficacies of some diphosphonates synthesised by Burgada's laboratory:
- Di-Propylene Triamine Pentamethane Phosphonic Acid (DPTPP)
- Di-Ethylene Triamine Pentamethane Phosphonic Acid (DETPP)
- Trimethane Phosphonic Amine (TPA)
- Piperazine Dimethane Phosphonic Acid (DPP)
- Ethylene Diamine Tetramethane Phosphonic Acid (EDTP)

and of the Calixarenes 6 and 8. We have compared the results to those obtained with the bicarbonate.

The experiments were carried on male Sprague Dawley rats.

Uranium in the kidneys:

The mean values of the amount of uranium retained in the kidneys (m ± 2s) of the control animals (n = 40) are:

6 hours : 16.71 ± 12 % of the injected amount
24 hours : 13.64 ± 4 " "
48 hours : 12.34 ± 5.2 " "

Some results differ significantly from the control of the same experiment (p=0.05) :the value obtained 48 hours after treatment with the DPP (dose 10) is 5.46 ± 6.6, wich represent 51% of the control. The value obtained 48 hours after treatment with the EDTP (dose 1) is 8.79 ± 8.6 wich represent 54 % of the control.

Uranium in the skull:

The mean values of the amount of uranium retained in the skull (m ± 2s) of the control animals (n = 8 assays of the skull of 5 animals pooled each time) are:

6 hours : 1.51 ± 1.22 % of the injected amount
24 hours : 1.77 ± 0.9 " "
48 hours : 1.72 ± 0.9 " "

The values obtained from the animals treated with the 2 doses of DTPP differ significantly (p=0.05) from the controls of the same experiment at 24 hours and 48 hours after treatment. DTPP dose 1- 24 hours: 0.60 % of injected amount (58 % of control), dose 1- 48 hours: 0.62 % of injected amount (58 % of control), dose 10- 48 hours: 0.73 % of injected amount (87 % of control), dose 10- 48 hours: 0.65 % of injected amount (55 % of control).

Uranium excreted in the urine:

The mean values of the amount of uranium retained in the urine (m ± 2s) of the control animals (n = 8 assays for 3 animals pooled each time) are:

6 hours : 12.64 ± 5.1 % of the injected amount
24 hours : 21.18 ± 10.8 " "
48 hours : 27.7 ± 19 " "

Some values differ significantly from the controls: TPA dose 1- 6 hours: 20.6 % of injected amount (149 % of control), dose 1- 48 hours: 58 % of injected amount (268 % of control), dose 10- 48 hours: 56.2 % of injected amount (265 % of control), and EDTP dose 10- 6 hours: 19.4 % of injected amount (169 % of control).

In this experiment, the excretion of uranium by animals treated with the highest dose of NaHCO3 (ration 1-800) is lower than this of untreated animals.

We have not observed any significant result with the Calixarene 6 or 8.
All this results must be confirmed by other experiments.

We have calculated the ratio R/R+U wich decrease for animals treated with the diphosphonates, compared to the controls.

3. Toxicity studies

We have tested the toxicity of the Calixarenes 6 and 8 and of the 4-hydroxy benzene-sulfonic acid, wich can be considered as the monomeric form of the Calixarenes.

Calixarene 6: the animals intoxicated with 14 mg/kg or more have developped a cirrhose with haemolytic anemia.

Calixarene 8: a cirrhose has been observed for the animals treated with 34 mg/kg.

Monomere:no toxic effect has been observed for the hightest dose tested (14 mg/kg)

4. Conclusion

- To obtain a good efficiency for decorporation, the chelating constant of uranyl with the molecule must be higher than the constant of uranyl with bicarbonate. The complex must be stable at pH values around 5, in order not to be dissociated in the kidneys, as it happens with the complex between carbonate and uranyl.
- For a contamination with intra-muscular injection we have noted that the pH of the injected solution was significant, it is essential to determine it with precision. We have done single injection of decorporating molecules ; it would be interesting to try other kinds of decorporating mode with repeated injections.
- In order to evaluate the decorporating action, it is usefull to follow the elimination. We are able to assay uranium in the urines, feces, the kidney, the liver, the intestinal tractus.
  To verify the effectiveness of the decorporating molecule, we will dose uranium in the femur.

REFERENCE rapport CEA/RP 92/37: Removal of incorporated radioactivity. Final report. 1992.

EARLY AND LATE EFFECTS OF RADIATION ON SKIN

Contract Bi6-063 - Sector B23

1) *Hopewell*, Univ. Oxford

Summary of project global objectives and achievements

The work carried out under this contract to an individual laboratory, formed part of a collaborative research programme involving three other centres; CEA/IPSN/DPS/SPE (Dr. Daburon), St. Bartholomew's Medical College (Dr. Coggle) and Berkeley Nuclear Laboratories - Nuclear Electric plc (Dr. Wells). The overall objective of the collaborative research programme was to evaluate the effects of radiation on the skin and subcutaneous tissues. The studies were designed to (a) develop different characteristics of radiation effects on hair as a regional biological dosemeter, (b) provide data that will lead to an improvement in radiological protection criteria for the skin, and (c) obtain a better understanding of the pathogenesis of high-dose radiation effects in order to provide a better rationale for the development of treatment modalities for accident victims that have received a local over exposure to the skin and subcutaneous tissue. These approaches were largely developed on the basis of well established models in the pig that mimic the observed phenomenon of acute and late radio-necrosis as seen in man. For an overview of all the studies carried out reference should be made to individual final reports of the other contributing laboratories.

Arguably the most important achievement over this reporting period has been the detailed re-evaluation of skin data obtained over the present and past reporting periods of CEC financial support to provide information for the recently revised ICRP guidelines for the skin as set in ICRP publications 59 and 60.

Project 1

Head of project: *Dr. Hopewell*

Objectives for the reporting period

The objectives of this laboratory over the last reporting period can be described under three broad headings:-

(a) improved regional biological dosimetry

(b) research related towards the improvement of radiological protection criteria and

(c) a better understanding of the pathophysiology of late radiation-induced damage to the skin to provide a guide to improved methods of treatment.

In the 2.3 years covered by the contract preference has been given to work under headings (a) and (b). However, some studies under heading (c) have been initiated to form a basis for increased collaboration within the CEC in subsequent years.

Progress achieved including publications

1. Regional biological dosimetry

Hair is situated on most parts of the body and radiation damage to the matrix cells of actively growing hairs can be identified by subsequent changes in the hair. It has been demonstrated that changes in hair could provide information on dose and its regional distribution in individuals suspected of over-exposure of the skin.

1.1 Reduction in hair diameter

Earlier studies have shown that radiation produces a transient and dose-related reduction in hair diameter which is quantitatively similar in mouse and pig (Sieber et al., Radiat. Protec. Dosim. 16, 301-306, 1986). This can be useful in indicating localised exposures in the range 1-6 Gy. In order to improve the accuracy of this approach, growing hairs in the pig, and the point of maximum reduction in hair diameter, have been identified by looking at the deletion of the medulla in the mature hair. Using a MagiScan image analysis system the reduction in hair diameter could be assessed. The results for single doses of X-rays (250kVp) in the range 0.1-4.0 Gy are illustrated in Table I. These data are consistent with a linear dose response for doses up to 3Gy; doses below 1 Gy produced a measurable response.

Table I. Dose-related changes in the reduction (%) in the diameter of hairs in the pig measured at 14 days after single doses of 250kV X-rays.

	Dose (Gy)							
	Control	0.1	0.3	0.5	1.0	2.0	3.0	4.0
Exp. 1.	0.17 ±0.12	1.08 ±0.16	1.24 ±0.16	-	3.76 ±0.35	8.00 ±0.65	11.11 ±0.70	-
Exp. 2.	0.44 ±0.37	-	-	1.99 ±0.30	4.10 ±0.44	7.80 ±0.96	11.18 ±0.95	18.29 ±0.79

Control values should be zero % but the lack of a deletion in the medulla makes measurements less reliable than from irradiated hairs. Errors represent standard errors (From Wells et al. 1991).

Some preliminary studies have also been carried out to demonstrate the validity of this approach for assessing dose to human skin. Patients receiving palliative radiotherapy for malignant disease were used in the studies (Ethical approval and individual patient consent was obtained). Growing hairs were plucked from patients 5-7 days after single doses of 2.9-13.6 Gy; hair from the chest, leg or scalp was used. The preliminary findings obtained as a result of the analysis of sites on 15 patients are illustrated in Figure 1. There was considerable scatter in the data but the overall response suggested a linear dose response, the slope of the regression line was shallower than that obtained for both pig and mouse hair.

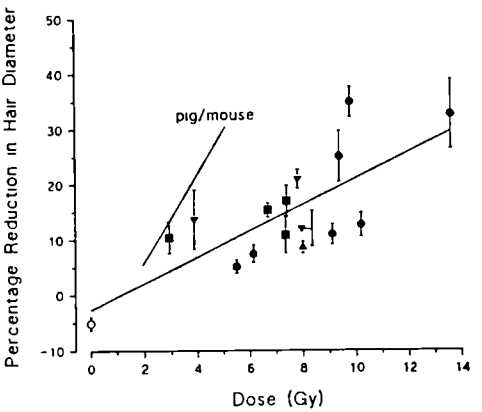

Figure 1: Shows the percentage reduction in the diameter of human hair following single exposures to ^{60}Co γ-rays (●), 8 MeV photons (■) or 250kVp X-rays (▼). Error bars indicate +SE (○ unirradiated controls). Regression line for pig and mouse results indicated for comparison.

1.2 Induction of transient (partial) epilation

Using an arbitrary scoring system it has been demonstrated that transient hair loss occurs in the pig after single doses of 250kVp X-rays of ≥6Gy. The incidence of detectable hair loss or >50% hair loss, noted in the first 10 week period after irradiation, was dose related and suggested ED_{50} values for these two levels of response of 9.8 ± 0.6 Gy and 13.8 ± 0.9 Gy, respectively (Sieber and Hopewell, Radiat. Protec. Dosim, 30, 117-120, 1990).

A more quantitative technique, in which the number of hair in an area were counted from weekly photographs over a 10 week period, has been found to be more sensitive. Hair loss over the first 10 weeks could be detected after doses of 1.0-2.0 Gy, the maximum reduction being approximately 20%. The severity of hair loss was dose-related up to 12Gy (Figure 2). No further loss of hairs was seen after higher doses suggesting that the 20-25% of remaining hairs were not actively growing. The inference that this quantitative method was more sensitive than the previously used arbitrary scoring technique was reinforced by the finding of a significantly lower ED_{50} value for ≥50% hair loss of only 6.8 ± 1.3 Gy.

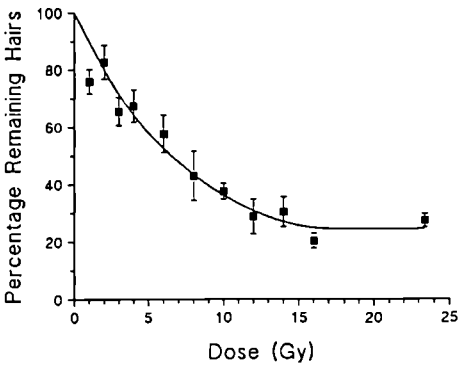

Figure 2: Shows the dose-related changes in the minimum number of remaining hairs (% control) assessed in the 10 week period after irradiation with single doses of 250kVp X-rays. Error bars indicate ±SE.

2. Radiological protection criteria

2.1 Dose limitation and the depth of potential target cells

Results obtained previously (Hopewell et al., Brit. J. Radiol, Suppl. 19 pp. 47-51), have been revised to take account of changes in dose that have resulted from new dosimetric calculations (Darley et al. Radiat. Prot. Dosim. 39, 61-66, 1991) particularly with respect to the dose estimate from small sources, ≤2mm diameter ('hot particles'), for doses measured over 1.1mm^2. The revised results for the early responses in pig skin to acute single dose exposures from $^{90}Sr/^{90}Y$ and ^{170}Tm are given in Figure 3. Dose estimates for the ED_{10} for the production of acute ulceration or moist desquamation, measured over 1.1mm^2, are compared with those averaged over 1cm^2. For the larger sources, where moist desquamation was the end point of concern, there was a clear energy dependence. When the ED_{50}, ED_{10} and estimated threshold doses for this response from these two energy sources were compared with

depth-dose curves, a crossover was obtained at a depth of 650-750μm. This reinforces the view as to the importance of epithelial target cells from the canal of hair follicles in the repopulation of the epidermis even after doses that do not result in moist desquamation. A dose of ~12Gy measured at 650μm would appear to represent the threshold dose to prevent moist desquamation after acute exposures.

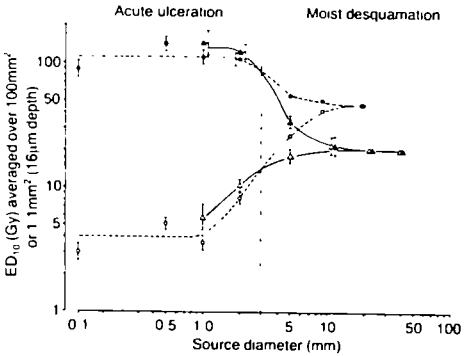

Figure 3: Variation in ED_{10} values (± SE) for acute ulceration or moist desquamation, with change in source diameter. Doses were averaged over either 1.1mm² (● ▲) or over 1cm² (○ △) at 16μm depth. Results are for $^{90}Sr/^{90}Y$ (▲ △) or ^{170}Tm (● ○)

For late radiation damage, assessed at 2 years after exposure to the same large sources, a more complex response with respect to dose measured at depth in tissue was found. The depth at which dose should be measured to produce a comparable degree of dermal thinning from the large $^{90}Sr/^{90}Y$ and ^{170}Tm sources increased with the increase in level of effect measured. A dose of ~5Gy, at a depth of ~600μm, was associated with the ED_{10} for a ≥20% reduction in relative dermal thickness. The corresponding dose for the ED_{50} for a ≥30% reduction in dermal thickness was ~9Gy, measured at 1200μm. The change in depth at which dose should be measured for different levels of late damage, when assessed after approximately two years, possibly reflects a complex interaction between the two phases of late dermal thinning that has previously been reported after $^{90}Sr/^{90}Y$ exposure and has now been confirmed after ^{170}Tm exposure (Figure 4). The time course of the changes was similar for the two types of source.

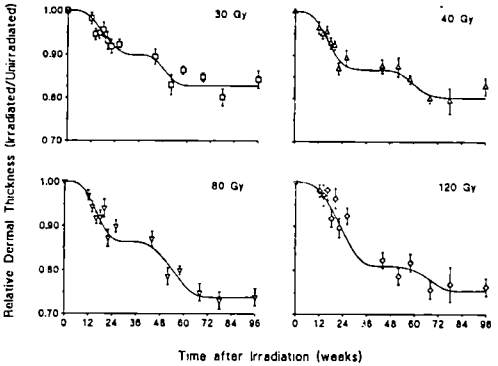

Figure 4: Time-related changes in the relative thickness of dermal tissue compared with adjacent unirradiated skin in the pig after irradiation with various single doses of ß-rays from a 10mm x 20mm ^{170}Tm plaque.

For 'hot particles' the dose required to produce acute ulceration in ~10% of sites exposed was ~120 Gy when averaged over 1.1mm^2 at 16µm depth in tissue (Figure 3). When doses are expressed at a depth of 100 - 150µm in the papillary dermis where damage is expressed, the results are consistent with a threshold dose of ~1 Gy averaged over 1cm^2 for each 'hot particle' exposure.

2.2 Dose-rate effects

The influence of dose-rate on the acute skin response has been established for large, 22.5mm diameter, ^{90}Sr/^{90}Y sources, with dose-rates of 1.0-300 cGy/min. Details of precise dose-effect relationships for moist desquamation have been established for sources with dose-rates of 2.2-300 cGy/min (Table 2). For doses given at a dose-rate of 1 cGy/min the threshold dose for moist desquamation was >100 Gy.

Table 2. ED_{50} and ED_{10} values for moist desquamation of the skin of pigs after ß-irradiation from ^{90}Sr/^{90}Y source of 22.5mm diameter of differing dose-rate.

Dose rate (Gy/min)	ED_{50} (Gy)	ED_{10} (Gy)
0.022	66.5	46.8
0.052	47.0	37.8
0.107	41.1	31.9
3.0	27.3	21.1

3. Pathogenesis of late radiation-induced damage

Following accidental over-exposure of the skin to radiation a late wave of erythema may develop after the main erythematous reaction has faded. This later phases of injury predominantly represents vascular insufficiency in the

dermal and subcutaneous tissues. Clinically there is oedema associated with this reaction and this may further exacerbate any primary vascular damage. Severe vascular damage will result in the development of necrosis. In order to further evaluate the significance of the oedematous changes, time-related changes in resting lymphatic flow have been assessed using a recently developed, ^{99m}Tm-Rhenium sulphide colloid, clearance technique.

For this study several sites were irradiated in the left flank of pigs and lymphatic flow was assessed after intervals of 3-78 weeks both in the irradiated sites and in unirradiated areas between those sites on the same flank of the pig. Irradiation was with a single dose of 18Gy of 250kV X-rays. This produces clinically detectable oedema but does not result in necrosis.

The time-related changes in the half-times for the clearance of the colloidal tracer are shown in Figure 5. Slower tracer clearance from irradiated sites was first seen after 6 weeks, prior to any clinical appearance of oedema, and the maximum impairment of lymphatic flow as seen at 12 weeks. Clinical oedema could be identified at 9 and 12 weeks. There was also impaired lymphatic clearance from the unirradiated areas between the irradiated sites, an observation consistent with the pattern of lymphatic drainage across the flank skin of a pig. There was the suggestion of a second wave of impairment of lymphatic flow at 52 weeks but there was no clinically detectable oedema. However, it does coincide with the initiation of a second phase of reduction in dermal thickness.

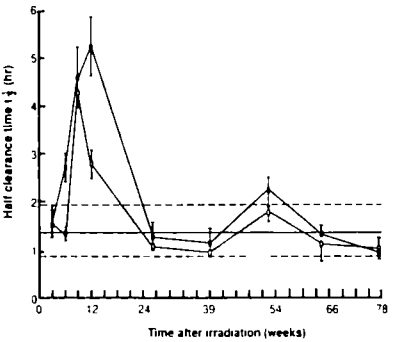

Figure 5: Time-related changes in the half times (± SE) for the clearance of a ^{99m}Tc-colloid from the dermis of irradiated (•) and adjacent areas of unirradiated (○) skin. Shaded area gives $t_{\frac{1}{2}}$ values for control dermal tissue.

Further studies devoted to the prophylactic treatment of late radiation induced changes in the skin and subcutaneous tissues will be directed towards the reduction of inflammation, oedema and to the improvement in the vascular supply.

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PROBLEMS RELATED TO SKIN AND UNDERLYING TISSUES AFTER ACCIDENTS INVOLVING LOCAL IRRADIATION. EXPERIMENTAL STUDY IN THE PIG

Contract Bi6-058 - Sector B23

1) *Daburon*, CEA

Summary of project global objectives and achievements

The work carried out under this contract to an individual laboratory, formed part of a collaborative research programme involving three other centres; CEA/IPSN/DPS/SPE (Dr. Daburon), St. Bartholomew's Medical College (Dr. Coggle) and Berkeley Nuclear Laboratories - Nuclear Electric plc (Dr. Wells). The overall objective of the collaborative research programme was to evaluate the effects of radiation on the skin and subcutaneous tissues. The studies were designed to (a) develop different characteristics of radiation effects on hair as a regional biological dosemeter, (b) provide data that will lead to an improvement in radiological protection criteria for the skin, and (c) obtain a better understanding of the pathogenesis of high-dose radiation effects in order to provide a better rationale for the development of treatment modalities for accident victims that have received a local over exposure to the skin and subcutaneous tissue. These approaches were largely developed on the basis of well established models in the pig that mimic the observed phenomenon of acute and late radio-necrosis as seen in man. For an overview of all the studies carried out reference should be made to individual final reports of the other contributing laboratories.

Arguably the most important achievement over this reporting period has been the detailed re-evaluation of skin data obtained over the present and past reporting periods of CEC financial support to provide information for the recently revised ICRP guidelines for the skin as set in ICRP publications 59 and 60.

Project 1

Head of project: *Dr. Daburon*

Objectives for the reporting period

Diagnosis, prognosis and treatment of acute localized irradiations in pigs.
Dosimetric assays by non invasive biophysical methods to evaluate the size and intensity of the radiolesions as an aid for surgery.
Pathogenic studies of irradiated tissues by histological, immunocytochemical and histoenzymological methods.
Pharmacological treatment screening in pigs and rabbits.
Surgical treatment in pigs.
Post-irradiation fibrosis studies in pigs: this healing process is investigated with respect to extracellular matrix synthesis,cellular proliferation abilities and molecular biology aspects.

Progress achieved including publications

1. Diagnosis

In our experimental model, two methods made possible the discrimination between irradiation doses involving either a spontaneous healing process (30-40 Gy) or a permanent ulcer (64-84 Gy): combined thermographic measurements with superficial and microwave probes and serum biochemistry of acute phase proteins and muscular enzymes; furthermore a threshold could be assessed for a muscular exposition of 20-30 Gy.
X Rays Computed Tomography and Nuclear Resonance Imaging made obvious, as soon as 2-3 days after irradiation, tissues areas exposed to doses above 40-50 Gy.
A additional interest of these biophysical, biochemical and biological methods was to make obvious, and to a certain extent to quantify, the effects of different treatments as dose reducing factors.
Using 201 Tl and 99m Tc labeled glycolipidopeptide for gammascintigraphies of the radiolesions made possible to follow the early hyperhemic reaction, the inflammatory reaction with migrating macrophages and finally the replacement of necrotized tissues by fibrosis.

2. Treatments

Surgical treatments trials in pigs led us to define two thresholds for muscle radiosensitivity: about 30-40 Gy for direct necrosis and 10-20 Gy for the limits of delayed fibrosis extent in spontaneously healing radiolesions. After early removal of irradiated skin, the fibrosis extent into the

underlying tissues is limited to tissue given above 25-30 Gy. Eleven pharmacological treatments were given for 8 weeks to a total of 240 rabbits irradiated on the back with 20 Gy: the combination of non steroïdal anti-inflammatory and haemorheological agents involved a dose reduction factor of 2.

3. Fibrosis studies

Objectives: Post-irradiation fibrosis exhibited a tendency to spread out in surrounding tissues, weakly or not irradiated; fibroblasts isolated from radiation-induced fibrotic tissues exhibited in culture an abnormal and activated phenotype. Two questions about that cellular activation was related to the initial events of fibrogenesis:
1) have the cells involved in the healing process been irradiated and subsequently retained cytogenetic anomalies ?
2) which were the stimulatory factors responsible for the chronic inflammation in the fibrotic tissues ?
Results: Fibrotic tissues were removed from the pig radiolesions between 1 and 24 months after irradiation and fibroblasts were isolated and put into culture medium. In fibrosis tissue samples taken off after 3-5 months total protein and collagen synthesis was respectively 10 and 20 times higher than in normal muscle. In fibrosis extracted fibroblasts (FEF) cultures fibronectin and glycosaminoglycanes synthesis was significantly higher than in normal dermal fibroblasts (DF). As far as FEF proliferation in culture was 10 times higher than DF (even in 20 months post-irradiation samples) the possible role of growth factors was to be investigated: the response of FEF to EGF (epidermal growth factor) assessed by increasing the cells number in culture was 2 times higher than for DF.
TGFβ (transforming growth factor) might be one of the main factors responsible for radiation fibrosis development: TGFβ gene is highly expressed in FEF and in irradiated tissues. An auto-stimulating network with self-sustained autocrine secretion is a possible hypothesis for explaining fibrosis extension.
Conclusion: The first results in cytogenetic studies suggested that FEF derived from irradiated cells. The high level of chromosome damages might be responsible for the pretransformed state of those fibroblasts. A consistent observation about this hypothesis was the spontaneous perennisation of FEF cell lines (at the present time more than 50 subcultures) when normal DF cultures died after 10-15 subcultures. In vitro modulation of the collagen phenotype by the heparin fragments showed that the degradation products of the extracellular matrix might be regulatory factors of the fibrotic processes.

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RADIATION EFFECTS ON THE SKIN AND SUBCUTANEOUS TISSUES: IMPLICATION FOR PROTECTION CRITERIA AND TREATMENT OF LOCALIZED ACCIDENTAL OVER-EXPOSURE

Contract Bi7-056 - Sector B23

1) *Coggle*, Med. Coll. St. Bartholomew's Hosp.

Summary of project global objectives and achievements

The objectives in this project were to define the target cell(s) for the acute epidermal reactions following alpha and beta exposure of varying areas of mouse skin. To study in the light of the Chernobyl and Goiania accidents any synergy between external gamma exposure of the whole body and the localised beta exposure of the skin. And to compare the skin cancer proneness of albino and pigmented strains of mice to ionizing radiation.

The relative roles of mitotic and interphase cell death of both basal and suprabasal epidermal cells in the acute skin reactions for different energy beta particles has been clarified. Minimal synergy was found between whole body exposure and localised skin lesions when the radiations were given simultaneously. However, prolonging the immune suppression by using whole body gamma doses 7 and 14 days after the localised beta dose significantly prolonged the repair of the skin lesions. Albino mice were 4-5 times more cancer prone than pigmented mice; with the different strains showing significantly different spectra of epidermal and dermal origin tumours.

Project 1

Head of Project: *Dr. Coggle*

Objectives for the reporting period

There were three objectives in this project.

The first was to define the target cells for the acute epidermal reactions following alpha and beta external exposures and the relative roles of epidermal basal cells and hair follicle cells in the resolution of the skin lesions.

The second objective was to study, in the light of the Chernobyl and Goiania accidents, the effects of external exposure of the whole body on the acute skin reactions in mice.

Thirdly, in parallel with the above acute reactions, studies were made of late neoplastic changes in four strains of mice using alpha, beta and neutron sources.

Progress has been made in all three.

Progress achieved including publications

1. To define the target cells for the acute skin reactions following alpha and beta exposures we have used the classical moist desquamation reaction with its onset in mice and 12 days post exposure. The reaction peaks at 20-25 days and is rapidly resolved by 35-40 days. This reaction is driven by the basal cell damage and basal cell kinetics. Use of thulium, promethium and strontium beta sources as well as low penetrating curium alpha particles of a range of source sizes has clearly demonstrated that this reaction is area and energy dependant with a significant role in repair being played by basal cell migration from both the edges of the irradiated field and from surviving hair follicle lining cells.

   A second reaction termed "acute ulceration" is one that involves the loss of epidermal and dermal cells by interphase death with moist desquamation and scab formation occurring as early as 5-6 days post-exposure.

   A third distinct type of "acute epidermal necrosis" occurred 6-7 days after high doses of the weakest beta emitter-promethium 147. This involves the interphase death of the upper layers of the epidermis but not damage to the dermis. The acute effects of thulium-170 beta irradiations were compared in four strains of mice with significantly different dermal thicknesses. It was found that the reaction was most severe in mice strains with thinner dermises but did not correlate with epidermal thickness (see reference 1).

   Finally the large series of curium alpha exposures clearly showed their much reduced effectiveness compared to that of beta irradiation. This was because the alphas did not penetrate to the basal layers of the epidermis and even at doses as high as 180 Gy, moist desquamation was not inducible. Alphas gave a dose related response fo the milder endpoints of erythema and discolouration but the more severe skin lesions were not inducible even with the large area curium sources.

   These acute studies in mice were conducted in parallel with Dr. Hopewell (Oxford) using his pigskin system and the result of this collaboration has been incorporated into the ICRP Skin Task Group document of 1991 and thus into ICRP thinking on the problem of non-uniform surface contamination of the skin i.e. the general problem of hot particles. The reassuring message to the radiation protection community of these beta studies is that as the area falls from hundreds of mm^2 to less than 1 mm^2 the dose for a given effect falls by

several orders of magnitude. Thus in mice to produce 50% moist desquamation a dose > 1,500 Gy of promethium betas is needed (at 0.3 mm^2) compared with 20 Gy for a large (100 mm^2) strontium 90 source.

2. The second objective was to study, in the light of the Chernobyl and Goiania accidents, the effects of external exposure of the whole body on the acute skin reactions in mice. To do this we set up groups of animals given 50 Gy of thulium-170 betas to 800 mm^2 of skin combined with either 0,1,2,4,6,8,9 or 11 Gy of whole body ^{60}Co gamma radiation at a dose rate of 1 Gy per minute. Three control groups were also set up - (A) depilated and sham irradiated (B) given betas only (C) given gamma radiation only. The haematological status of animals given 2, 4, 8 and 10 Gy of whole body gamma ray was serially assayed for monocyte, lymphocytes and granulocyte numbers. The results showed there was no synergy detectable for gamma ray doses < 4 Gy. But for whole body gamma doses 4, 6 and 8 Gy there was a 4-5 day prolungation in the time course of localised beta induced skin reaction but no significant exacerbation of the severity of the reaction. This rather surprising finding of minimal synergy between whole body exposure and a localised skin burn may be due to the fact that the gamma-ray-induced immune incompetence of the animals significantly recovered ahead of the maximum skin response - so that any exogenous or endogenous infection of the skin lesions that might have exacerbated wound healing is prevented by the timely recovery of immune competence. The details of these experiments are to be found in reference 2.

   Recent experiments involving a more chronic suppression of the immune system using two doses of 7 Gy whole body gamma radiation given 7 and 14 days after the initial skin beta dose produced much more significant synergy with a 14 day prolongation of the healing of the skin damage after 50 Gy of localised beta exposure.

3. In parallel with the acute reactions we have studied late neoplastic changes in 4 strains of mice using alpha and neutron sources. This long term arm of the project goes back over 4 years. Earlier model studies of the hot particle problem showed that the greater the non-uniformity of the dose the less carcinogenic was the response. Once again these data have recently become incorporated into the ICRP 1991 Skin Task Group Report as a clear refutation of the hot particle theory of carcinogenesis in the skin.

   Our recent carninogenesis work has centred upon investigating the skin cancer proneness of 4 strains of mice (2 albino (CD1 and SAS/4), and 2 pigmented (S7B1 and CBA)). Fig 1 shows a typical dose response curve for the cumulative skin tumour incidence in SAS/4 mice following 2-200 Gy of thulium betas, the best fit is a linear induction followed by a quadratic cell killing component. There is no evidence of a threshold to the curve.

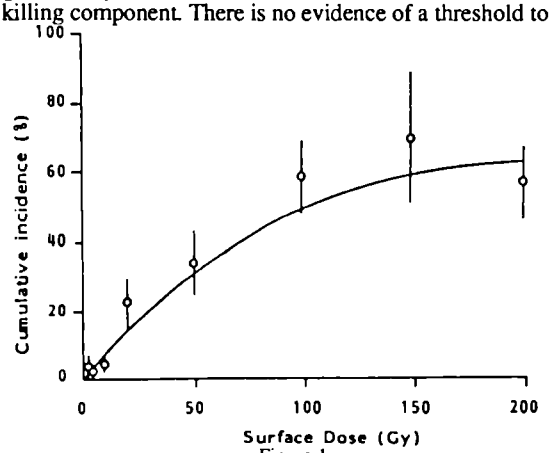

Figure 1

Figure 2 shows the wide mouse strain variation in cumulative skin tumour incidence as a function of time for a surface dose of 50 Gy of thulium betas. The absolute skin tumour incidences at 50 Gy were 51% (CD1); 27% (SAS/4); 16% (C57 BL); and 15% (CBA). Albino mice are seen to be more cancer prone than pigmented mice. This is underlined in the complete dose response curve in Fig. 3 where the albino CD1 mice show an approximate 4 fold greater cancer proneness than the pigmented CBA mice over a wide range of doses.

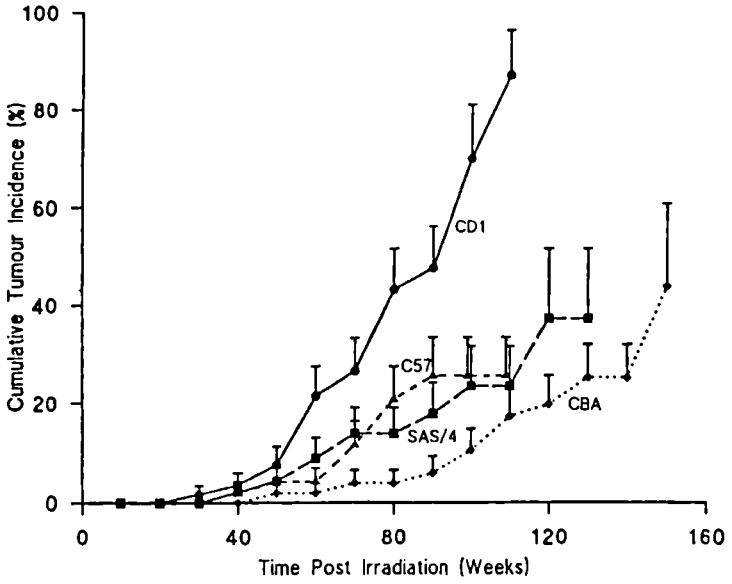

Figure 2

The histopathology of over 300 tumours induced in these studies has revealed quite a wide variation in the percentage of dermal versus edipermal tumours. In the CD1 and SAS/4 strains over 95% of the tumours were dermally derived from the fibroblasts; malignant fibrous histiocytomas and fibrosarcomas being the most frequently occurring tumours. In contrast in CBA skin, with its much lower skin cancer proneness, only 60% of the tumours were of dermal origin.

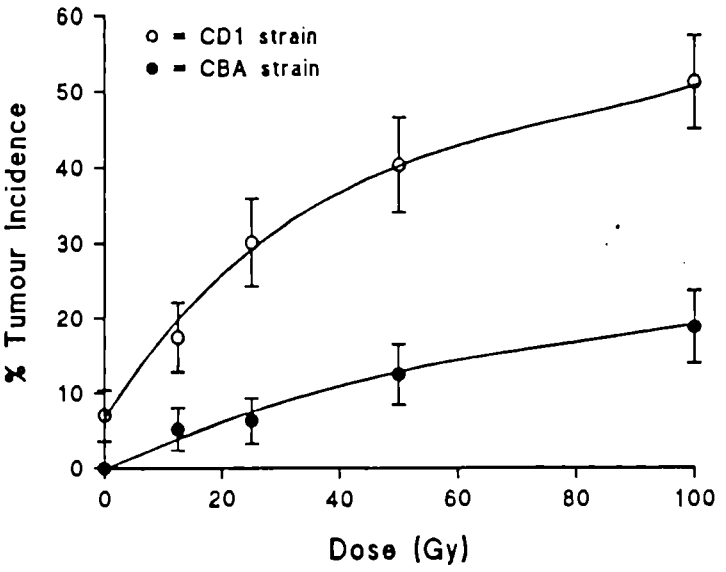

Figure 3

The alpha particle data in Table 1 reinforces the predominant role of dermal tumours following ionising radiation and shows the skin tumour incidence after a range of curium alpha doses in SAS/4 mice. These alpha particles do significant epidermal damage especially to supra basal cells but do not penetrate into the dermis. This explains their lack of tumourgenicity; the five tumours that were seen were dermal in origin and probably represent the spontaneous incidence in this strain (of <1%).

Table 1. Summary of the data from the exposure of SAS/4 mice to curium 244 alpha irradiation

Dose (Gy)	No. of animals	No. of tumours	Time of incidents (weeks)
180	84	1	103
120	76	0	-
80	76	0	-
40	75	2	60,79
20	92	0	-
10	93	1	108
5	93	1	76
2	99	0	-
0	77	0	-
Total	777	5	

Finally a small carcinogenesis experiment involving intermediate energy 24 keV neutrons indicated a RBE of between 4-5 for the neutrons relative to 320 kVp X-rays. All these longterm studies are being analysed using lifespan models prior to publication.

In summary in this CEC project we have developed a reproducible skin tumour induction system for mice of different skin cancer proneness and we propose in 1992-1994 to bridge the gap between the acute reactions and these late reactions by studying the cell and molecular biology of the chronic inflammatory and fibrotic reactions that occur in the irradiated mouse skin.

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EUROPEAN CLINICAL RESEARCH ON PRACTICAL PROTOCOLS FOR THE DIAGNOSTICS AND TREATMENT OF LOCALIZED OVEREXPOSURE

Contract Bi7-049 - Sector B23

1) *Góngora* , Institut Curie - 2) *Strambi* , ENEA
3) *Herránz-Crespo* , Hospital General Marañón

Summary of project global objectives and achievements

Les brûlures radiologiques représentent la pathologie la plus fréquente engendrée par les accidents radiologiques. Elles sont différentes des brûlures thermiques et chimiques ; elles posent des problèmes diagnostiques et thérapeutiques spécifiques. Le traitement optimal des brûlures radiologiques implique que la quantité d'énergie délivrée aux différents tissus soit parfaitement connue ; aussi le programme de recherche porte sur la mise au point de protocoles relatifs à la dosimétrie biologique et sur des protocoles d'investigations paracliniques. Ces derniers font appel essentiellement à la termographie I.R. , à la capillaroscopie et aux méthodes nucléaires. Le traitement des brûlures radiologiques est, en fonction de la gravité, soit médical, soit chirurgical. Sur le plan médical les protocoles de recherche concernent les méthodes d'isolement segmentaire ou total, les problèmes de la douleur qui présentent des caractères spécifiques, les traitements par enzymes fondés sue des données physiopathogéniques. Le traitement chirurgical pour être aussi conservateur que possible doit faire appel aux données dosimétrique physiques et paracliniques pour définir les volumes d'excision et choisir judicieusement les méthodes de recouvrement (greffe, lambeau, peau artificielle). Le programme de recherche porte sur ces différents domaines.

Project 1

Head of project: *Prof. Góngora*

Objectives for the reporting period

- Apport de la capillaroscopie au diagnostic, au traitement et à la surveillance à long terme des brûlures radiologiques.
- Apport de l'étude de la vascularisation par scintigraphie au diagnostic et à la surveillance à long terme
- Physiopathologie de la peau irradiée
  - Immunohistochimie
  - Culture d'explants de peau irradiée
- Approche thérapeutique
  - Traitement des fibroses post radiques par la superoxyde dismutase
  - Prévention des fibroses post radiques par la superoxyde dismutase
  - Traitement des radiodermites par des facteurs de croissance

Progress achieved including publications

1. Capillaroscopie

L'étude des modifications capillaroscopiques après irradiation aiguë a porté sur 29 observations. Il s'agit d'irradiation des mains accidentelles dans la plupart des cas.
- Les anomalies capillaires son fréquentes.

On observe deux catégories de modifications : les unes importantes consistent en raréfaction des anses, zones désertes, hémorragies, ectasies diverses et néogénèse . Ces anomalies sont souvent associées et sont en relation directe ou indirecte avec la zone exposée ce qui confère une certaine spécificité et permet le diagnostic différentiel avec des maladies systémiques. Les autres sont plus subtiles : capillaires sinueux ou dilatés

Il est important de prendre en considération le moment où l'examen est pratiqué par rapport au moment de l'exposition. En effet, comme pour d'autres moyens d'investigations (thermographie et scintigraphie vasculaire), les résultats diffèrent en fonction du délai qui sépare l'examen du moment de l'exposition. Mais alors que thermographie et scintigraphie montrent des modifications qui s'estompent par la suite, à l'inverse, la capillaroscopie, le plus souvent ne montre pas de modifications significatives immédiatement ; les anomalies n'apparaissent que plus tardivement. (Dans certains cas, cependant, une modification capillaroscopique est le seul témoin de l'exposition). Aussi, la capillaroscopie présente davantage un intérêt pronostique que diagnostique. Elle est toutefois utile au diagnostic topographique.

En outre, les modifications capillaroscopiques morphologiques sont très longues à restaurer et peuvent constituer tardivement le seul témoin d'une exposition.

Bien que les modifications capillaroscopiques ne soient pas très précoces, il est très important de pratiquer un examen précoce de référence notamment dans le cas où il y a une pathologie associée.

Les expositions des mains engendrent une symptomatologie capillaroscopique qui prend tout son intérêt dans le contexte clinique et dans le contexte paraclinique (thermographie, scintigraphie vasculaire.)

2. Examens radioisotopiques

Ils portent essentiellement sur l'étude des modifications vasculaires et l'étude des réactions osseuses.

Les méthodes d'investigations de la vascularisation utilisant des traceurs radioactifs ont essentiellement deux objectifs : étude des modifications des débits vasculaires, étude des modifications de la perméabilité vasculaire après irradiation. Largement étudiées sur le plan expérimental chez l'animal, leur appréciation en clinique est relativement restreinte.

Comme pour la thermographie, les modifications de la microcirculation et de la circulation en général sont dépendantes de multiples facteurs affectant les territoires de référence et peuvent contribuer à accroître artificiellement les différences de débit entre tissus irradiés et tissus sains.

Ces méthodes présentent un intérêt majeur pour le diagnostic précoce, pour le bilan préchirurgical, pour le suivi des séquelles et des complications.

Lors d'une irradiation accidentelle, c'est généralement un ensemble de formations tissulaires qui est affecté et non pas exclusivement le revêtement cutané. L'atteinte osseuse est fréquente ; elle dépend bien entendu de l'intensité et de l'énergie du rayonnement ; or, dans les irradiations accidentelles, les énergies en cause sont généralement relativement élevées ; c'est le cas pour la gammagraphie industrielle.

Des modifications précoces peuvent être enregistrées par scintigraphie à l'aide de molécules ostéotropes. Il s'agit généralement d'hyperfixation osseuse des territoires irradiés. Exceptionnellement, on peut observer à l'inverse pour des doses très élevées une "sidération" des fonctions métaboliques et l'absence de fixation physiologique.

3. Physiopathologie de la peau irradiée

L'étude a porté sur les modifications immunohistochimiques et physiopathologiques de la peau humaine irradiée.

3-1 - Immunohistochimie de la peau irradiée

L'objectif dc l'étude immunohistochimiques est de définir, en fonction du délai après l'irradiation, l'évolution du phénotype des fibroblastes activés et les modifications biologiques en rapport avec le développement de la fibrose pathologique.

Des prélèvements cutanés mammaires ont été collectés chez 30 femmes opérées à des délais variables (3 mois à 71 mois) après irradiation thérapeutique de la glande mammaire par ^{60}Co. (dose peau 25 à 40 Gy en 5 à 6 semaines) soit dans le champ d'irradiation (peau irradiée) soit en dehors du champ (peau non irradiée).

3-1.1 - Protéines du cytosquelette

- La vimentine

Tous les fibroblastes dermiques examinés expriment la vimentine, que les peaux aient ou non été irradiées. Cependant, au niveau du derme normal, les fibroblastes visualisés par l'anticorps anti-vimentine sont en nombre modéré et répartis à travers le derme superficiel et profond. Dans le derme irradié, une accumulation de cellules vimentine-positives est observée au niveau de la zone superficielle, immédiatement adjacente à la jonction dermo-épidermique, le long de la membrane basale.

- L'alpha-actine de muscle lisse

Au niveau des peaux non irradiées, l'anticorps anti-alpha actine marque essentiellement les médias musculaires des vaisseaux ainsi que les cellules myoépithéliales des glandes sudoripares. De surcroît, un certain nombre de fibroblastes de derme irradié expriment l'alpha actine de muscle lisse ; par ailleurs, le marquage de la média et de l'adventice fibreuse des vaisseaux télangiectasiques est particulièrement intense, sur les coupes de peau irradiée.

Ce phénotype alpha actine - positif est généralement identifié comme caractéristique de fibroblastes "activés", réactionnels ou "myofibroblastes".

- La desmine
L'anticorps anti-desmine n'a visualisé que les formations musculaires périvasculaires ou quelques fibres musculaires éparses dans le derme des peaux irradiées ou non. Il n'a pas été observé de marquage des cellules fibroblastiques du derme.
En conclusion, les fibroblastes de derme irradié présentent donc un phénotype V+A+D-caractéristique des myofibroblastes dans 22/30 cas. Les peaux non irradiés présentaient un faible marquage des fibroblastes dermiques par l'alpha actine de muscle lisse dans 3/9 cas (desmoplasie?).

3-1.2 - La fibronectine

- Dans les peaux non irradiées:
L'anticorps antifibronectine marque faiblement les espaces intercellulaires au niveau de la partie profonde de la couche basale, en regard de la membrane basale. La fibronectine est également visualisée autour des parois vasculaires et le long de membranes cytoplasmiques d'un petit nombre de cellules fibroblastiques du derme superficiel. L'intensité de marquage est globalement faible.
- Dans les peaux irradiées:
Au niveau de l'épiderme, le marquage, d'intensité plus forte, s'étend aux couches basale, parabasale et parfois intermédiaire. La fibronectine, essentiellement intercellulaire et quelquefois membranaire, est également visualisée dans le cytoplasme sous-membranaire des cellules épithéliales des couches parabasale et intermédiaire, dans 6/30 cas.
Au niveau du derme, la fibronectine apparaît essentiellement inter- et péricellulaire, marquant la quasi-totalité des fibroblastes observés. Un marquage des parois vasculaires est également observé.

3-1.3 - Le TGF Beta

- Dans les peaux non irradiées:
Au niveau de l'épiderme, le TGF Beta est visualisé sur les membranes cellulaires cytoplasmiques, parfois nucléaires, des cellules de la couche basale de l'épiderme ; exceptionnellement, l'anticorps anti-TGF Beta marque faiblement les membranes cytoplasmiques de rares fibroblastes dermiques.
Un marquage vasculaire, d'intensité variable, est également observé à la limite entre l'intima et la media des vaisseaux intradermiques, évoquant ainsi une localisation du TGF Beta sur la membrane basale sous-endothéliale.
- Dans les peaux irradiées:
Les cellules de l'épiderme présentent un marquage nucléaire prononcé par l'anticorps anti-TGF Beta, précisément localisé dans la couche intermédiaire, lorsque l'épiderme est de faible épaisseur et le derme épais et apapillaire, étendu aux couches parabasale et superficielle lorsque l'épiderme est plus épais et le derme papillaire. Une large majorité des fibroblastes du derme montre un marquage intranucléaire par l'anticorps anti-TGF Beta.
Le marquage vasculaire reproduit celui observé dans le derme des peaux non irradiées.

3-1.4 - Le Récepteur de l'EGF

- Dans les peaux non irradiées:
L'épiderme est faiblement marqué au niveau des couches basale et plus rarement parabasale profonde ; ce marquage est uniquement membranaire.
Dans le derme, seules sont quelquefois marquées les membranes cytoplasmiques des cellules glandulaires des glandes sudoripares.
Les cellules endothéliales vasculaires sont négatives.
- Dans les peaux irradiées:
Le Récepteur d'EGF est également membranaire, mais visualisé au niveau de la totalité des couches cellulaires de l'épiderme jusqu'aux couches superficielles. Le marquage est beaucoup plus intense généralement que dans les épidermes de peaux non irradiées, en particulier lorsque le prélèvement est pratiqué entre 3 et 6 mois après la fin de l'irradiation.

La topologie et l'intensité de marquage apparaissent caractéristiques d'une irradiation antérieure, même ancienne de la peau. Dans le derme, il n'a pas été observé de différence entre le derme irradié et non irradié.

Ainsi l'analyse immunohistochimiques de la peau irradiée montre un phénotype activé des fibroblastes, surtout dans la zone adjacente à la jonction dermo-épidermique. Les cellules épidermiques montrent une surexpression de récepteurs de facteurs de croissance et de facteur fibrosant (TGF Beta). L'ensemble des résultats suggère une interaction dermoépidermique de type paracrine.

3-2 - Physiopathologie du fibroblaste irradié

La mise en culture d'explants des peaux irradiées ou non permet d'observer :
- l'extension retardée des fibroblastes de peau irradiée
- la migration et la colonisation à distance des fibroblastes de peau irradiée, contrairement à la prolifération contiguë des fibroblastes de peau non irradiée
- la formation de structures nodulaires après confluence dans les cultures de peau irradiée, l'absence de ces formations pour les peaux non irradiées (inhibition de contact)
- la capacité des seuls fibroblastes irradiés de croître sans sérum.

Ces résultats suggèrent l'acquisition d'un caractère "transformé" des fibroblastes irradiés, confirmé par l'analyse immunocytochimique.
Ceci a conduit à l'étude de la surexpression de certains facteurs potentiellement liés à la prolifération autocrine. L'analyse par Northern blot de mRNA extrait des cultures d'explants et de prélèvements de derme irradié ou non a été entreprise. Les sondes utilisées sont celles du TGFß, TGFa, PDGF. Cette étude n'est pas terminée.

4. Approche thérapeutique des lésions radiques localisées

4-1- Traitement de fibroses constituées

47 malades ayant développé une fibrose post radique après traitement radiothérapique pour cancer du sein ont été traités par superoxyde dismutase. La dose tumeur était supérieure à 50 Gy. Ces malades présentaient une fibrose mammaire ou axillaire étendue douloureuse s'accompagnant de gêne fonctionnelle. Le traitement a comporté l'application locale biquotidienne d'une préparation liposomale de superoxyde dismutase érythrocytaire bovine à 4000 unités par mg. La durée du traitement était de trois mois et la quantité totale de superoxyde dismutase administrée par malade était de 100mg. L'efficacité du traitement a été évaluée par rapport à la situation initiale par l'aspect clinique (score de Laugier modifié), par téléthermographie infrarouge et par pHmétrie cutané. Les contrôles ont été effectués avant traitement, à 6 semaines, 3 mois, 6 mois et un an de la fin du traitement. On observe une amélioration objective caractérisée par une réduction du score qui en un an passe de 69,7±29,2 à 37,9±17,45. Les réponses portent dans l'ordre chronologique sur la douleur (à partir de la 2ème semaine), sur l'assouplissement de la fibrose (à partir de la 4ème ou 5ème semaine) , sur la diminution de la pigmentation et des télangiectasies (à partir de 6 mois) et sur l'amélioration fonctionnelle (entre 9 et 12 mois). Cette amélioration paraît liée à la quantité totale de superoxyde dismutase avec un seuil de réponse à 30 mg, une réponse optimale pour 90 à 100 mg.

4-2-Traitement préventif des radiolésions par la superoxyde dismutase

30 malades soumises à une curiethérapie intrautérine ont reçu un traitement préventif des réactions et des complications rectales.
Le traitement a comporté l'application locale de superoxyde dismutase ; la surveillance clinique a porté sur la douleur, la diarrhée, les hémorragies ; l'évaluation paraclinique sur les données de la fibroscopie et de l'histologie sur biopsie. Le recul est de un an. Les resultats preliminaires indiquent un effet peu important du traitement préventif.

4-3- Application de l'EGF au traitement des radiodermites

Récemment, a débuté une étude de l'utilisation de l'EGF (Epidermal Growth Factor) en application locale pour le traitement des radiodermites. 5 patients, présentant des séquelles récentes d'une irradiation aiguë localisée (thérapeutique) sous forme de radiodermite ulcérée évolutive ont été traitées par application locale biquotidienne (4 semaines) de pommade contenant 10 microgrammes/g d'EGF recombinant humain.

Une amélioration clinique a été constatée dans les 5 cas traités. L'amélioration n'étant définie actuellement que par comparaison avec l'évolution spontanée habituelle de ces lésions, il convient maintenant de rendre plus objective l'évaluation de l'efficacité thérapeutique et de préciser les indications du traitement. Aucun effet de l'EGF recombinant n'a été observé sur la fibrose sous jacente. Ce résultat est en accord avec la localisation immunohistochimiques intra-épidermique du récepteur de l'EGF.

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Project 2

Head of project: *Dr. Strambi*

Objectives for the reporting period

The objective of the reporting period was to:
-standardize the methodology and the semiologic interpretation of capillaroscopy between France and Italy
-evaluate the worth of telethermography with thermostimulation after local radiation overexposure.

Progress achieved

1. Capillaroscopy
The data from Italy were analysed together with the data from France to reach a common consensus onmethodological standardisation and semiology. See conclusions of project 1.

2. Telethermography with thermostimulation in the medical surveillance of radiation workers.(Pr F. Ippolito, Dr A Di Carlo,Roma)

Infrared thermography is a very usefull method for the evaluation of blood flow in the skin, since minimal variations of thermal gradients strictly correspond to modifications of the extrmely superficial blood flow, namely the subpapillary nutritional network.
The precision of the thermographic measurement is 0.1°C, which limits the possibility to identify alterations of the microvasculature causing thermal gradients below 0.1°C.
The auxiliary technique of thermal stimulation (+ 5°C for 20 sesonds) performed with a special thermal probe (1) let us know about sequential thermal recovery times (TRT) of the single thermal points that constitute the baseline pattern, namely the thermal subgradients. One hundred and fifty cases of irradiated workers have been studied by thermostimulation (with priungueal regions of the hands as special area of interest) over the last ten years. It was possible to distinguish between different models based on TRT: one with very fast TRT (less than 30 seconds) in cases of severe radiodermitis, the other one with prolonged TRT (more than 15 minutes) in cases with inapparent clinical manifestetions. Physiological TRT values range between 2 and 6 minutes.
These data let us better follow the workers exposed to radiation by periodical thermographic recordings and provide the possibility (clinically or experimentally) to evaluate a dose-effect relationship.

Project 3

Head of project: *Dr. Herránz-Crespo*

Objectives for the reporting period

The objective was to standardize hair follicle culture methods for their possible application in biological dosimetry in non uniform irradiation.

Progress achieved

-The follicle hair culture has been implemented

The methodology used dermic area desinfection and pluking of 30-40 hairs, two series of 3 cultures for each case. One of the culture medium was changed in the 4th. or 5th. day of incubation to 37C° with 5% of CO2. The other one was kept in the same culture medium during the whole process.
Each series comprised 3 cultures :

- a) In suspension
- b) Between two cover slips
- c) Between a porous cell growth membrane and a cover slip.

After proper growth (about 2-3 weeks) the cells were harvested and stained through the modified Wells methods.
These initial culture conditions have led to the obtention of 1 to 10 metaphases from each hair follicle. Modifications of culture conditions are beeing worked out in order to improve the yield of metaphases and the reproducibility. prior to establishing the in vitro dose effect relationships

IRRADIATION AND THYROID DISEASE

Contract Bi7-005 - Sector B24

1) *Dumont*, Univ. Libre de Bruxelles (ULB) - 2) *Malone*, St James Hospital
3) *Smyth*, Univ. College of Dublin, Belfield

Summary of project global objectives and achievements

1) Development of a model of differentiated human thyroid cell line: human thyroids have been transfected and immortalized with the genes E6-E7 of HPV; they retained many differentiation characteristics but dedifferentiated after more than 100 doublings.

2) Development of models of transgenic mice: 2 models have been developed using the thyroglobulin promoter coupled to oncogenes. A model of dedifferentiated, metastasizing thyroid carcinoma caused by thyroid expression of SV40 large T. A model of autonomous hyperfunctioning adenoma caused by thyroid expression of the physiologically constitutive adenosine A2 receptor.

3) Control of proliferation of human thyroid cells: various steps of the thyrotropin cAMP mutagenic cascade have been defined.

4) Estimate of fetal thyroid dose after I^{131} administration: fetal dose is of the same order of magnitude as maternal dose.

5) RBE of I^{131}: in vivo experiments are in progress in collaboration with the National Cancer Institute (USA).

6) Estimates of the thyroid consequences of the Chernobyl accident: the consequences have been analyzed and calculated for the various countries of the EEC. Preventive generalized iodine prophylaxis has been recommended.

7) Baseline data for dietary I uptake, thyroid volume have been established in Ireland.

8) Seasonal variations of iodine intake have been demonstrated and the effects of low dose of iodine on urinary excretion assessed.

9) Thyroid volume and urinary I secretion in normal adults and pregnant women have been carried out in Ireland. These suggest a moderate I deficiency.

Project 1

Head of project: *Prof. Dumont*

Objectives for the reporting period

1. Development of the model of differentiated human thyroid cell line for radiobiological studies.

2. Development of models of transgenic mice for specific gene expression in the thyroid undifferentiated cancer, hyperfunctioning adenoma.

3. Further development of our knowledge of the control of proliferation in human thyroid cells (effects of growth factors).

Progress achieved including publications

1. Development of a model of human thyroid cell line

The study of the radiobiology of the human thyroid has had until now to rely on unsatisfactory models:

a. animal thyroids (mostly rats and mice) in vivo, providing reliable but relatively imprecise data on cells of other species; even in such studies measurements of risks for low doses are scarce;

b. human thyroids studied in vivo: epidemiological data are available for moderate doses but are almost impossible to obtain for low doses because of the huge numbers of patients required;

c. human and animal cells primary cultures which because of their short lifespan and low plating activity can only give inaccurate and even doubtful data;

d. cell lines derived from animal tissues (eg. FRTL5) which provide accurate and reliable data, but on a material that may have little relevance for human cells in vivo.

The need for differentiated cell lines has therefore been recognized as a major aim of radiobiological research at the EEC Dublin "Cell Transformation and Radiation induced Cancer" meeting. Some attempts have already been made to create such a line either using thyroid cancer cells from surgical samples or using normal cells transfected with oncogenes. However the cell lines obtained are completely dedifferentiated.

Relatively well differentiated human keratinocyte cell lines have been obtained using the immortalizing genes of human papilloma viruses. We have therefore studied the feasibility of applying this methodology to human thyroid cells. A subgenomic fragment of the tumorigenic HPV-16 has been cloned in the pMC2 vector (derived from pBR322). The DNA fragment containing the full sequences of the immortalizing genes E_6- E_7 is under the control of the powerful LTR promoter of M_0-M4 LV.

Several protocols have been tried. The final protocol is described hereafter. Human thyroid cells transfected by the lipofection method have been cultured for one week, trypsinized, plated again and treated with a general cyclic AMP enhancer (forskolin) for 3 weeks, then

passaged again for another 2 weeks. While many cells then degenerate and die, some foci of cells with epitheloid morphology appear. These cells have been passaged 19 times with alternative treatment with forskolin and TSH for 11 months after the transfection. These cells multiply with a doubling time of 60-70 hrs in medium with 0.2% serum. They exhibit a typical epitheloid morphology. They secrete thyroglobulin and this secretion is stimulated by a factor of 3 by thyrotropin (from 5 to 15 ng of TG/pg DNA/48 hours) (the results are similar to those obtained in primary cultures of human thyroid cells).

Their cyclic AMP levels are enhanced by a factor of 3 in response to TSH 500 μU/ml (from 0.4 to 1.3 pMole/μg DNA). However these cells did not require TSH or cyclic AMP for growth. Moreover after 120 generations they completely dedifferentiate (loss of cyclic AMP response to TSH, loss of thyroglobulin gene expression). New preparations transfected either separately or together with E_6 or E_7 are now developed using similar constructs.

2. Development of model of transgenic mice for thyroid tumorigenesis

The thyroglobulinpromoter has been placed upstream of chloramphenicol acetyl transferase cDNA. When injected into mouse oocytes within a pBR322 vector, this promoter has been shown to be able to target the expression of the gene specifically in the thyroid of injected mice and of their offspring. Depression of the thyroid by triiodothyronine treatment decreases, while stimulation by antithyroid drugs increases the expression of the gene. The same type of contruction has been used to target SV40 Large T (LT) immortalizing gene. In the transgenic mice and their progeny LT expression in the thyroid was confirmed by Northern blotting and immunohistochemistry. Moreover these mice developed progressive goiters immediately after birth. The growth of the goiter with its clinical consequences (difficulty to breathe) was restrained by T3 administration, which also delayed the death of the animals. However, tumors progress resumed after a few weeks showing that they become independent of TSH. The follicular tumors concentrated radioiodide but the oxidation of this iodide was greatly decreased. They involved the whole thyroid. Later (6 months) autopsies demonstrated metastases. These results have now been extended to a larger series of animals.

We have demonstrated that the A2 adenosine receptor, which we have cloned is physiologically constitutive i.e. permanently activated by endogenous adenosine. When expressed under the control of the thyroglobulinpromoter in transgenic mice it induces an hyperfunctioning autonomous adenoma of the whole gland. The animals develop huge goiters and hyperthyroidism. Thus we have created a model of in vivo chronic stimulation of the thyroid and of autonomous adenoma.

3. Human normal and cancer thyroid cells

The expression of the mRNA for the TSH receptor has been studied in cultured cells in vivo. This expression is very robust and almost constitutive. In human tumors, RTSH expression remains present until the fully undifferentiated stage. These results provide an experimental and rational basis for the use of TSH suppressive therapy in human thyroid tumors.

4. Epidemiology of iodine deficiency in the Community

Data have been obtained on the normal radioiodine uptake and urinary iodide excretion in various European centers. These data, published in the J. of Endocrinological Investigation, demonstrate a wide range of dietary iodine supply in Europe with large areas of mild to severe iodine deficiency. The resulting thyroid radioiodide uptakes vary by a factor of 3. As effects of radioiodine contamination are directly proportional to the relative thyroid uptake, it can be shown that general iodine prophylaxis in Europe would, besides its clinical beneficial effects, prevent more than 2/3 of the eventual population radiation burden from nuclear accidents, or otherwise.

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Project 2

Head of project: *Prof. J.F. Malone*

Objectives for the reporting period

Year 1:

(a) To ensure optimum use of resources in respect of determining the transformation rate in the thyroid; (b) to develop a formal approach to the question of the appropriateness of absorbed dose as an index for risk in the thyroid; (c) to resolve some residual questions in the issue of foetal thyroid dose arising from maternal ingestion of 131-I.

Year 2:

(a) To continue the work in respect of the appropriateness of absorbed dose with particular reference to determination of number of cells/g of thyroid throughout Europe using approaches based on (1) tissue digestion; (2) modelling; and (3) literature/existing laboratory data; (b) to continue developing a formal analytical statement of the above problem. This development will bear in mind the fact that the problem is probably not confined to the thyroid and will seek to introduce the approach to breast tissue; (c) to reach a conclusion of the present phase of the study of Foetal Thyroid Dose; (d) to re-establish cell culture work in respect of issues that are complimentary to and/or supportive of the major in vivo study in this area to be undertaken by the NCI in the USA; (e) to continue the established collaborations and apply the results acquired viz a viz dosimetry and iodine kinetics.

Progress achieved including publications

1. Introduction

Work within the present contract in this area continued previously developing themes into sharp and focused questions that remained to be resolved. Particularly prominent among these were questions arising of foetal thyroid dosimetry, dose to the foetal brain arising from a radiation by the foetal thyroid, verification of computations in the above two areas using thermoluminescent dosimetry measurements, the continuing problem of the relative biological effectiveness of iodine 131, and the newly identified question of the appropriateness of the absorbed dose as an index for expressing the quantity of radiation to which the thyroid had been exposed.

2. Foetal Thyroid Dosimetry

The uncertainty surrounding the dose to the foetal thyroid is even greater than that for the thyroids of children or adults. Notwithstanding this it has been modelled in a number of cases. It is widely agreed that the iodine trapping function, and consequently

the absorbed dose, commences about the 12th week after conception and thereafter rises and peaks fairly rapidly. However uncertainties remain as to its subsequent functioning and aspects of the kinetics involved. Within these uncertainties doses calculated within this project indicate with reasonable confidence that the foetal thyroid dose is the same order of magnitude as the maternal dose. In practice the dose maybe up to twice the maternal dose, but some models show it declining towards roughly the same value as the maternal dose as term approaches. The latter is in keeping with suggested values used by ICRP.

3. Foetal Brain Doses

The data of Otake and Schull as cited in ICRP 60 demonstrate that mental retardidation and lowering of IQ are consequences of relatively low dose radiation. In view of this the dose to the foetal brain arising from a radiation by the maternal or foetal thyroid are matters of concern. This problem was studied in three phases during the project. First it was established that the dose to the foetal brain from the mother was the same order or less than the dose to the maternal organs from a radiation by iodine distributed through the mother's own body. Second an initial study based on various assumptions about iodine kinetics was conducted for the weeks 8-16 of the gestation period. This study was extended to cover the entire duration of pregnancy from week 12. Finally a worse possible case based on a dose calculation for the region of the brain closest to the thyroid in the foetus was calculated. The results demonstrate that relatively large amounts of 131-I would have to be given to the mother to give foetal brain doses that exceed those from natural background radiation.

4. RBE of 131-I in the Thyroid

In the 1985-1989 contract, it was established that in cell culture system the RBE of 131-I was about 0.2 for cell survival as an index. Experimental approaches to induction of transformation during this programme meet with some success using high dose x and gamma rays with sheep thyroid cultures. However the results of the experiments were equivocal when 131-I was used, or when human cultures were employed. This pattern of uncertainty persisted into the present project in respect of these two cell models. At the same time the question of the biological effectiveness of 131-I was under active consideration by the National Cancer Institute in the United States, and this Group contributed to the development of a proposal for a definitive set of experiments to resolve the question invivo. Work within this area was suspended pending clarification of whether or not these experiments would proceed, and in the event of their proceeding whether or not they would be complete. However, it is now felt worthwhile to re-establish cell culture experiments with a limited scale of investigation in this area.

5. Development of the Critique of the Appropriateness of Absorbed Dose

It is generally assumed that radiation induced cancer arises out of a single transformed cell that has undergone initiation and promotion events, and that the probability of a cancer forming depends on the energy deposited per cell and the number of initiated cells. If we assume initiation to be a stochastic process, then the number of initiated cells increases linearly with the number of cells in which energy is deposited. This hypothesis contradicts the conventional approach of risk estimation which takes no

account of the increase from risk from depositing energy in a larger number of cells. The same considerations apply to mammography, or where any variable tissue mass is involved. These considerations are further exacerbated where the assumptions of the MIRD dosimetry system, which assume a uniform dose distribution throughout an organ, breakdown. Throughout the project considerable effort was devoted to developing a formal solution to this problem that would be consistent with the needs of the international thyroid community and the bodies involved with radiation units and standards. An approach based on "Integral Absorbed Dose" is presently being tried.

6. Dose Distribution throughout Europe arising from Iodine Distribution

Arising from the second major release from a nuclear reactor in the commonwealth of independent states the question of the dose distribution in the countries and regions of the EC arising from iodine releases was re-examined. It became clear that the data now existing since the Chernobyl release are of such improved quantity and quality to warrant a new dosimetry study that would greatly improve on the results used in the analysis of the Chernobyl accident. A proposal to this effect is included in the revised scientific proposal presently before the Commission.

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Project 3

Head of project: *Dr. Smyth*

Objectives for the reporting period

1. Establishment of baseline data for dietary iodine intake, thyroid volume and gross morphology in an area without endemic goitre, against which changes in dietary habits with respect to iodine ingestion can be compared.

2. To study seasonal variations in dairy milk iodine content and compare with patterns of urinary iodine excretion.

3. To report on the kinetics of low dose iodine prophylaxis and to make recommendations on iodine dosage and the frequency of administration required to maintain optimum iodine levels.

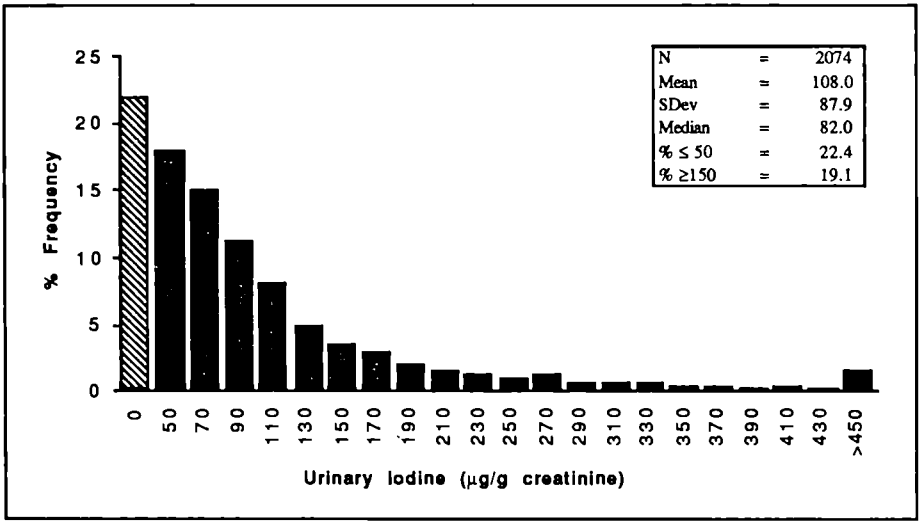
4. Using ultrasound scanning to determine thyroid volume in adults and schoolchildren residing in the study regions, with a view to providing the missing components for accurately measuring risk factors from defined exposures to radioactive iodine.

5. To study variations in ultrasound measured thyroid volume and urinary iodine excretion during the three trimesters of pregnancy and postpartum.

Progress achieved including publications

1. Baseline dietary iodine intake in an area without endemic goitre

The % frequency distribution of urinary iodine excretion values (UI) in random urine specimens from 2740 Irish subjects sampled at different study centres over the period 1989-1991 is shown below.



Individual values varied widely (10-622ug/g). The population mean of 108±SD 88ug/g; Median 82, while excluding severe iodine deficiency in the study population, obscured the fact that 22.4% of individual values were suggestive of iodine deficiency (< 50 μg/G) while only 19.2% had values > than the lower limit of daily iodine intake (150 ug) recommended by the WHO. Some regional differences in UI were encountered with relatively greater numbers of individual values <50ug/g being encountered. However the significance of these regional variations was uncertain as considerable variations in mean UI excretion also occurred in different study centres within the Dublin metropolitan areas ranging from 70.7 ± 37 to 184 ± 120 μg/g.

2. Seasonal variations in dietary iodine intake

There was no obvious explanation for these findings but it was noted that urine sampling had taken place at different times of the year. As milk has been reported to provide the major source of dietary iodine in Northern European countries, the iodine content of milk from two sources was therefore examined:

- Individual farm supply
- Daily bulk dairy milk supply.

A wide range of individual values were obtained at both seasonal samplings G-229 and 15-239 ug/l respectively. The mean value of 96.5±62ug/L in winter was significantly greater than that of 61±58ug/l recorderd in summer ($p<0.01$). A similar variation was observed in the iodine content of bulk dairy milk applied in the Dublin area tested over a year. Monthly mean values varied from a high of 222 μg per litre in February to a low of 44 μg/l in June. These values were paralleled by seasonal variations in urinary iodine excretions with patterns consistent with iodine deficiency (<50 μg) been more frequent in summer than winter. These variations were most marked in schoolchildren in which 20.1% had values less than 50 μg in summer compared to 5.0% in winter.

3. Low dose iodine kinetics

Dietary iodine supplementation is the recommended therapy in areas of endemic goitre.
However optimum dosage and frequency of delivery is little understood. In this study the utility of iodine (KI) in producing a desired plateau of urinary iodine excretion (UI) was studied in spot urine specimens obtained from healthy volunteers taking various I regimes (100,400 & 1500ug KI) for 29 days.
Progressive rises in I/C ($p<0.05$) occurred in all test Groups during weeks 1-4. At the lower dosage (100ug/day) mean urinary iodine excretion increased from 74±16ug/g- 100±16ug/g. At 400ug KI the corresponding increases were from 91±32- 117±27. Only at 1500 ug/day was there a significant in mean Ul excretion (75±14-254±34ug/g). However when even the higher I dosage (1500 ug) was withdrawn, I/C returned to the basal value after 24 hrs. It is concluded that duration and interval of intake may be more important than dosage as even the higher dosages used in this study did not produce persistent elevation in UI. In view of the variability of urinary iodine excretion and its dependence on dietary intake in the immediate past, measurement of serum iodine may provide a more reliable index of iodine status, and thus allow accurate calculation of the iodine dosage necessary to achieve the desired blockade of radioactive iodine uptake.

4. Ultrasound measured thyroid volume

Thyroid volume measured by ultrasound in 311 adults showed a mean value of 13.85±6.75ml. The mean value for females was 12.2±7.7ml. and for males 15.6±5.0ml ($p<0.01$). This difference could be accounted for by greater body weight in males as the mean ratios of thyroid volume/body weight for females and males respectively were 0.2±0.02 and 0.2±0.07. Significant thyroid enlargement was observed in 8.2% of women compared to 2.6% of men (3:1). A comparison of thyroid volumes in schoolchildren residing on either side

of the Irish Sea showed t mean volumes of 5.57±2.3ml in Dublin Ireland and 5.0±1.2ml in Cardiff, Wales. The % of individual children having enlarged thyroids (>80Ml) was also similar (9.9 in Dublin v 9.4% in Cardiff) suggesting a degree of iodine deficiency in both populations.

5. Thyroid volume and urinary iodine excretion in pregnancy

Further evidence of bordeline dietary iodine intake in Ireland was provided by the finding of increased mean thyroid volumes during the three trimesters of pregnancy. This increase reached a maximum of 50% over the corresponding mean volume in age matched nonpregnant controls during the second and third trimesters of pregnancy. Mean values (ml) for thyroid volume in groups of different subjects assessed during the three trimesters of pregnancy were (TI) 13.9±4.2;* (T2) 15.6±5.4;** (T3) 16.0±4.9.** Mean thyroid volumes remained significantly greater than the nonpregnant control value (11.3±5.0 ml) at 6 and 15 weeks postpartum; (PP6) 15.1±6.0** and (PP15) 14.8±4.0* (*$p<0.05$, **$p<0.01$). The number of patients having significantly elevated thyroid volumes (>18.0mls.) increased from 6.3% in controls to 30.2% in T3 and only began to decline at PP15 (22.2%). Surprisingly the increased thyroid volumes observed during pregnancy in Irish subjects were paralleled by increases in urinary iodine excretion. This increase commenced as early as T1, reaching a maximum during T3 and falling precipitously at delivery, reaching control levels at 6 weeks postpartum (PP6). The mean iodine excretion values (µg/g creatinine) were Controls 76.7±39.4; T1 176±96.3;** T2 170±108.5;** T3 173±108.5;** Delivery 90±53; PP6 73±24. A similar pattern was observed when results were expressed as µg/l urine. These results are at variance with other findings in areas of low iodine intake and suggest that iodine handling during pregnancy may be influenced by relatively small variations in dietary iodine intake.

In conclusion, the findings while indicating Ireland to be an area of moderate dietary iodine intake are also relevant to other countries in that they clearly demonstrate the need to take both seasonal factors and relatively minor variations in dietary iodine intake into account when attempting to establish the need for iodine prophylaxis in a population residing in an area without endemic goitre. They demonstrate that despite the absence of endemic goitre, inadequate dietary iodine persists which will significantly increase the thyroid gland uptake of radioiodines in the event of a nuclear accident. As demonstrated in this study this situation can be rectified by minor increase in dietary iodine intake with the unique prospect of providing a degree of protection in advance of a nuclear accident.

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Hetherton, A.M., O'Herlihy, C., Ryan, R. and Smyth, P.P.A., "Assessment of maternal and neonatal iodine status", Journal of Endocrinology, 132, 1992, p.324.

Doran, M., McDermott, E.W.M., Smyth, D.F., Mercer, P.M., Hetherton, A.M., Cross, K.S., O'Higgins, N.J. and Smyth, P.P.A., "Dietary iodine intake in the presentation of thyroid cancer", Journal of Endocrinological Investigation, 15, 1992, p.35.

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Communications

"Iodine status of a population without endemic goitre"
International meeting "Iodine and the Thyroid", Athens, Greece, September 1990.

"Iodine excretion and thyroid volume in pregnancy"
International meeting "Iodine and the Thyroid", Athens, Greece, September 1990.

"Thyroid enlargement in breast cancer"
5th Congress of the European Society for surgical oncology, Brussels, October 1990.

"Thyroid volume in breast cancer"
First European congress of surgery, Paris, October 1990.

"Thyroid status and pregnancy in Ireland"
Annual meeting Irish endocrine society, Galway, November 1990.

"The effect of orally administered T4 and iodine on urinary iodine excretion"
10th International thyroid conference, The Hague, February 1991.

"Alternations in iodine status and thyroid volume during pregnancy"
Merck symposium, 'The thyroid and pregnancy' Brussels, February 1991.

"The thyroid gland during pregnancy and postpartum"
Annual meeting of the Irish Perinatal Society, Dublin, March 1991.

"The goitrogenic effect of pregnancy"
10th Joint meeting of British Endocrine Societies, Brighton, April 1991.

"Thyroid growth in breast cancer"
10th Joint meeting of British Endocrine Societies, Brighton, April 1991.

"Factors determining the iodine status of a population"
9th Joint meeting of British Endocrine Societies, Glasgow, Scotland, March 1990.

"Normal thyroid volume in females"
9th Joint meeting of British Endocrine Societies, Glasgow, Scotland, March 1990.

"Iodine status of a population without endemic goitre"
International symposium "Iodine and the thyroid", Athens, September 1990.

"Iodine excretion and thyroid volume in pregnancy"
International symposium "Iodine and the thyroid", Athens, September 1990.

"Thyroid enlargement in breast cancer"
5th Congress of the European Society of surgical oncology, Paris, October 1990.

"Alterations in iodine status and thyroid volume during pregnancy"

International symposium "The thyroid and pregnancy", Brussels, February 1991.

"The goitrogenic effect of pregnancy"
10th Joint meeting of British Endocrine Societies, Brighton, UK, March 1990.

"The effect of orally administered T4 and iodine on urinary iodine excretion"
10th International thyroid conference, The Hague, February 1991.

"Thyroid disease in breast cancer"
10th International thyroid conference, The Hague, February 1991.

"Iodine status of mother and neonate in Ireland"
Annual meeting Irish Endocrine Society, Belfast, November 1991.

"Contrasting thyroid volume in areas of varying dietary iodine intake"
Annual meeting Irish Endocrine Society, Belfast, November 1991.

"Aetiologies of goitre"
7th Annual Nordisk prize lecture, Belfast, November 1991.

"Sonographic determination of thyroid volume in an area of iodine deficiency"
11th Joint meeting of British Endocrine Societies, Harrogate, March 1992

"Glucose-6-phosphate dehydrogenase (G6PD) activity in human breast smears"
11th Joint meeting of British Endocrine Societies, Harrogate, March 1992.

"Assessment of maternal and neonatal iodine status"
11th Joint meeting of British Endocrine Societies, Harrogate, March 1992.

"Assessment of iodine status in an area of moderate dietary iodine intake"
11th Joint meeting of British Endocrine Societies, Hanover, August 1991.

"Status of iodine deficiency in Ireland"
"Iodine deficiency in Europe. A continuing concern"
Workshop, Brussels, April 1992.

"Dietary iodine intake in the presentation of thyroid carcinoma"
20th Annual meeting of the European Association, Dublin, June 1992.

"Changes in iodine status in mother and neonate"
20th Annual meeting of the European thyroid association, Dublin, June 1992.

"Thyroid disease and breast cancer"
European thyroid association clinical symposium "The female thyroid in health and disease", Dublin, June 1992.

"Iodine status in the host country"
International Council for the Control of Iodine Deficiency Disorders (ICCIDD) I Workshop control of iodine deficiency disorders, Dublin, June 1992.

Radiation effects on the developing organism

EFFECTS OF RADIATION ON THE DEVELOPMENT OF THE CENTRAL NERVOUS SYSTEM

Contract Bi7-003 - Sector B31

1) *Reyners*, CEN-SCK - 2) *Ferrer*, Hospital Principer de España
3) *Coffigny*, CEA - Bruyères-le-Châtel

Summary of project global objectives and achievements

1. The radiosensitivity of the foetal brain

Assessing the deleterious effects of an accidental exposure of the central nervous system to a low dose of ionizing radiations, specially during the fetal period, is still a much debated issue: the radiosensitivity of the developing brain was even recently questioned by Mole (1990) who claims that the observed damage is a consequence of abscopic effects, in particular of an oxygen deprivation due to impaired erythropoiesis. In contrast with these views, field studies using the revised DS86 dosimetry have estimated that an exposure to a dose as low as 1 cGy could have induced severe mental retardation in a number of Hiroshima and Nagasaki survivors (Otake et al., 1987).

2. Animal experimentation

The aim of the present joint project was to cast more lights on the very low dose exposures by means of a multidisciplinary experimental approach involving in vitro neuroreceptor studies (France), neuronal immunocytochemistry (Spain) and automatic image analysis of the white matter (Belgium). Contrarily to the epidemiological investigations, the animal experiments allow to use an accurate dosimetry but also a material of well known foetal age at the time of irradiation.

3. Acute versus protracted irradiations

In addition, and possibly of more practical relevance, a part of the project has focused on the evaluation of the risks of low dose rate exposures protracted over a number of days during the pregnancy. No data were available on this sensitive topic which still today is sometimes dealt with using assumptions from "environmental" data (after mercury, trimethyltin or even alcohol intoxications; see the UNSCEAR draft-report on irradiation of the developing human brain, 1991). The results below unexpectedly show that protracted exposures to gamma rays during selected periods of the pregnancy produce brain alterations after dose levels (as low as 20 cGy) previously thought to be damaging only under acute conditions. This finding was considered of great importance for the sake of the radiation protection and a series of additional experiments not originally scheduled in the present project were carried out; they involved large amount of rats in order to detect the threshold dose in such conditions; part of this material was sent to Barcelona for an evaluation of the possible changes in natural cell death.

4. Interrelationships between the 3 different approaches

Many topics of importance were assessed during the 2 years of work devoted to the Bi7-003 contract. The 3 research groups have developed techniques relatively new to their laboratories, mostly in the field of immunocytochemistry but also in automatic image analysis.

The group of Hervé Coffigny (CEA, France) pioneered the assessment of the primordial nerve cells observed at a very short time after an acute foetal irradiation with doses as low as 25 cGy on day 14 of the pregnancy. His results reflect the difficulty of working with a material still totally immature and undifferentiated: at that time, the typical neuronal and glial immunological markers are still absent and in consequence, the different cell populations cannot be distinguished. Nevertheless, the uptake of certain neurotransmitters (DA and GABA) by these cells was already functional and showed a negative dose-effect relationship.

Coffigny also noted that the survival of the foetal nerve cells linearly decreased down to doses as low as 25 cGy; this observation could provide an explanation to a most puzzling finding by the spanish contractors, Isidre Ferrer and his coworkers (Univ. Barcelona), namely the fact that the natural phenomenon of the early postnatal neuronal cell death was largely diminished (!) after a prenatal irradiation. Indeed, the massive natural necrosis which takes place normally in the rat brain during the first days of postnatal life (and particularly on day 7) was significantly depressed after a foetal exposure on day 15. It was assumed that the natural elimination of this nervous material, which is considered by Ferrer to be redundant or at least provisional, is lowered because a large part of the neuronal precursors had actually already been killed and eliminated directly after the prenatal irradiation. As a confirmation of these views, a postnatal irradiation of the head increased the necrotic cells noted in the 7 day old brain.

Parallel to the normal overproduction of nerve cells in the early brain, an abundance of apparently superfluous spines (synaptic connections) was detected on the dendrites of the irradiated pyramidal cells in 15 day old pups. This excess was temporary and was followed by a depletion in the older animals. As published by Ferrer et al. (1991), it might have been related to an abnormal arrival of afferent projections in the irradiated cerebral cortex consequent to the decreased natural cell death mentioned above.

In possible relation with the late depletion of the dendritic spines comes the observation (at Mol, Belgium) that a large component of the corpus callosum, the cingulum bundle, was always depleted in 3 month old rats which had been prenatally exposed to radiations (acute or protracted). This decrease is now evaluated with the help of a new automatic image analyzer and interpreted as a consequence of a loss of afferent and efferent axons coming to and from the cerebral

cortex. However, to cope with the above findings by Ferrer, the cingulum of the irradiated rats should pass through a period of hypertrophy in the 15 day old pups; this has yet to be studied.

In conclusion, the project has allowed the different groups to explore new areas in the difficult but sensitive field of the very low doses; a prenatal exposure to only 1 cGy of neutrons (about 35 mSv) was found to cause a significant brain atrophy in the offspring. This dose is not much larger than the legal safety limit (20 mSv /year) presently recommended for workers. Of possible more practical importance was the totally unexpected finding that the protraction (over 4 or 6 days) of a foetal irradiation with a low dose did not largely reduce its effects. Further investigations on this subject will be the main topic of a new program of cooperative research.

Publications

A number of papers have been produced by the contractors as a direct result of the present CEC sponsored joint endeavour; a few manuscripts have also been accepted or are in a state of advanced preparation. The contractors have presented their data at each meeting of the European Society for Radiation Biology and will participate again at the 24th meeting in Erfurt, later this year.

Project 1

Head of project: *Dr. Reyners*

Objectives for the reporting period

1) Evaluation of the **ACUTE EFFECTS** of an exposure to 600 KeV neutrons on day 15 post-conception (PC) in the Wistar rat: measuring brain weight and volume of the cingulum in adults.

2) Evaluation of the **PROTRACTED EFFECTS** of a low dose rate of gamma exposure during whole or part of the pregnancy.

3) Automatic Image Analysis (AIM) of the **MYELINATION** in the cingulum bundle of the corpus callosum after protracted low dose gamma exposures.

4) Evaluation of the effects of the **DOSE RATE** after an exposure to 40 cGy of Cs-137 gamma rays on day 15 PC (Wistar rat)

5) Comparison of the effects of irradiation between different rat **STRAINS**: Wistar and Sprague-Dawley.

6) **PUBLICATIONS**

Progress achieved including publications

Objectives 1 to 3: The main results of objectives 1 to 3 are given in Table 1 (which is extracted from a manuscript now accepted by Int.J. Rad. Biol. It deals with the effects of acute and protracted low dose exposures to different types of radiation. The losses in brain weight and in cingulum volume are given for 3 month old rats irradiated at different periods of their pregnancy. Measurements were also carried out on groups of older rats but the slopes of the dose effect relationships were always identical revealing that brain atrophy was not a function of age.

ACUTE EXPOSURES: This absence of age effect allowed to pool the data from 3, 15 and 24 month old after transforming them in the percentages of their respective control means. In these conditions, the slight microcephaly (a 2% brain weight loss) found (in all age groups) after an exposure to only 1 cGy (35 mSv; Fig.1) resulted significant ($F_{1,104}$ =6.6; P<0.012).

DOSE PROTRACTION: If it always remains true that protracted exposures produce less effects than acute ones, it also appears that a careful selection of the period of irradiation

during the pregnancy, namely by irradiating between day 12 and day 16 PC, produces a brain atrophy nearly as important as the one caused by an acute exposure to the same dose given in 20 seconds during day 15 PC!

This discovery was unsuspected and a series of unscheduled experiments was programmed in order to evaluate the threshold dose after a protracted exposure to gamma rays before the end of the present contract. As shown in figure 2, the dose effects on the brain weight did not show anymore after exposures to 5 or 10 cGy of gamma rays even when given during the most sensitive period of the corticogenesis (day 12PC to day 16PC). In these conditions, the threshold must be located somewhere between 10 and 20 cGy for the brain weight endpoint. However, numerous cases of ventriculomegaly were observed in this 5 and 10 cGy material and remain to be assessed carefully. A future project dealing with the effects of protracted exposures to 4 - 10 cGy of neutrons will certainly cast more light on this sensitive domain.

Brain atrophy may not always represent the best available estimator of the effects of a prenatal irradiation of the brain. The decrease of the volume of the cingulum (CiVol; a purely white matter area located above the corpus callosum) in relation to the dose is in many cases more important than the loss in BrW. However, the variability of this measurement is important in spite of the recent introduction of automatic image analysis techniques, and this still spoils the sensitivity of this criterion for low dose assessments.
The reasons for the radiosensitivity of the cingulum remain unclear. An attractive hypothesis arose from a recent observation by Ferrer who found a reduction of a neuronal population (immunologically positive for the calbindin antigen) selectively occurring in the cingular cortex, an area of the cerebral cortex located just above the cingulum.

Other objectives

4) Evaluation of the effects of the DOSE RATE after an exposure to 40 cGy of Cs137 gamma rays on day 15 PC (Wistar rat)

When 40 cGy of gamma rays were given to pregnant rats on day 15PC, during exposures ranging from 2 minutes to 2 hours, the effect was the same (- 6 %) for all animals. Similar absence of effects was found with 20 cGy X rays whether given at 2cGy/minute or at 300 cGy/minute. These results are essentially the same as when the exposure had been protracted over days as above (Table 1); all these informations tend to pinpoint that the repair mechanisms are very inefficient in the developing rat brain.

5) Comparison of the effects of irradiation between different rat STRAINS: Wistar and Sprague-Dawley.

The brains of Sprague Dawley animals were found to be more radiosensitive than the Wistar rat when prenatally irradiated on day 15PC. A reverse situation had been found to take place in the adult brain in the case of the late effects of an irradiation of the head.

Publications

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in Frontiers in Radiation Biology, E. Riklis Ed. VCH publ., Weinheim. p347-353, 1990.

Gianfelici de Reyners E. and H. Reyners.
Bimodal effects of X-rays on adult microglia.
23rd. Congress of the European Society of Radiobiology. Book of Abstracts. Dublin, 1990.

Reyners H., Gianfelici de Reyners E., L. Regniers and Maisin J.-R.
Effects of in utero gamma ray irradiation on the development of the rat brain: low versus high dose rates.
23rd. Congress of the European Society of Radiobiology. Book of Abstracts. Dublin, 1990.

Reyners H., Gianfelici de Reyners E., T. Yeung and J.W. Hopewell.
An ultrastructural analysis of the development of the late effects of X-irradiation in a brain area at major risk: the Fimbria Hippocampi.
23rd. Congress of the European Society of Radiobiology. Book of Abstracts. Dublin, 1990.

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Development of dendritic spines in the cerebral cortex of the micrencephalic rat following prenatal X-irradiation.
Neuroscience Letters 125:183-186, 1991.

Ferrer I., Soriano E., Marti E., Laforet E., Reyners H. and Gianfelici de Reyners E.
Naturally occurring, postnatal cell death in the cerebral cortex of the micrencephalic rat induced by prenatal X-irradiation.
Neuroscience Research 12:446-451, 1991.

Reyners H. and Gianfelici de Reyners E.
Brain atrophy after prenatal exposure to very low doses of irradiation: an automatic image analysis using the Fisher algorithm.
Biol. Cell,73, 29, 1991.

Reyners H., Gianfelici de Reyners E., Poortmans F., Crametz A. and Maisin J.-R..
Brain atrophy after prenatal exposure to low doses of ionizing radiations.
accepted in: International Journal of Radiation Biology.

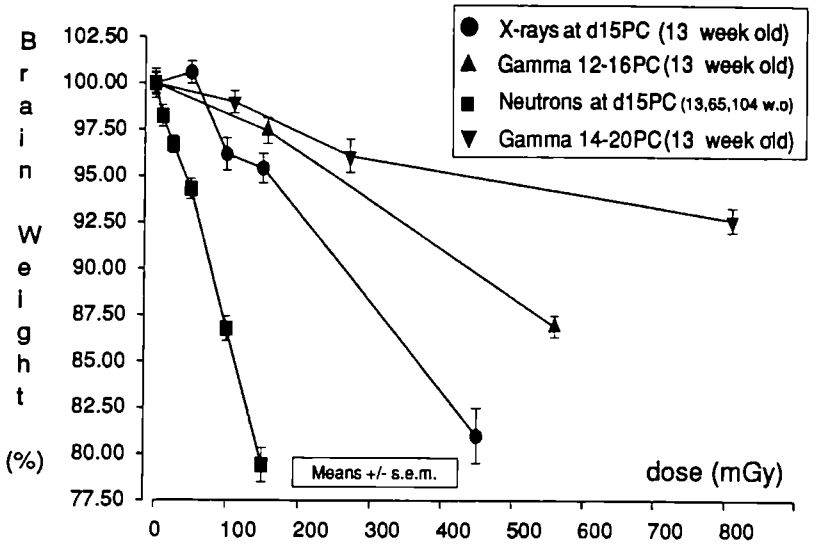

Fig. 1 - Adult Brain Weight after prenatal Irradiation

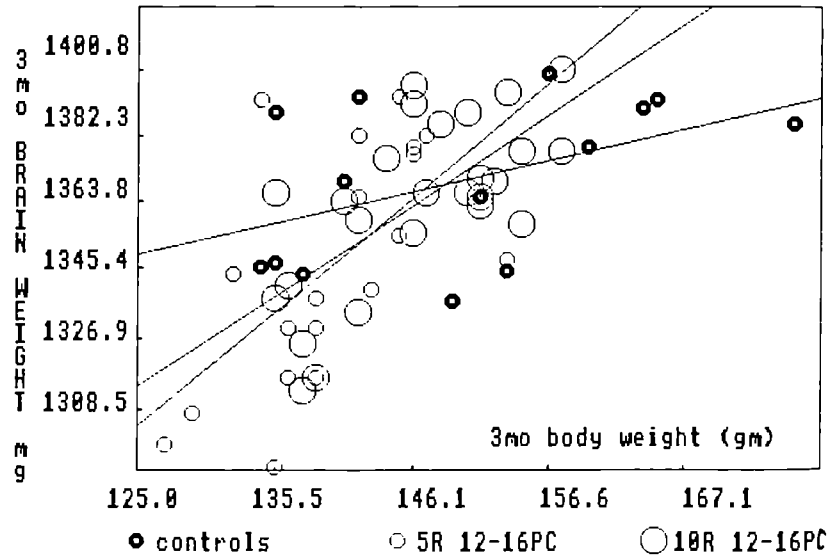

Fig. 2 - Brain Weight 3mo VS body weight after 60Co protracted foetal GAMMA Exposure (d12PC-d16PC)

TABLE 1 : Brain changes in the 3 month old rat after prenatal exposure to low doses of radiation.

Type of Radiation	Endpoint	Measurements						
ACUTE EXPOSURES								
Neutrons on day 15 PC	Brain wgt	*Dose (mGy):*	*0*	*10*	*25*	*50*	*100*	*150*
		Effect (%)	0	-3.6 *	-4.5 *	-6 *	-13 *	-22 *
		± sem	0.59	1.02	0.88	1.06	1.16	1.27
		n	30	15	20	18	14	11
	Cingulum Volume	*Dose (mGy):*	*0*	*10*	*25*	*50*	*100*	
		Effect (%)	0	-3.5	-10.3 s	-18.6 *	-72.6 *	
		± sem	3.07	3.34	4.32	3.48	8.05	
		n	19	14	15	15	7	
X-rays on day 15 PC	Brain wgt	*Dose (mGy):*	*0*			*50*	*100*	*150*	*455*
		Effect (%)	0			+0.6	-3.8 *	-4.5 *	-18.6 *
		± sem	0.62			0.59	0.88	0.79	0.84
		n	15			14	14	15	12
	Cingulum Volume	*Dose (mGy):*	*0*			*50*	*100*	*150*	
		Effect (%)	0			-2.7	-9.8 s	-15.6 s	
		± sem	1.24			4.07	3.12	6.44	
		n	4			4	3	3	
PROTRACTED EXPOSURES									
Gamma rays from day 12 to 16 PC	Brain wgt	*Dose (mGy):*	*0*	*60*	*100*	*160*	*350*	*560*
		Effect (%)	0	-1.4 s	-0.5!	-2.6 *	-3.6 *	-13.1 *
		± sem	0.53	0.5	0.4	0.70	0.76	0.57
		n	11	23	31	15	11	6
Gamma rays from day 14 to 20 PC	Brain wgt	*Dose (mGy):*	*0*	*70*	*110*	*170*	*340*	*800*
		Effect (%)	0	-0.6	-1	-4.5 *	-3.9 *	-7.3 *
		± sem	0.77	0.69	0.57	0.55	0.78	0.67
		n	15	20	11	20	12	9
	Cingulum Volume	*Dose (mGy):*	*0*				*340*	*800*
		Effect (%)	0				-10 s	-18.7 s
		± sem	5.19				2.2	4
		n	14				6	8

Legend: The effects represent the differences in % between the treated and the sham-treated control means. Their significance is given by a t-test where s stands for $P \leq 0.05$ and * for $P < 0.01$. sem: is the standard error of the mean; it is expressed in % of the control mean. n : number of samples.

Project 2

Head of project: *Dr. Ferrer*

Objectives for the reporting period

At the beginning of this project our objectives were focused on the following items:

1. Study of normal postnatal mortality of nerve cells in the cerebral cortex;

2. Vulnerability of discrete neuronal populations to low-dose irradiation during the embryonic period;

3. Development of dendrites and dendritic spines on cortical pyramidal cells in micrencephalic rats induced by prenatal X-irradiation.

Since most of these objectives were accomplished during the first year, our additional goals have been:

4. The study of local-circuit neurons in micrencephalic rats and in cortical malformations induced by prenatal X-irradiation;

5. The development of experimental models of human cortical malformations and the study of the neurogenesis and neuronal migration in these X-rays-induced cortical abnormalities.

Progress achieved including publications

1. Examination of naturally occurring cell death during postanatal development in the cerebral cortex in the normal rat

We have studied the morphology, distribution and temporal patterns of cell death in the neocortex and hippocampus of the rat during postnatal development. This study was necessary because no full information was available on this subject before.

As a result, two important papers appeared:

- Ferrer, I., Serrano, T., Soriano, E., *Naturally occurring cell death in the subicular complex and hippocampus in the rat during development*, Neuroscience Research 8 (1990) 60-66.
- Ferrer, I., Bernet, E., Soriano, E., del Rio, T., Fonseca, M., *Naturally occurring cell death in the cerebral cortex of the rat and removal of dead cells by transitory phagocytes*, Neuroscience 39 (1990) 451-458.

2. Examination of postnatal cell death and development of dendritic arbors in the cerebral cortex of micrencephalic rats induced by prenatal X-irradiation

We produced micrencephalic rats by irradiating the embryos *in utero* at different times of embryonic life, mainly at embryonic day 15 (beginning of the cortical neurogenesis) and 18

(middle/later period of cortical neurogenesis). We observed that postnatal cell death is reduced in the cerebral cortex of micrencephalic rats, and that the developmental pattern of dendritic spines on cortical pyramidal cells is altered in these rats.

This work was carried out in collaboration with our colleagues in Mol, Drs. H. Reyners and E. Gianfelici de Reyners, and was communicated as a preliminary report during the 22nd Annual Meeting of the European Society for Radiation Biology.

Two papers reflected our findings:

- Ferrer, I., Soriano, E., Martì, E., Digon, E., Reyners, H., Gianfelici de Reyners, E., *Development of dendritic spines in the cerebral cortex of the micrencephalic rat following prenatal X-irradiation*, Neuroscience Letters 125 (1991) 183-186.

- Ferrer, I., Soriano, E., Martì, E., Laforet, E., Reyners, H., Gianfelici de Reyners, E., *Naturally occurring, postnatal cell death in the cerebral cortex of the micrencephalic rat induced by prenatal X-irradiation*, Neuroscience Research 12 (1991) 446-451.

In addition, a review on naturally and induced cortical cell death during development, which summarizes and extends our results, has appeared:

- Ferrer, I., Soriano, E., del Rio, J.A., Alcántara, S., Auladell, C., *Cell death and removal in the cerebral cortex during development*, Progress in Neurobiology 39 (1992) 1-43.

3. Study of interneurons in the cerebral cortex of micrencephalic rats and brain malformations induced by prenatal X-irradiation

We have labelled local-circuit neurons with different antibodies against GABA, calbindin D-28k, parvalbumin and different neuropeptides, and examined the distributions of these neurons in animals subjected to X-irradiation during the embryonic period. The attention has been focused for the first time on local-circuit neurons in these cortical abnormalities, because these neurons play a pivotal role in the cortical organization.

Two papers are in preparation:

- Ferrer, I., Alcántara, S., *Parvalbumin and calbindin D-28k-immunoreactive neurons in the cerebral cortex of micrencephalic rats induced by prenatal X-irradiation.*

- Ferrer, I., Alcántara, S., Zújar, M.J., *Structure and pathogenesis of cortical nodules induced by prenatal X-irradiation in the rat.*

4. Study of neuroblast migration in cortical malformations induced by prenatal X-irradiation

A four-layered cortical malformation, reminiscent to human lissencephaly type I has been produced in the cerebral cortex of the rat following X-ray exposure at embryonic day 16. This experimental model has been studied in detail in relation to neuronal brithdating, radial glial fibres and cytoarchitectonics.

A paper is submitted for publication:

- Ferrer, I., Alcántara, S., Martì, E., *A four-layered lissencephalic cortex induced by prenatal X-irradiation in the rat*, Neuropathology and Applied Neurobiology.

Project 3

Head of project: *Dr. Coffigny*

Objectives for the reporting period

In the first part of the contract, an *in vitro* model was developed in order to study the radiosensitivity of the mesencephalic and striatal rat cells freshly isolated. This radiosensitivity was assessed using three parameters:
- nerve cells lethality
- neurites growth
- dopamine (DA) and gamma amino butyric acid (GABA) uptake in 3-day-old cell culture irradiated on day zero.

In the last reporting period only striatal cell lethality and neurites growth were measured. This study was completed by measurement of these parameters on mesencephalic cells.

The identification of neurons and glial cells by immunohistochemistry of neurofilaments, vimentine and glial fibrillary acidic protein (GFAP) was carried out. With the same method, identification of DA and GABA neurons is just in a preliminary phase.

Progress achieved including publications

1. Methods

Mesencephalic and striatal cells , freshly isolated from 14-day-old rat fetuses, were irradiated with 0.25, 0.50, 0.75, 1.5 and 3 Gy gamma rays and cultured 3 days in serum free medium before being analysed.

The lethality was assessed by counting the trypan blue negative living cells.

The lengths of both the longest and the whole neurites of each nerve cell were measured on micrographs. Nerve cells were classified as monopolar, bipolar, tripolar and multipolar.

The ^{3}H DA and ^{14}C GABA uptakes were determined. All results were expressed as a percentage of control values.

Three-day-old cell cultures were fixed 10 minutes in a 4 % paraformaldehyde solution in phosphate buffer before being assayed with antibodies against neurofilaments (160 kD), vimentine and GFAP. These antibodies were detected with a labeled anti-immunoglobulin antibodies. Fluorescent markers were fluorescein or texas red.

2. Results

The relative number of living cells decreased significantly from 0.25 Gy for mesencephalic cells and 0.50 Gy for striatal cells (figure 1).

The longest bipolar striatal neurite was reduced with the lowest dose of 0.25 Gy (figure 2) but no modification was observed either in tripolar and multipolar cells or in all mesencephalic cell categories. The ratio of monopolar, bipolar, tripolar and multipolar nerve cells of both structures was not changed by exposure in the dose range studied.

DA uptake by mesencephalic cells and GABA uptake by cells of both structures were decreased with 0.25 Gy or more (figure 3). The effect was dose dependent.

The GFAP in glial cells and the neurofilament (160 kD) in neurons were not detected by our antibodies. The vimentine was detected in many cells of different morphologies. The vimentine was expressed in young glial cells as well as in indifferentiated neurons. One specific young neuron antibody is under investigation.

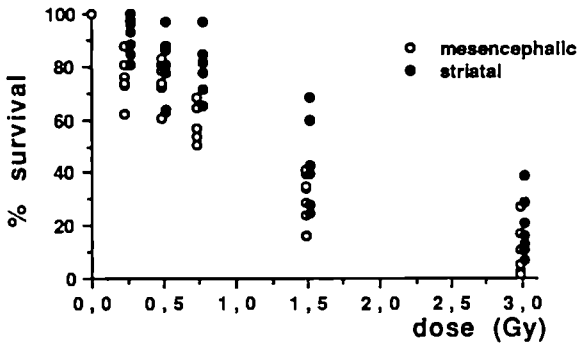

Figure 1.Percentage of mesencephalic and striatal nerve cell survival vs dose.

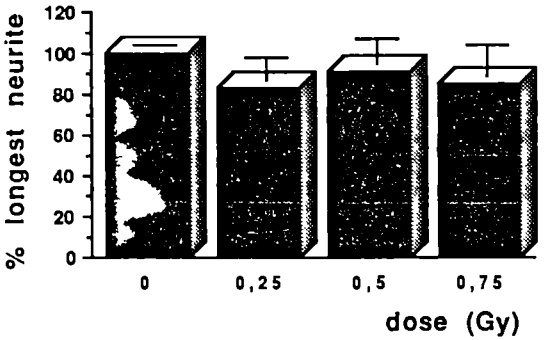

Figure 2. Percentage of the longest neurite of bipolar striatal cells vs dose.

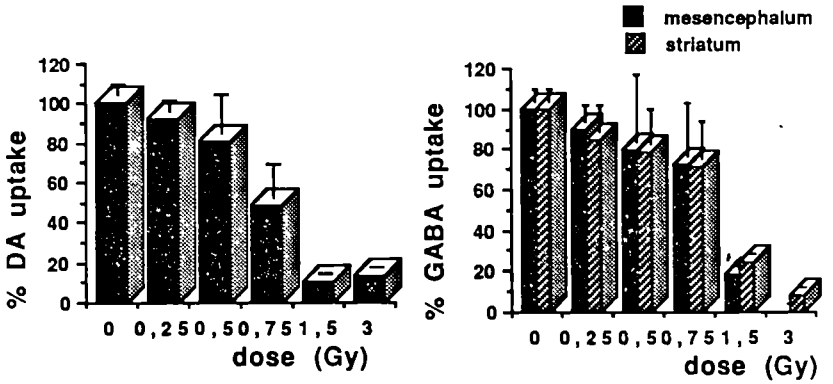

Figure 3. Percentage of DA uptake in mesencephalic cells and GABA uptake in mesencephalic and striatal cells vs dose.

The indentification of DA and GABA neurons was not possible in preliminary assays but is still under investigation.

3. Discussion-Conclusion

The mesencephalic cells were more sensitive to the lethal effect of gamma irradiation than striatal cells. Conversely, only monopolar and bipolar striatal cell neurites were reduced from 0.25 Gy onwards. Nevertheless GABA uptake was similarly decreased in cells of both structures with as low as 0.25 Gy. With all parameters, irradiation effects were observed with 0.25 Gy and then the response was dose-dependent. The threshold value of acute gamma irradiation was under 0.25 Gy but certainly near this value.

The negative results of immunohistochemical detection of glial cells and neurons with GFAP and neurofilament (160 kD) respectively need confirmation with GFAP antibodies of different sources and neurofilament 70 KD and 200 kD antibodies. Recently, we have received an antibody directed against a membrane protein of indifferentiated neurons. If it works, irradiation effects could be studied on glial cells and neurons selectively.

The identification of neurons with neurotransmitter antibodies will make it possible to compare the exposure effects on different categories of neurons.

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DYSFUNCTION AND NEOPLASIAS OF HAEMOPOIETIC AND OSTEOGENIC TISSUE FOLLOWING EXTERNAL IRRADIATION OR BONE-SEEKING RADIONUCLIDE CONTAMINATION *IN UTERO* OR DURING NEONATAL DEVELOPMENT

Contract Bi7-001 - Sector B32

1) *Humphreys*, MRC Radiobiology Unit - 2) *Vandenheuvel*, CEN-SCK
3) *Lord*, Paterson Institute Cancer Research - 4) *van Bekkum*, TNO-ITRI
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Summary of project global objectives and achievements

The relative sensitivities to radiation of tissues in the developing compared with those in the adult animal are of crucial current importance. Recent experiments in mice have demonstrated an apparently greater sensitivity to α-particle irradiation of foetal tissues than of those of adult animals from measurements of haemopoiesis made in neonate and juvenile animals by *in vivo* and *in vitro* techniques.

The aims of the contract therefore are to determine:

a) The most radiosensitive period during pre- and post-natal development for both the response of stromal and haemopoietic marrow cells and for the dysfunction or induction of neoplastic change in bone and bone marrow following contamination with α-particle emitting radionuclides or comparable doses of external low LET irradiation.

b) The functional quality of mature cells generated from haemopoietic tissue damaged by such radiations.

c) The identity and location of the sensitive cell populations.

d) The role of haemopoietic growth factors in regulation and recovery of irradiation damaged tissue.

e) The features of the stromal populations identified by cellular and molecular techniques.

Contamination *in utero* or neonatally with α-particle emitting radionuclides, namely ^{239}Pu, ^{241}Am and latterly ^{228}Th, has been shown to generate various manifestations of long-term damage to haemopoiesis. (The kinetics of ^{228}Th have been investigated, establishing it as a useful source of chronic ^{224}Ra contamination.) Superficially, the production of mature functional cells is normal but their pluripotent and committed progenitors together with cells of the regulatory microenvironment undergo a variety of changes. These are manifest in long-term (> 2.5 years) failure of the progenitor cells to develop their normal complement and although committed progenitors are stimulated by the long-term effects on the microenvironment, pluripotent progenitors are not fully supported. The self-reproductive capacity of the stem cell populations is also reduced. Compensatory proliferation in the maturing (and possibly committed) stages helps to keep the output of functional cells normal. However, while cellular output is normal, granulocyte function is grossly stimulated.

These long-term changes in haemopoiesis have, to date, failed to be manifested as any late effect originating in marrow. In an on-going study, 56% of mice contaminated at 4 d gestation and 38% contaminated at 13 d gestation have died, some with lymphomas but most with the liver and lung tumours seen at necropsy which are common in an ageing population of this mouse strain. There is no evidence to suggest so far that *in utero* contamination has led to any late effect on the offspring.

Although the ^{241}Am study failed to identify a 'most radiosensitive' phase of development, the same degree of long-term damage resulted from contamination in the embryonic (4 d gestation) and foetal (13 d gestation) phases despite transplacental uptake and retention measurements showing 10 fold lower levels of ^{239}Pu from the embryonic stage. Higher levels of uptake in the neonatal and post weaning period resulted in no extra damage indicating even lower sensitivity post-natally.

From the post natal performance of the stem and microenvironmental cell populations, it was clear that mechanisms of long-term damage depend on the stage of contamination. Contamination at 13 d gestation with ^{239}Pu preferentially affects the stromal cell populations while at 4 d, the stem cells are damaged with the stroma developing normally. While ^{239}Pu contamination of the neonate via the mother's milk is negligible, it was concluded that lactation contributes about 60% of the accumulating post-natal radiation dose from ^{241}Am. Preliminary studies of premating paternal contamination with ^{241}Am or ^{239}Pu have established some degree of haemopoietic instability in their developing offspring but its nature remains to be established.

The development of the spatial distribution (microarchitecture) of haemopoietic progenitor cells in the femur following birth was mapped and shown to be complete by 3 weeks of age. These data were used to compare the effects of radiation from internal emission with dose of external low LET radiations. It was established that the effects of cumulative doses of 3.6 Gy γ-rays during the final trimester of intrauterine development were less than from an estimated average dose to the foetal liver of 10-14 mGy for ^{239}Pu. The effective RBE of ^{239}Pu-α-irradiation is therefore very high *in vivo*.

Studies using external γ or X-irradiation on neonatal and adult animals, albeit at higher doses, have tended to corroborate the findings with α-emitters. Long-term deficiencies in the quality and number of pluripotent progenitor cells are accounted for by differences in stromal cell regeneration. Even in situations where a morphologically normal-looking stroma is generated in long-term culture, it was demonstrated that excess production of GM-CSF is a consequence of *in vivo* radiation and a result of this is a generation of hyperfunctional mature granulocytes. A similar phenomenon may well explain the excess production of GM-CFC in normal marrow grown on stroma from ^{241}Am contaminated offspring. The stroma, damaged or otherwise, thus plays a significant role in haemopoietic efficiency. In studies with both α-emitters and external γ or X-irradiation, a correlation between stromal damage and enhanced granulocyte function, demonstrated by excess superoxide anion production, was established.

We are now more aware of the heterogeneity within the pluripotent progenitor compartment of haemopoietic tissue and means of sorting and assaying their properties have been established. The results obtained in these various studies, however, emphasise the need to study also the stroma in more detail. Although there is evidence that some elements of

human stroma may be isolated, this approach does not seem practicable within the context of this programme and there still seems no satisfactory way of progressing in this area. Emphasis, therefore, has been switched to analysing the expression of adhesion molecules and growth factor receptors on sorted stem cells. It is anticipated that this approach will yield unambiguous results regarding the identity and function of specific adhesion molecules that regulate the interactions between stem cells and stroma.

The role of haemopoietic growth factors and growth regulators in modulation of late effects is also seen as of potential importance and initial work on TNF-α as a radioprotector has demonstrated a lack of correlation between *in vitro* and *in vivo* experiments. It appears that the protection afforded *in vitro* is not endorsed by studies *in vivo*.

Theoretical considerations and measurement of the rates of growth of developing haemopoietic tissue suggest that the potential for residual injury might be greater in younger animals. Experiments with radiation doses up to about 7 Gy and with varying dose-rates have not been conclusive in this respect. At lower doses, however, 0.5 Gy X-rays at 17 d gestation produces a late developing (> 6 m) deficiency in committed progenitors which is not seen when radiation is given at 2 d, 8 d or 12 weeks of age.

An analysis of the clonal expression of genetically marked progenitor cells in the context of the programme was clearly desirable. This represents another developmental area of the work and successful high level integration has been achieved. Progeny of these cells have been analysed for only 3 months. Integration into primitive cells, now seems probable and the long-term continuous expression of their clones is being confirmed.

Project 1

Head of project: Dr. Humphreys

Objectives for the reporting period

To demonstrate the late effects of ^{239}Pu administered *in utero* on male offspring from CBA/H females given 16, 32 or 64 Bq g^{-1} ^{239}Pu on either day 4 or day 13 of gestation. To explore the potential of colloidal ^{228}Th administered paratibially to pregnant CBA/H mice as a means of continuously contaminating the offspring with ^{224}Ra during the period of development.

Progress achieved including publications

In utero contamination of pregnant CBA/H mice with ^{239}Pu.

Materials and methods

^{239}Pu was obtained from Amersham International as a solution of the element (99% ^{239}Pu, 1% ^{240}Pu - other isotopes not detected) in $3MHNO_3$. This material was standardised against a ^{239}Pu standard (also obtained from Amersham International) by counting in a Beckman Model LS5000CE liquid scintillation counter.

Solutions of ^{239}Pu in 1% trisodium citrate solution (adjusted to pH 5.5 by the addition of $3MHNO_3$) were prepared, containing concentrations of ^{239}Pu of 1600, 3200 and 6400 Bq g^{-1} solution enabling each mouse to be injected with one-hundredth of its body mass of injection solution to achieve the required activities of 16 , 32 or 64 Bq g^{-1} body mass respectively.

Female CBA/H mice were mated with male CBA/H mice and on day 4 or day 13 of gestation (conception was considered to take place on day zero) injected intravenously via lateral tail vein with the appropriate injection solution.

The offspring were sexed as soon as possible after birth and only the males entered into the experiment. These were weaned after 21 days, housed four to a box, fed and watered *ad libitum* and subsequently examined at frequent intervals by a standard procedure (Humphreys *et al* 1989).

Results

Table 1 shows the current status of the experiment. To date 437 animals are dead and the results of examinations for gross pathology are available for them all. Of these full histopathological reports are also available for a total of 164 animals. No myeloid leukaemias have been confirmed and, although malignant lymphomas have been diagnosed, no correlation with injected activity has so far been established. Most of the animals which have died or been killed show at examination for gross pathology the liver and lung tumours

which are common in an ageing population of CBA/H males. The differences in survival seen in table 1 reflect the different times that the mice were introduced into the experiment and not an effect of different amounts of contamination. There is no evidence to suggest so far that *in utero* contamination has led to any effect on the offspring.

Table 1
In Utero injection of ^{239}Pu
Status September 1992

^{239}Pu (Bq g^{-1})	16	32	32	64	64
Days gestation	13	13	4	13	4
Number of offspring entered	195	158	200	200	200
Number of offspring dead	99	36	92	76	134
Mouse-days exposure	132174	97349	144121	132025	157774

Protracted contamination of offspring after paratibial injection of ^{228}Th into female mice prior to conception.

Materials and methods

^{228}Th, in equilibrium with all of its daughters, was obtained from AEA Fuel Services, Harwell, England as a solution in either 2MHCl or $3MHNO_3$. The injection solution was prepared by mixing an aliquot of this with ^{232}Th as carrier and then carefully neutralising the rapidly stirred unbuffered solution with a solution of sodium hydroxide. The amount of ^{228}Th added was adjusted so that each mouse was to be given 55.2 Bq g^{-1} - calculated (Müller 1991) to be about 4X the amount to give a maximum leukaemogenic effect from liberated ^{224}Ra in adult mice. 50 µl of the resulting colloidal solution was then injected paratibially into each of fourteen 12-week old female CBA/H mice under halothane anaesthesia. Each injection was made approximately at the middle of the left gastrocnemius muscle with the tip of the needle just touching the bone.

Two days later the mice were mated with male CBA/H mice and day zero of gestation recorded as the time of appearance of a vaginal plug.

Two pregnant mice were killed on each of days 14 and 17 of gestation and maternal and foetal tissues sampled. The remaining mice were killed in pairs 1 day, 4 days, 1 week, 3 weeks and 8 weeks after birth and similar maternal and neonatal tissues sampled. Pairs of virgin age-matched mice were killed and at the same time as the pregnant mice. All of the samples, together with standards prepared from the injection solution were transferred to glass ampoules and the ampoules sealed in a gas flame.

The only significant source of gamma rays in the ^{228}Th decay chain arises from the decay of ^{212}Pb. The intensity of gamma rays with energies in this region was used as a measure of the presence of members of the chain. The samples obtained from the mice were counted three times in an LKB Compugamma automatic counter set to count all gamma emissions with energies near to that of the major energy of ^{212}Pb. The first count was made as soon as possible after dissection and the second and third counts not before 106 hours after death and

not before 36 days after death respectively. At the time of the third count the decay chain is in equilibrium and the gamma count determines the ^{228}Th activity present at death; from this the amounts of ^{212}Pb and ^{224}Ra grown in at the times of counts 1 and 2 can be calculated using the appropriate Bateman equation (Bateman 1910). At the time of count 2 any ^{224}Ra present at death will be in equilibrium with its daughters and gamma activity measured at this time is a measure of ^{224}Ra present at death. In this way ^{212}Pb activity at death not derived from either ^{224}Ra or ^{228}Th and ^{224}Ra activity at death not derived from ^{228}Th are then calculated as well as ^{228}Th activity present at death.

Results

Since all of the ^{212}Pb and most of the ^{224}Ra present in the injection solution will have decayed by the time of death (16 days minimum - 36 half lives for ^{212}Pb and 4.4 half lives for ^{224}Ra), activities from these radionuclides found in tissues are considered to have originated in the paratibial deposit of ^{228}Th.

Thorium behaves chemically as an actinide and is deposited preferentially in the skeleton and liver. The percentages of injected activity found in the right maternal femur and in the liver in the present results, however, are only of the order of 2 or 3% of what has been recorded (unpublished experiment) from an injection of the citrate complex of a 1% solution of trisodium citrate. These findings result from the retention of the major proportion of the nuclide at the site of injection and the release of only small fractions into the circulation. Over the period of observation, the proportion of injected activity remaining in the left femur fell slightly while that in the right femur rose. This can be interpreted as a loss of thorium from the site of injection accompanied by an increase in thorium activity in the remainder of the skeleton.

The amount of ^{228}Th found in the tissues of the offspring were, in some cases, barely measurable but, where measurement was possible, the amount of thorium present, as a fraction of that present in the corresponding maternal tissue, was of the same order as that found for plutonium (Mason *et al* 1991). The results suggest, therefore that very little ^{228}Th is being liberated from the paratibial deposit but that which is liberated is distributed in a similar pattern to what would be expected from 'soluble' nuclide. The amounts of thorium seen in the gut samples increased between 1d and 1w after birth during lactation; a sharp decrease seen at three weeks was coincident with a change in the diet from milk to solid food; the offspring were fully weaned at three weeks.

Comparisons of tissue activities of ^{212}Pb, ^{224}Ra and ^{228}Th showed a variation of relative retentions. In maternal liver at all times of measurement, ^{212}Pb activity was considerably greater than that of radium or thorium, probably resulting from the binding to the red blood cell membranes of ^{212}Pb released from the paratibial deposits and from the ^{220}Rn released from bone in all parts of the skeleton; radium activity was generally smaller than that of thorium. In both maternal femurs radium activity was greater than that of thorium or lead. Similar patterns were seen in offspring livers and femurs although in the 1-day neonate femurs the amount of ^{212}Pb was greater than that of ^{224}Ra reflecting, perhaps, the greater relative blood content of these primitive bones. In contrast to the slight fall in radium activity seen in the maternal femurs there was a very marked rise in the radium activity of offspring femurs.

In summary these preliminary findings show that a paratibial injection of ^{228}Th before conception provides a poor source of ^{228}Th for foetal contamination but a rich source of ^{224}Ra mostly during lactation.

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Project 2

Head of project: *Dr. Vandenheuvel*

Objectives for the reporting period

In order to identify a radiosensitive stage in development, Balb/c mice are radiocontaminated with 241-americium at different developmental ages (before, during and after gestation) and in different ways (acute and chronic administration of 241-Am). The effect of this internal irradiation on haemopoietic and stromal cell populations in the bone marrow is studied quantitatively and qualitatively.

An initiation is made to study the damage present in long-term cultures (LTC). Cellular and extra-cellular matrix components are analysed. The haemopoietic capacity of the stromal layer is evaluated by reseeding the stroma with haemopoietic pluripotent stem cells.

Progress achieved including publications

1. Methods

1. Balb/c mice were radiocontaminated with 241-americium. Different ways of contamination included:
- single i.v. injection of pregnant mice at 14th day of gestation (14 kBq/mouse); offspring were fostered by contaminated mother during first 3 weeks after birth;
- continuous infusion using osmotic pumps between 7th and 14th day of gestation (11.15 kBq/mouse); offspring transferred to foster mother;
- continuous infusion using osmotic pumps between 14th and 19th day of gestation (7.5 kBq/mouse); offspring transferred to foster mother;
- contamination of neonates via lactation during 3 weeks after birth (foster mother received 14 kBq/mouse: i.v. injection);
- single i.p. injection of male mice (6.2 kBq/mouse) 32 days before mating with female mice.

13, 24, 32 and 51 weeks after birth haemopoietic and stromal stem cell studies were performed in the offspring or neonates:
- quantitative evaluation using short-term clonal assays to assess the number of CFU-s, CFU-GM and CFU-f;
- qualitative evaluation of haemopoietic function using long-term bone marrow cultures (LTC) which is a culture system to maintain haemopoiesis *in vitro*.

95 weeks post-contamination stem cell studies were performed following 241-americium *in utero* (injection at the 14th day of gestation) and via lactation.

2. To assess the functional capacity of stroma to maintain haemopoiesis *in vitro*, stromal layers from control and 241-Am contaminated mice were recharged with complete haemopoietic bone marrow (0.5×10^5 c/ml) or with sorted haemopoietic pluripotent stem

cells (HPSC) (Rh-123 dull cells, Facs sorted by Jan Visser, TNO, Rijswijk). The CFU-GM output was taken as a measure of the haemopoietic capacity of the stromal cells.

Initially, we tested if HPSC (from Balb/c mice of TNO, Rijswijk) could proliferate and differentiate on our stromal layers (from Balb/c mice, SCK, Belgium.

3. The stromal layer in LTC from control and 241-Am contaminated mice (see 1) was characterised. The presence of different cell types (macrophages, alkaline phosphatase and acid phosphatase positive cells) and extracellular matrix components (sulphated- and non-sulphated glycosaminoglycans) was studied using histochemical staining techniques. The mentioned components are believed to have a function in the regulation of haemopoiesis.

2. Results

2.1 Cellularity and number of haemopoietic and stromal stem cells

- Neither the bone marrow cellularity, nor the amount of pluripotent haemopoietic stem cells were disrupted after the different ways of contamination.
- The amount of progenitor cells for granulocytes and macrophages (CFU-GM) tended to decrease (equal to control values or significantly lower [t-test, $P \leq 0.05$]), while in contrast the number of stromal stem cells had the tendency to increase (equal or higher than control values).

2.2 Long-term bone marrow cultures

13 weeks post partum no differences were seen in the haemopoietic activity of LTC, which reflect the functional capacity of stromal cells to maintain haemopoiesis *in vitro* from either control mice or contaminated mice.

24 weeks post partum the haemopoietic activity of LTC was diminished: the CFU-GM output in cultures from contaminated mice (regardless of the route of 241-Am contamination) was lower compared with the CFU-GM yield in cultures derived from control mice.

32 weeks postnatally, the CFU-GM yield in LTC derived from offspring contaminated *in utero* using osmotic pumps either between the 7th and 14th day of gestation or between the 14th and 19th day of gestation was significantly lower than the CFU-GM content in LTC from control mice.

CFU-GM output in LTC from the other groups was similar to the CFU-GM output in LTC from control mice.

2.3 Effect at long-term

95 weeks after birth, *in utero* contamination at the 14th day of gestation did not result in significant differences ($P \leq 0.01$) between the control and radiocontaminated mice, in bone marrow cellularity and stem cell concentrations (CFU-s, CFU-GM, CFU-f). LTC derived from 241-Am contaminated mice showed a decreased CFU-GM output compared with cultures from control offspring (two-way ANOVA, $P \leq 0.01$).

2 Preliminary results indicate that HPSC can be maintained for a short period on a stromal layer.

Recharging stromal layers, derived from control and 241-Am contaminated mice (51 weeks after contamination) with total bone marrow cells resulted in a higher CFU-GM output in cultures with a stroma originating from contaminated mice. In contrast, after reseeding the stromal layers with HPSC, the cultures from control mice gave the highest CFU-GM output.

3 Phenotypic characterisation of the confluent adherent stromal layer yielded no obvious differences in cell types and extracellular matrix components between stromal layers derived from control animals and 241-Am contaminated mice.

3. Discussion

1. We have seen effects on the bone marrow cells after contamination of mice at different developmental stages. The associated α-irradiation dose to the femur was estimated on the basis of previous retention studies in fostered and non-fostered offspring of mice contaminated at the 14th day of gestation with 14 kBq of 241-Am.

The cumulative dose to the femur in offspring reared by their own contaminated mother reached 1.7 cGy at 13 weeks postcontamination, 2.6 cGy 24 weeks after contamination, 3.3 cGy at 32 weeks postcontamination and 5 cGy one year after contamination.

Mice fostered during the lactation period by a contaminated mother accumulated respectively 0.9 cGy after 13 weeks and 1.5 cGy after 24 weeks due to 241-Am contamination of the milk.

In the male mice contaminated 32 days before conception, the cumulative dose to the testis until conception amounted to 2.1 cGy.

These low radiation dose levels induced effects on the quantity and quality of bone marrow cells. However we cannot yet identify the most radiosensitive period. Residual damage is similar in the different contaminated groups. Its role remains to be established.

After contamination of mice at the 14th day of gestation with 14 kBq 241-Am, damage to bone marrow cells in offspring evaluated via LTC persisted for a long period. At 95 weeks postcontamination, LTC are still suboptimal. The associated cumulative dose to the femur at that time is 8.5 cGy.

2. To identify the nature of the radiation damage in the LTC, working with purified haemopoietic populations and separated stromal populations will be of great benefit. The contrasting results seen after reseeding stromal layers with total bone marrow cells or HPSC illustrate this need.

3. Phenotypic characterisation of the stromal layers yielded no obvious differences between stroma of control or contaminated mice. Therefore we will apply other techniques (ie factor dependent cell lines, *in situ* hybridisation) to study growth factor and extracellular matrix production.

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Project 3

Head of project: *Dr. Lord*

Objectives for the reporting period

To investigate the transplacental uptake of maternal ^{239}Pu or ^{224}Ra contamination and its effects on the development and maintenance of haemopoietic tissue. To compare the relative effectivity of radiation from transplacental ^{239}Pu to that of external γ-irradiation during pregnancy. To consider the possibility that pre-mating paternal contamination with α-emitting radionuclides might affect the development of haemopoiesis in offspring.

To compare long term repopulation of haemopoietic and stromal precursor cell populations after γ-irradiation at 1, 4 or 11 weeks of age. To assess the radioprotective effect of TNF-α *in vivo* and to investigate the potential for assessing residual injury in terms of deficiencies in megakaryocyte precursor cells and in marrow repopulating ability.

Progress achieved including publications

In view of the affinity of α-emitting radionuclides for bone, the location of appropriate target cells with respect to bone is an important aspect. The cellular microarchitecture of the bone marrow was therefore investigated and the spatial distributions of the relevant cell populations was shown to be fully established by three weeks of age.

Approximately 1% of ^{239}Pu used to contaminate pregnant mice at mid-term gestation appears in the newborn offspring - most of this is in the foetal liver. When contamination occurs early in gestation, uptake in the new born offspring is ten-fold lower. Effects on haemopoiesis in the long-term however, are comparable. Reduced numbers of stem cells are required to maintain a higher level of proliferation in order to maintain cell output. The mechanisms in the two situations are different: the one is determined primarily by effects on the haemopoietic stem cells; the other by effects primarily on the stromal microenvironment.

A combination of these effects probably arises as a result of chronic irradiation throughout intrauterine development. An injection of ^{228}Th (55.2 $Bq.g^{-1}$ - see project 1) to female mice, 1-6 d before mating in order to supply a chronic dosage of transplacental ^{224}Ra resulted in neonatal mice with only half their normal level of haemopoietic stem cells in both the bone marrow and spleen - in spite of achieving normal cellularities in these tissues. As with transplacental ^{239}Pu uptake, although the mice managed to maintain near normal cellularities, residual damage at 33 wks of age showed still reduced (50%) stem cell levels.

To compare with the effects of ^{239}Pu ingestion by pregnant mice at mid-term gestation, pregnant mice have also been irradiated using low doses of Co-60 γ-rays. Previous work used doses of 50, 100 and 150 mGy/day delivered continuously between days 13 and 18 of gestation. Assessments of the spatial distribution of CFU-S in femoral marrow were made in the offspring when they had reached 8 weeks of age. Significant changes in the CFU-S

distribution were found after irradiation of the fetus using 100 and 150 mGy/day. These data indicated that the quality factor of 20 employed to relate the efficiencies of α-particles and γ-rays was too low to account for the larger effects observed after ^{239}Pu contamination. The studies with γ-rays have now been extended to include 600 mGy/day. This is near the limit of dose which can be given without deaths occurring. Even at this cumulative dose of 3.6 Gy, the reduction in the number of CFU-S in the young adult and the accompanying modification to the axial/marginal CFU-S distribution were not as marked as after the estimated 10-14 mGy accumulated dose from ^{239}Pu. This indicated that the quality factor is very high for this endpoint.

Studies are underway comparing the response of continuous γ-irradiation with daily acute doses in order to relate values of effectiveness to acute, as well as to protracted, exposures.

Studies have been instigated to study the effects of preconceptual paternal α-radionuclide contamination. Male mice were injected with 64 $Bq.g^{-1}$ ^{239}Pu, one or 3 months before mating with normal females. Haemopoietic progenitor cells and their regulatory microenvironment were assessed in the offspring at times up to 160 d after birth. Ill-defined changes arose in CFU-S, *in vitro* CFC, CFU-F and renal capsule forming capacity indicating significant instability in the developing haemopoietic tissue. These studies are currently being refined in order to define better the specific changes and the nature of the residual damage in these tissues.

During normal growth, the number of marrow cells per femur increased from about 10^7 at 4 weeks of age to 1.8×10^7 at 37 weeks. The corresponding increases for day 8 CFU-S were from 3,000 to 4,000, for day 12 CFU-S 3,000 to 5,000, and for iv-CFC 30,000 to 55,000. In contrast, CFU-F numbers declined from around 750 at 4 weeks of age to 400 at 15 weeks, and then increased to 650 at 37 weeks. The rates of change in these parameters were higher for younger mice than for adults. Thus, if growth is reduced by irradiation, this indicates the potential for greater residual injury, in the younger animals.

Regarding CFU-S response and recovery after γ irradiation: (a) there was no significant dose-rate effect between 6 and 60 cGy/min for acute survival, (b) acute survival levels were consistently higher for day 12 than for day 8 CFU-S, but the difference disappeared by 6 months post irradiation recovery, (c) long-term recovery at 6 months was equally good in mice of all ages, except perhaps after the highest dose (4.5 Gy) used in the 1 week old mice. Regarding CFU-S per colony (a) the recovery levels were in general lower in 1 week old mice than in the other ages, (b) the effects of radiation on this endpoint were greater than for CFU-S numbers, in mice aged 1 week or 10-12 weeks, but not 4-5 weeks, (c) there was a tendency for better recovery after lower doses delivered at the lower dose-rate (6 cGy/min) in mice aged 1 week or 4-5 weeks, but this was not seen in adults.

Concerning recovery of i.v. -CFC there was: (a) no significant dose-rate effect, (b) better recovery than CFU-S in 4 week old mice but with similar levels in 1 week old mice or in adults.

Regarding CFU-F (a) an acute dose-rate effect was observed for 4-5 week old mice but the reverse was found for adult mice, (b) recovery was in general poorer in 1 week old mice than in the other ages, (c) a marked dose rate effect was observed for the levels of recovery in 4

week old mice. This was not so marked for adult mice, and there was a tendency towards the reverse effect in 1 week old mice.

Residual injury was detected as alterations in the number and quality of marrow precursor cells at 6 months after 1.5, 3.0 or 4.5 Gy γ-irradiation of mice aged 1 week, 4 weeks or 11 weeks compared to age-matched controls. Levels of recovery as low as 40% were measured for fibroblastoid colony-forming units (CFU-F) at 6 months after irradiation of 1 week old mice. The self-reproduction capacity of CFU-S measured as spleen colony-forming units generated per spleen colony, was similarly low. In adults, the CFU-F recovery levels at 6 months were much higher (c. 90%), although the values of CFU-S per colony were lower (~50%). Residual injury at 6 months after the higher doses was more severe for the 1 week old mice than that for mice of the other ages tested.

For both α- and γ-irradiation, mature neutrophils demonstrated long-term changes in their activity as shown by superoxide anion production (see project 5).

The literature carries some controversy regarding the value of TNF-α as a long-term radioprotector. In the current experiments, up to 800% protection of haemopoietic progenitor cells was obtained by incubating marrow for 72 hrs *in vitro* before irradiation. However, this apparent protection was not supported by the injection of equivalent amounts of TNF-α *in vivo*. The subsequent radiation survival and recovery curves for cellularity, *in vitro*-CFC and CFU-S in both bone marrow and spleen were identical. Our results, therefore, showed a lack of correlation between *in vivo* and *in vitro* radioprotective effects of rhTNF-α on murine haemopoiesis.

Preliminary work to establish the baselines for investigating the platelet producing megakaryocyte progenitors has been completed and basic survival and recovery curves out to 30 d established for 5 and 8 Gy total body γ-irradiation. The results indicate a more radioresistant progenitor than either the pluripotent CFU-S or the granulocyte/macrophage committed-CFC.

Further preliminary work on the most primitive marrow repopulating cells suggest that their long-term (~ 2.5 yr) levels in mice treated with ^{239}Pu or ^{228}Th are significantly below normal.

The findings in these preliminary investigations will be carried forward into future project work.

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Project 4

Head of project: *Dr. Visser*

Objectives for the reporting period

This part of the programme has the objective to identify the different cell types that are involved in the interactions between the haemopoietic cells and their supportive stroma. It is focussed on the analysis of purified murine pluripotent haemopoietic stem cells with respect to their long-term culture capability on irradiated stromal layers. In the course of the project a number of investigators reported new results concerning the identity of the stem cell and as a consequence concerning its purification. Therefore the objectives of this project had to be adapted to include the analysis of these new candidate stem cell fractions.

In addition, the project aimed at the purification of the stromal stem cells by applying a similar strategy as had been successful for the characterization and subsequent isolation of the pluripotent haemopoietic stem cell (PHSC).

Analysis of the culture of purified haemopoietic stem cells on well-defined cell layers arising from isolated stromal stem cells should answer questions about the effects of radiation on the different components that play a role in the regulation of haemopoiesis.

These studies were to be conducted in close collaboration between TNO-Rijswijk where the cell separation studies and the *in vivo* assays would take place, and the SCK/CEN in Mol, where the cells would be cultured on stromal layers and analysed for the presence of stromal precursor cells.

Progress achieved including publications

The results of series of cell separation experiments indicated, that fractions of sorted cells gave different numbers of stem cells in a variety of different assays which were all thought to be specific for detecting stem cells. This suggested that the haemopoietic stem cell compartment is heterogeneous, and the question has become which assay system detects the pluripotent haemopoietic stem cell capable of self renewal and of long term repopulation of haemopoiesis after transplantation into lethally irradiated recipients. Long-term repopulation *in vivo* was found to be correlated with long-term maintenance of haemopoiesis *in vitro* in long-term bone marrow cultures on stromal layers.

1. Methods

Pluripotent haemopoietic stem cells were isolated from mouse bone marrow using equilibrium density centrifugation and fluorescence-activated cell sorting. The sorting parameters were: forward light scatter, side scatter, binding of wheat germ agglutinin (WGA) and of an antibody directed against monocytes and granulocytes called 15.1.1, and staining with the dye Rhodamine 123 (Visser and Van Bekkum, 1990, Exp Hematol. 18:248).

Long-term repopulation *in vivo* was determined quantitatively in female recipients of male bone marrow cells using fluorescent *in situ* hybridization with a mouse Y-chromosome specific DNA probe (Visser *et al.*, 1991, Seminars in Hematology 28: 117-125).

Long-term culture on stromal layers was performed and analysed at the SCK/CEN in Mol after transporting the sorted cells from TNO-Rijswijk. Cobblestone area formation in stromal cell layers was determined by Dr. R. Ploemacher using stem cell fractions sorted at TNO-Rijswijk that were cultured at the Erasmus University in Rotterdam.

2. Results and discussion

Pluripotent haemopoietic stem cells (PHSC) were pre-enriched from mouse bone marrow using equilibrium density centrifugation to select low-density cells (< 1.080 g/cm^3 at pH 6.7). The low density cells were sorted using a FACS to obtain cells with low to medium forward light scatter intensity, low side scatter intensity, medium or high binding of WGA and no binding of the antibody 15-1.1. The dye Rhodamine 123 was also employed. It was found to make a distinction between primitive haemopoietic cells with active and with resting mitochondria. A Rhodamine 123 (Rh123) bright fraction could be sorted which gave many spleen colonies (CFU-s) in lethally irradiated recipients (up to 10 per 100 transplanted cells) but no long-term reconstitution of haemopoiesis as measured with the Y-probe. Another fraction, Rh123 dull, yielded considerably less spleen colonies, whereas it gave rise to nearly 100% male blood cells in female recipients for more than one year. Spleen, lymph nodes and bone marrow showed a similar pattern of chimaerism one year after transplantation of these two fractions. This indicates that the chimaerism is in all differentiation lineages: erythroid, myeloid and lymphoid. Consequently, the CFU-s assay cannot be used reliably to detect pluripotent haemopoietic stem cells and our knowledge about stem cells as it is based on nearly thirty years of CFU-s determinations has to be carefully reevaluated. As a consequence even the frequency or incidence of the pluripotent stem cell is not known and the purity of the sorted preparations can only be estimated.

Interestingly, also another test system which is in use to detect stem cells, *viz* the radioprotection or 30-day survival assay, is also shown to be misleading in this experiment. Mice which received the Rh123 bright sorted primitive cells lived for more than one year without any sign of chimaerism. Apparently, these sorted primitive cells produced sufficient offspring (together with spleen colonies) for the short time period that the recipients were at risk due to radiation induced anaemia, whereas endogenous stem cells recovered and subsequently reconstituted haemopoiesis. About three times more of the Rh123 bright sorted cells were needed for 30-day survival than of the Rh123 dull sorted cells.

We demonstrated that the low stainability of stem cells with Rhodamine 123 was due to their smaller and less active mitochondria (Visser *et al.*, 1991. Seminars in Hematol. 28;117). During 1991, it has become clear that the low stainability is also the result of the expression of the MDR-1 gene by stem cells (Chaudhary and Roninson, 1991, Cell 66:85). This gene encodes a membrane molecule, P(gp), which is an efflux pump, and the fluorescence intensity of Rhodamine 123 stained stem cells is low because the cells efficiently pump out this dye. This finding might also explain our earlier observation (Baines and Visser, 1983, Exp, Hematol. 11:701) that stem cells are not easily stained with the dye Hoechst 33342.

The Rh123 dull cells containing the PHSC could not be cultured efficiently in serum free or serum containing media supplemented with single growth factors or combinations thereof. A plating efficiency of 15% was obtained maximally (IL-1+IL-3+CSF-1). The Rh123 bright cells, however, showed a plating efficiency of up to 50% (IL-1+IL-3+CSF-1) whereas also single growth factors already gave good efficiencies (20%). This indicates that the culture system is of sufficient quality. The low plating efficiency of the pluripotent stem cells (the Rh123 dull fraction), therefore, indicates that either the right growth factor was not present amongst the ones we tested, or that the stem cells require other signals for optimal growth. Such signals may be derived from adhesion molecules or bound growth factors in stromal cultures. Therefore, the sorted cells were also cultured on stromal cell layers. This yielded higher plating efficiency. It could be estimated that 30% of the Rh123 dull and 50% of the Rh123 bright sorted cells gave so called "cobblestone areas" in stromal cultures.

The cobblestone area like colonies of haemopoietic cells derived from Rh123 dull cells persisted in the cultures for more than four weeks. Those obtained from Rh123 bright sorted cells, however, disappeared within three weeks. It may be speculated that these activated cells are highly responsive to haemopoietic growth factors and that they therefore rapidly differentiate both *in vivo* (providing short-term repopulation) and *in vitro*, whereas the quiescent Rh123 dull cells express less growth factor receptors and therefore have more time to find the sites where a combination of adhesion and bound growth regulating molecules favours self renewal.

With respect to the analysis and sorting of stromal stem cells new observations were reported by investigators in Seattle, where an antibody against the human stromal stem cell was developed (Simmons and Torok-Storb, 1991, Blood 78:55). This antibody, STRO-1, labels part of the CD34-positive cells in human bone marrow. Interestingly, the CD34 antigen is found on early haemopoietic cells, including the human haemopoietic stem cell. The light scatter properties of both stem cells were also found to be similar. The stromal stem cell apparently has a number of phenotypical features in common with the haemopoietic stem cell. On the other hand, the CD34 antigen is also found on vascular endothelial cells in a variety of tissues (Fina *et al.*, 1990, Blood 75:2417), and it may be expected that the STRO-1 antibody is found on a variety of other stromal cells. In addition, since there is no mouse equivalent of CD34 known as yet, this finding could not be easily extrapolated to our studies. The work with the new antibody is noteworthy, however, since it indicates that stromal stem cells exist and can be purified.

In addition, Simmons and Torok-Storb demonstrated that the sorted stromal stem cells gave rise to a heterogeneous layer of stromal cells that supported haemopoiesis. The heterogeneity was almost as complex as in stromal cultures that are initiated with total bone marrow. Therefore we abandoned one of the original objectives of our project to purify the stromal stem cell to facilitate the molecular analysis of interactions between isolated haemopoietic stem cells and the regulatory microenvironment. Instead, studies were initiated to analyse the expression of adhesion molecules and growth factor receptors on sorted pluripotent haemopoietic stem cells. These studies have become possible because of the introduction of reverse transcriptase PCR techniques that could be applied to rare cells such as the stem cells. A number of new genes have been discovered in these studies and the expression of known growth factor receptors in different candidate stem cell fractions could be determined. It may be expected that this approach will yield unambiguous results regarding the identity and function of specific adhesion molecules that regulate the interactions between the stem cells and the stroma.

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Project 5

Head of project: *Dr. Tejero*
Scientific staff: *S. Gaitan, E. Cuenllas, P. Sancho, J.M.J. Herranz, S. Escribano*

Objectives for the reporting period

The objectives for the present period were to extend our previous investigations with respect to superoxide anion production by granulocytes at different doses (single and repeated) (4.5, 7, 10, 3 x 4.5 Gy) types of radiation (X-rays, gamma rays) and age in mice (neonatal and adult). The effect of ^{239}Pu contamination at different gestational age has also been quantified.

The study done during the reporting period has been carried out on granulocytes obtained from peripheral blood and long-term bone marrow cultures (LTBMC) from B6D2F1 and C57Balb/C F1 mice over long periods after irradiation or contaminations.

As O_2^- is generated by a NADPH-dependent oxidase system, the hexose monophosphate shunt acquired a special relevance in neutrophils, thus preliminary studies on glucose 6-phosphate dehydrogenase (G6PD) activity have been performed in granulocytes from X-rays irradiated mice.

Progress achieved including publications

1. Methodology

- Male and female B6D2F1 mice (10-12 weeks old) were total body irradiated with 4, 5 or 10 Gy, with ^{60}Co gamma-rays at 65 cGy/day or with 4.5 Gy X-rays at a dose rate of 70 cGy/min. Some mice were irradiated 3 x 4.5 Gy X-rays at 3 week intervals.

- C57Balb/C females were whole body irradiated with 7 Gy X-rays at 8 days or 12 weeks old. Some mice (10-12 weeks old) were irradiated with 5 Gy X-rays. The dose rate was 105 cGy/min for these experiments.

- For the intrauterine ^{239}Pu contamination studies, C57B16 females (10 weeks old) were induced into oestreus with DBA2 males. On days 4 and 13 of gestation, mice received 30 kBq/kg of ^{239}Pu by injection via lateral tail vein.

- Peripheral blood granulocytes were isolated by Dextran T-500 (1.5%) sedimentation plus Ficoll-paque centrifugation (1600 xg, 20 min, 20°C). Contaminated erythrocytes were removed by hypotonic lysis (25 sec).

- LTBMC were established according to Dexter's method. Briefly, one femur and one tibia were flushed in 10 ml Fischer's medium supplemented with 20% horse serum and 10^{-5} hydrocortisone sodium hemisuccinate. Cultures were fed weekly and mature granulocytes subsequently assayed for O_2^- production and G6PD activity.

- Superoxide anion production was determined by the continuous spectrophotometric measurements of the superoxide dismutase (SOD) - inhibitable reduction of ferricytochrome c at 550 nm. Samples were stimulated with 1 µg PMA. Superoxide generation was calculated from the linear increase in absorbance based upon an extinction coefficient for ferricytochrome c reduction of 21 mM^{-1} cm^{-1}.

- G6PD activity was measured spectrophotometrically at 37°C according to Battistuzzi *et al* modified by Bautista *et al*. The assay mixture containing 1 M Tris HCl buffer pH 8; 0.1 M $MgCl_2$; 10 mM NADP; 1.3 mM G6P and an enzymatic extract containing 0.04 mg of protein.

2. Results

Superoxide anion production one year after 7 Gy irradiation of 12 week and 8 day old mice.

	% Control	
Bone Marrow Source	*Peripheral Blood*	*LTBMC*
Normal	100.0 ± 10.0	100.0 ± 10.3
12 week-old irradiated mice	223.3 ± 16.7**	228.1 ± 31.9**
8 day-old irradiated mice	263.3± 20.0**	271.9 ± 21.9 ***

Values expressed X ± SEM. Net experiments 3-6. Included statistical significance with respect to control using Student's t-test.
** $p < 0.01$; *** $p < 0.001$.

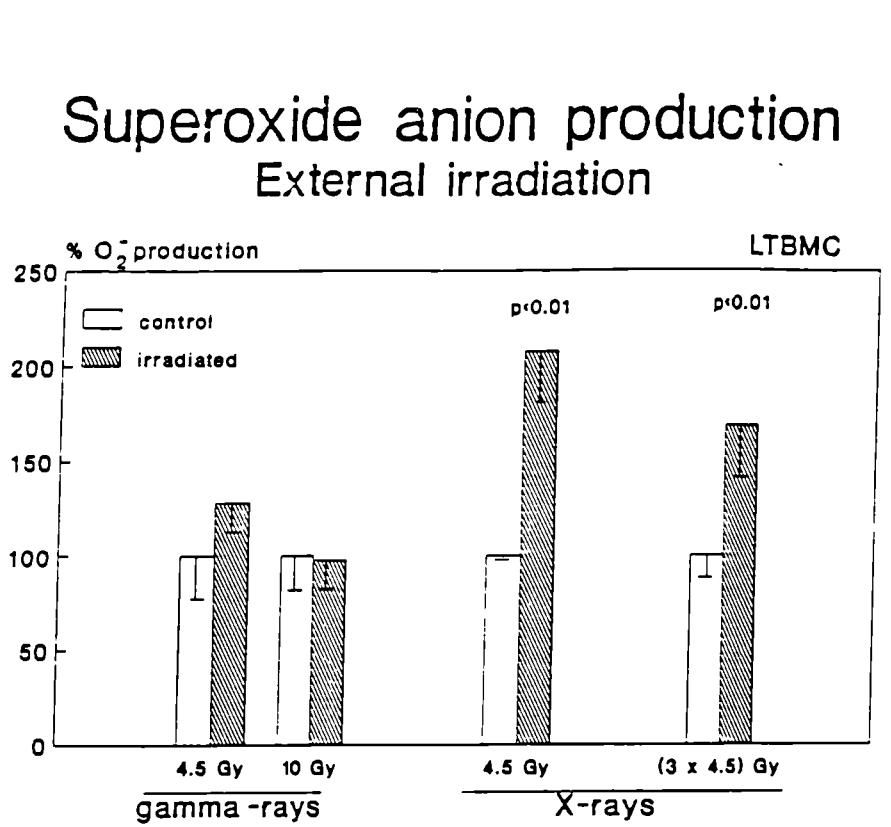

Figure 1: The measurements have been performed in granulocytes from cultures established one year after irradiation. Values expressed as percent of controls X ± SEM. Net 6-8 experiments. Insert in the figure statistical significance of difference from control using student's t-test.

LTBMC granulocytes from mice irradiated with X-rays had significantly increased O_2^- production but gamma-irradiation did not stimulate O_2^- production in the way that X-rays did. This difference may be related to the low dose rate used for gamma- compared to X-rays.

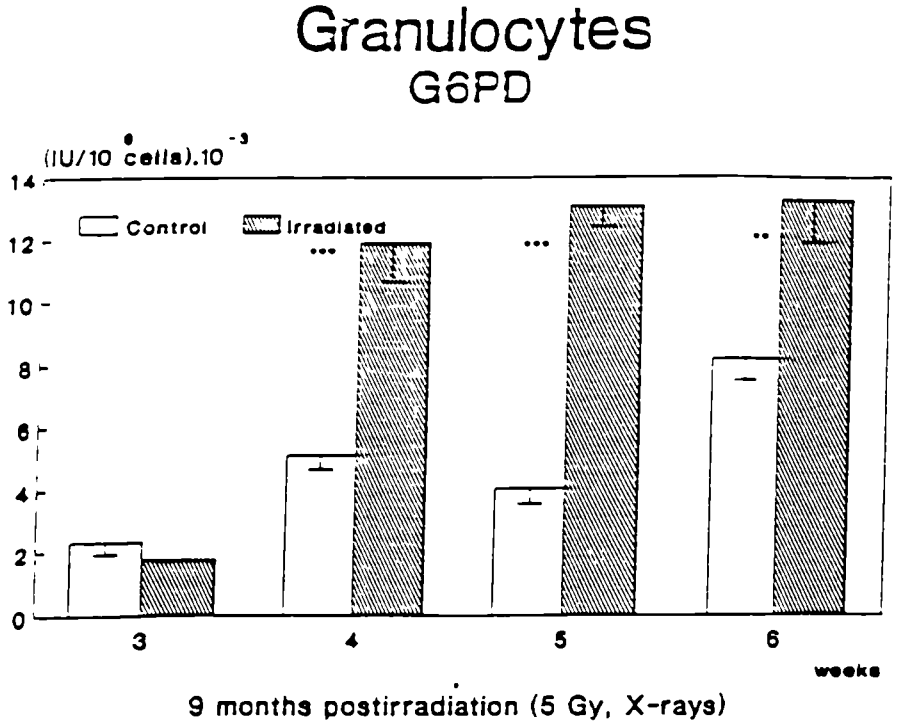

Figure 2: The values expressed X ± SEM. p-significance of difference from control using student s t-test. * $0.05 > 0.01$; ** $0.01 > p > 0.001$; *** $p < 0.001$. G6PD level is increased in granulocytes from LTBMC of irradiated mice with respect to age-matched control animals. This effect is observed at 9th month post irradiation and at different weeks of culture studied. This increase could be associated with a great production of NADPH to perform phagocytosis.

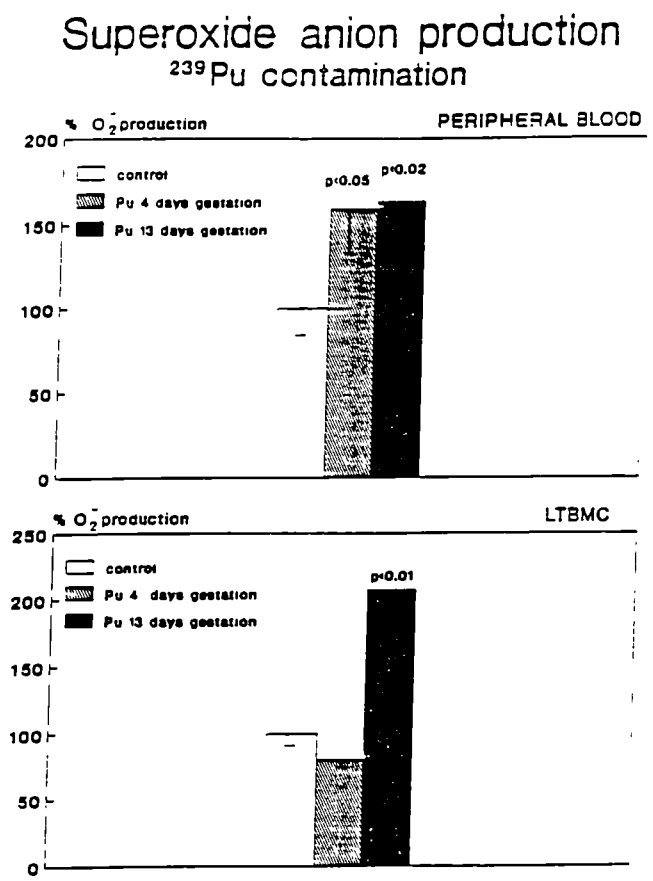

Figure 3: The experiments have been carried out at one year after birth for peripheral blood granulocytes. Cultures were established at 2.5 years after birth. Values expressed as percent of controls, X ± SEM. Net 4-6 experiments. Insert in the figure statistical significance of difference from control using student's t-test.

Granulocytes from mice 13 days intrauterine ^{239}Pu contamination, showed a significant enhancement of O_2^- production both from peripheral blood and LTBMC. This effect may be associated with the residual stromal damage described previously.

LTBMC from 4 day ^{239}Pu contaminated animals did not show differences with respect to control. These results suggest that the existance of a competent microenvironment leads to a granulocyte population with normal function.

On the other hand, the fact that peripheral blood granulocytes from 4 day ^{239}Pu contamination express an extraproduction of O_2^- might be as a consequence of their response to extramedullary sources of endogenous CSFs.

3. Conclusion

Our results demonstrate that treatments which produce stromal damage, induce compensatory mechanisms which are reflected in mature granulocytes, in such a way that their functional capacity is enhanced.

Scientific staff S. Gaitán, E. Cuenllas, P. Sancho, J.M.J. Herranz and S. Escribano.

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Project 6

Head of project: *Dr. Bueren*

Objectives for the reporting period

- To characterize the differential stromal and hematopoietic injuries in adult and suckling irradiated mice.

- To analyse the hematopoiesis of mice following external irradiation in embryonic stages of development.

- To analyse the clonal expression of genetically marked hematopoietic stem cells following *in vivo* transplantation in mice or *in vitro*, in Long Term Bone Marrow Cultures (LTBMC).

- To determine the influence of the irradiation on the expression of hematopoietic stem cell clones.

Progress achieved including publications

1. Analysis of the differential stromal and hematopoietic injuries in adult and suckling irradiated mice

In the last reporting period we described the long-term evolution of the hematopoiesis of mice irradiated with 7 Gy. A persistent reduction in the content of femoral hematopoietic progenitors (CFU-S, CFU-GM and BFU-e) was noticed for the time studied (20 months) in adult irradiated mice. By contrast, in 8 day-old irradiated mice a progressive recovery of these precursors was observed, achieving essentially normal values at one year post-irradiation (1,2).

In order to study the role of the microenvironment in the different hematopoietic behaviour of both groups of irradiated animals, LTBMCs were established one year after irradiation. Analyses performed in the fourth week of culture consistently showed that adult irradiated mice generated poor stromas, while essentially normal adherent layers were noted in cultures of young irradiated mice, suggesting that differences in the stromal regeneration of young mice may account for the different long-term hematopoietic recovery.

In collaboration with Dr Tejero's group it was established that LTBMCs from normal bone marrow released negligible amounts of GM-CSA. However, supernatants of cultures established from the bone marrow of adult and young irradiated mice were capable of stimulating the growth of granulocyte-macrophage progenitors (Table I). Either *in vivo* and in LTBMCs, the O_2^- production of granulocytes corresponding to both groups of irradiated mice was 2 to 3 times higher than values corresponding to granulocytes harvested from control cultures (1,3,4,5).

To confirm that the growth of CFU-GM was promoted by an overflow of GM-CSF, the activity of the supernatants was also tested after neutralization with GM-CSF antiserum (1). Under these circumstances no colonies were observed (Table I), demonstrating the increased release of GM-CSF as a long-term consequence of the *in vivo* irradiation of mice. This supports that a persistent activation of the regulatory microenvironment is produced to compensate residual hematopoietic failures induced by the irradiation.

Table I: Supernatant Colony Stimulating Activity analysis of LTMBCs established one year after 7 Gy irradiation of 12 week old and 8 day old mice.

LTBMC Supernatant Source	*CFU-GM/10^5 Cells Stimulated with LTBMC Supernatants*	*% of Neutralization with Anti-GM-CSF*
Normal mice	1.2 ± 0.8	100%
12 week-old irradiated mice	10.1 ± 2.4 ($p<0.01$)	100%
8 day-old irradiated mice	18.5 ± 5.4 ($p<0.01$)	100%

To analyse long-term failures in the self-renewal capacity of the CFU-S population, spleen colonies generated by CFU-S from mice that had been irradiated one year before were transplanted into secondary recipients. In adult and 8 day-old irradiated mice this parameter was decreased to about 13% and 35% respectively, in comparison to age-matched controls. This reflected a long-term impairment of the CFU-S quality, which was more evident in the case of the adult mice (6).

To further determine the role of the stroma in the persistent reduction of the number and self-renewal capacity of the CFU-S, bone marrow plugs obtained one year after the irradiation of adult and 8 day-old mice were implanted beneath the renal capsule of non-irradiated recipients. In relation to control ossicles, ossicles from both types of irradiated mice were incapable of sustaining normal values of CFU-S (about 50% reduction in CFU-S/10^5 cells). These precursors, however, generated higher numbers of analogous CFU-S in secondary transplantations (more remarkable in ossicles derived from suckling irradiated animals), indicating that failures in the hematopoietic stroma are involved in the persistent reduction of hematopoietic progenitors observed after the 7 Gy irradiation of adult mice, but not directly in the quality impairment of the hematopoietic stem cells noticed in these animals (7,8,9).

2. <u>Analysis of the hematopoiesis of mice following external irradiation at embryonic stages of development</u>

It has been previously shown by collaborating contractors that contamination of embryos with α-emitting radionuclides induces long-term hematopoietic depression at very low cumulative doses. In an attempt to investigate possible hematopoietic failures after low LET

external irradiation in early stages of growth, a single dose of 0.5 Gy of X-rays (300 kV; dose rate: 1.03 Gy/min) was given to pregnant mice at 17 days of gestation, as well as to 2-day old, 8-day old and 12 week-old mice (10).

Results obtained in 17 individual determinations carried out 3 or 6 months after the irradiation of 12-week old mice, 8-day old mice and 2-day old mice did not reveal significant differences in the femoral content of CFU-GM, BFU-E and CFU-S, with respect to their age-matched controls. In the case of mice irradiated at the 17th day of embryonic development, six animals were analysed 6 to 9 months after birth. Although in these animals normal values of CFU-S12 were determined, a significant reduction of granulocyte-macrophage progenitors was apparent at 9 months post-irradiation (Figure 1), (10).

These data suggest the induction of a long-term hematopoietic failure as a consequence of a single 0.5 Gy irradiation of the embryo that is not produced in newborn or young adult mice. Further experiments are in progress to confirm dysfunctions in the hematopoiesis of mice irradiated at this stage of growth and to identify further hematopoietic failures induced by irradiation at other stages of embryonic development.

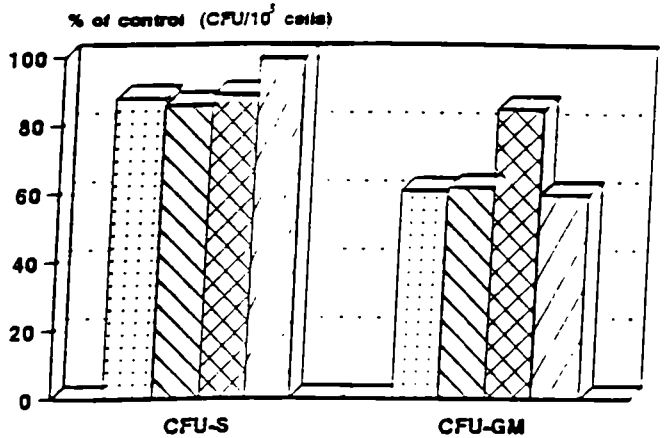


Figure 1: Proportion of femoral hematopoietic progenitors 9 months after irradiation of mice with 0.5 Gy of X-rays at the 17th day of embryonic development.

3. Analysis of the clonal expression of genetically marked hematopoietic stem cells following *in vivo* transplantation in mice

In order to study possible differentiation failures of the most primitive hematopoietic stem cells following irradiation, we have attempted to genetically mark such precursors by means of retroviral vectors, at present the most efficient procedure to insert genetic tracks into hematopoietic stem cells.

In the last reporting period we obtained high integration efficiences of the reporter neo^r gene into the CFU-S population when selection in geneticine was included in the infection protocol (90-100% of CFU-S contained the reporter gene) or when cocultures of ψ_2 and PA

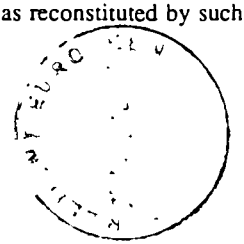
317 cells were prepared for bone marrow infection (80-90% of CFU-S were genetically marked) (11). Southern analyses carried out in the long-term, revealed that such protocols render a low but detectable expression of genetically marked stem cells. In the case of the geneticine-selected bone marrow, genetic marks became undetectable by Southern blotting at 4 months after transplantation. The mixed coculture procedure, although efficient for the infection (this procedure did not require the selection step), seems to produce significant amounts of helper viruses which would invalidate studies of stem cell differentiation.

In this reporting period, we have therefore studied further possibilities which would allow not only the tracking of the CFU-S population, but also alternatives which allow the long-term follow up of the hematopoietic stem cells in irradiated recipients. In order to improve the collection of bone marrow cells enriched in proliferatively active precursors, experiments were conducted with bone marrow suspensions prepared after *in vivo* 5-FU treatment. Bone marrow cells stimulated with IL-3 plus Stem Cell Factor generated a high increase in CFU-GM numbers within the 3-day incubation period required for the retroviral infection and gene expression. Such stimulation rendered a population containing abut 10% of CFU-GM and 1% of CFU-S 12d (12). To determine whether the very primitive stem cells had been depleted because of a potential differentiation stress to the bone marrow, 10^5 male bone marrow cells incubated for three days in media containing IL-3 plus SCF were transplanted into female irradiated recipients. Hybridization with the pY2 probe revealed that these cells regenerated the hematopoiesis of irradiated animals, at least as efficiently as non-incubated bone marrow cells (12,13).

Because of the significant amplification of the hematopoiesis noticed in bone marrow cultures stimulated for 3-days with IL-3 plus SCF, bone marrow cells were infected with the pXT1 vector in the presence of these Growth Factors and subsequently selected in 1 mg/ml of G-418. This protocol improved the proportion of CFU-S 12d in the bone marrow population about 10 fold, with respect to values obtained in the last reporting period. As before, every CFU-S 12d contained the genetic label (12,13).

One million to 4 x 10^6 cells infected under these conditions were transplanted to irradiated recipients to follow the fate of the hematopoietic stem cells in the long-term. Ten weeks after transplantation, animals were sacrificed and different hematopoietic organs were analysed by Southern blotting. The infection protocol that was investigated allowed that three out of the four analysed animals, presented a very high proportion of labelled cells, either in the bone marrow, and also in spleen and thymus (from 50 to 100%). The other animal was slightly positive (< 10%), and was mainly reconstituted by endogenous stem cells, as revealed by sex-mismatched analysis.

A representative Southern analysis of the retroviral vector integration pattern is shown in Figure 2. Either the bone marrow and spleen of this animal were mainly reconstituted by the same stem cell clone containing two copies of the provirus, or alternatively by two different stem cells containing a single provirus insert. The expression of a different stem cell, probably restricted to the T lineage was detected in the Southern blot. Only faint bands corresponding to this clone were detected in the bone marrow and spleen, while the band found in the thymus indicated that almost every cell in this organ was reconstituted by such stem cell (Figure 2), (12,13).



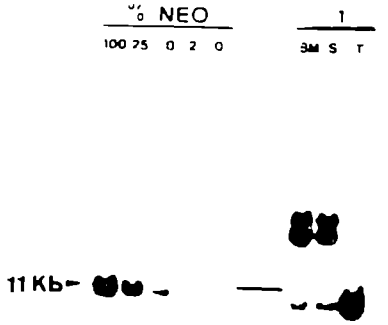


Figure 2: Analysis of the hematopoietic stem cell differentiation in mice reconstituted with 4.10^6 bone marrow cells genetically marked with the retroviral vector pXT1. The Southern blot analysis was carried out 10 weeks after bone marrow transplantation. (BM: Bone Marrow, S: Spleen, T: Thymus)

Prior to investigating possible radiation-induced failures in the differentiation of hematopoietic stem cells, further experiments are in progress, in order to confirm the continuous expression of long-lived hematopoietic stem cells genetically marked.

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THE DOSIMETRY AND EFFECTS OF FETAL IRRADIATION FROM INCORPORATED RADIONUCLIDES (NRPB ASSOCIATION)

1) *Harrison*, NRPB - 2) *Henshaw*, Univ. Bristol
3) *Coffigny*, CEA-Bruyères-le-Châtel

Objectives for the reporting period

An important aspect of the assessment of risks from incorporated radionuclides is the possibility of intakes by pregnant women and in utero exposure of the developing fetus. The overall objective of the project was to provide experimental data for the development of dosimetric models and assessment of risk. Studies included measurements of $^{239/240}$Pu, ^{210}Po and other alpha-emitters in human fetal tissues and placentae and animal studies of the biokinetics of radionuclide transfer and effects. Animal biokinetic studies were mainly concerned with comparing the uptake and distribution of ^{210}Po, ^{238}Pu and ^{241}Am in rats and guinea pigs for different exposure conditions. The data obtained in these studies have been used, together with the human data, to develop dosimetric models. Studies of the effects of in utero irradiation have been carried out using mice and rats, initially comparing external irradiation at different times during gestation to provide information on the radiosensitivity of particular tissues and allow subsequent comparisons with internal irradiation.

Progress achieved

A detailed investigation has been undertaken at UB on the distribution of natural alpha radioactivity within the human fetus, using autopsy samples obtained from various stages of development from 18 weeks to stillborn. Samples from 67 cases have been collected, mainly from the Bristol area but including samples from West Cumbria and the region around Chernobyl. Placentae from healthy births in the Bristol area have also been collected with information on mothers' ages and smoking habits. Alpha-activity in tissue samples, largely due to ^{210}Po, was measured using the track detector, TASTRAK. Methods for determining backgrounds have been refined to allow separate assessment for each individual tissue autoradiograph. Detection limits for ^{210}Po on the autoradiographs were in the range 30 - 70 mBq kg^{-1}. For the samples from the Bristol area for which analyses are complete, ^{210}Po concentrations in soft tissues were below the limit of detection but concentrations in fetal vertebrae, the selected bone sample, ranged from the detection limit to about 500 mBq kg^{-1}. Concentrations on the outer bone surface appeared to be greater than on the inner surfaces. Measurements for ^{226}Ra showed concentrations in the vertebrae ranging from the limit of detection of about 8 mBq kg^{-1} up to about 40 mBq kg^{-1}. Differences in ^{210}Po

concentrations in fetal vertebrae in relation to the mothers' place of residence were analysed and showed some evidence of a correlation between distance from the sea at Avonmouth on the Severn estuary and decreasing concentration. Results are being used in the development of models for the kinetics/dosimetry of $^{210}Po/^{210}Pb$ in the human fetus.

NRPB have obtained samples of human fetal tissue and placentae from terminations in west Cumbria and Oxfordshire. The fetal ages ranged from 14 to 25 weeks and the maternal ages from 14 to 37 years. Levels of $^{239/240}Pu$ were close to the limit of detection by mass spectrometry but results indicated concentrations of a few uBq kg^{-1} compared with maternal whole body concentrations of about 1 mBq kg^{-1}. Concentrations of ^{210}Po in fetal tissues, measured by alpha-spectrometry, were about three orders of magnitude greater than those of $^{239/240}Pu$. Concentrations of ^{232}Th and ^{238}U have also been measured by mass spectrometry.

Plutonium-238, ^{241}Am and ^{210}Po have been administered systemically to rats and guinea-pigs at different stages of pregnancy and transfer to the embryo and fetus determined by autoradiography and tissue analysis. For ^{238}Pu, retention in a single fetoplacental unit (FPU: maternal decidua, placental trophoblast, membranes and embryo/fetus) of both rats and guinea-pigs reached about 0.3 - 1% of injected activity for administration late in gestation. Direct comparisons of the transfer of ^{238}Pu and ^{241}Am in rats showed that uptake of ^{241}Am in the FPU in late gestation was about an order of magnitude lower than that of ^{238}Pu. The distribution of ^{238}Pu and ^{241}Am in the FPU was also different with the yolk sac retaining most ^{238}Pu activity and the placenta accounting for most ^{241}Am; uptake in the fetus accounted for a similarly small proportion of total FPU activity for the two nuclides. For ^{210}Po, transfer in late gestation to the FPU and fetus in rats was similar to that for ^{238}Pu. Concentrations of ^{238}Pu and ^{210}Po in the rat yolk sac during haemopoiesis were similar and of the same order as concentrations in maternal liver; concentrations of ^{241}Am in the yolk sac were one to two orders of magnitude lower. Autoradiographic studies of the distribution of ^{210}Po in rat tissues at earlier stages of gestation have shown that, like Pu, it is concentrated in the yolk sac membrane from the time of its formation. In addition, as for Pu, some evidence was observed of the association of activity with the developing hind-gut. The transfer of ^{239}Pu and ^{241}Am to the fetus from existing maternal deposits has also been studied using rats and guinea pigs, showing that administration of activity one month before conception resulted in fetal concentration from one to two orders of magnitude lower than in short-term transfer studies.

In a collaborative experiment between NRPB and CEA, the transfer of ^{210}Po, ^{237}Np, ^{238}Pu and ^{241}Am to the fetus of a baboon in late gestation has been studied. The results generally show greater levels of transfer to the fetus and accumulation in the placenta than for rodents but similar concentrations in fetal tissues.

The animal data are being used to develop dosimetric models for the human fetus, concentrating particularly on doses to haemopoietic tissues. The estimated in utero doses to haemopoietic tissue including doses to the egg cylinder and yolk sac where stem cells may originate, were about 60

times greater for ^{210}Po than ^{239}Pu and about five times less for ^{241}Am than for ^{239}Pu. For ^{239}Pu and ^{241}Am, because of their long physical and biological half-lives, an important consideration is the activity present in the offspring at birth. The total lifetime dose to haemopoietic tissue in the offspring was calculated to be about 100 times less than to the mother for ^{239}Pu and 300-400 times less for ^{241}Am. For ^{210}Po, consideration of activity present at birth makes little difference to dose estimates because of the short physical and biological half-lives of this radionuclide.

Studies undertaken at CEA have quantified effects of protracted in utero irradiation in rats and mice, particularly for effects on the brain, comparing exposure to gamma (^{60}Co) and neutron (^{252}Cf) sources. The gamma dose-rates were in the ranges 0.03 - 0.4 Gy d^{-1} for rats and 0.2 - 0.6 Gy d^{-1} for mice; neutron dose-rates for irradiation of rats were 0.015 - 0.15 Gy d^{-1}. For gamma or neutron exposure throughout gestation, brain weight in the fetus at the end of gestation and in offspring at 3 months of age was reduced with increasing dose-rate and cumulative dose. In the offspring, the effect was confined to the cerebrum (forebrain + midbrain) with no significant change in the hindbrain. The RBE for neutrons was about 4 for this effect on the cerebrum. For prenatal, post-implantation mortality and fetal body weight the RBE for neutrons was about 6. For effects on the brain, experiments in which gamma-irradiation was continued for only part of pregnancy showed that exposure during the last third of gestation was as effective as exposure continuing throughout gestation. No gross malformations were observed in the brain in the range of dose and dose-rate studied. Results for changes to testes and ovaries in 3 month-old offspring show a reduction in weight with increasing dose and dose-rate. A significant decrease in testis weight occurred at the lowest neutron dose-rate of 0.015 Gy d^{-1} whereas 0.03 Gy d^{-1} gamma irradiation had no effect. After exposure to 0.1 Gy d^{-1} of either radiation, histological examination showed that germ cells were completely absent. Ovary weights decreased with increasing dose rate and cumulative dose from 0.03 Gy d^{-1} gamma or neutron irradiation. These studies have not shown dose-rate effects but the dose-effect relationships established have provided data which will allow estimates to be made of doses from radionuclides incorporated into fetal tissues.

The continuation of these studies forms part of a new coordinated proposal: Dosimetry and Effects of Parental, Fetal and Neonatal Exposure to Incorporated Radionuclides and External Radiation.

Project 1

Head of project: *Dr. Harrison*

Objectives for the reporting period

The overall objective of the project was to provide experimental data for the development of dosimetric models and assessment of risk. Studies included measurements of ^{210}Po and other alpha-emitters in human fetal tissues and placentae and animal studies of the biokinetics of radionuclide transfer. The animal biokinetic studies were mainly concerned with comparing the uptake and distribution of ^{210}Po, ^{238}Pu and ^{241}Am in rats and guinea pigs for different exposure conditions. The data obtained in these studies have been used, together with the human data, to develop dosimetric models.

Progress achieved including publications

1. Human data

Measurements of the concentration of the naturally-occurring nuclides, ^{210}Po, ^{210}Pb, ^{238}U and ^{232}Th, have been made on 24 sets of fetal tissues from Oxfordshire and west Cumbria; measurements of $^{239/240}$Pu concentrations have also been made. The tissues were from second trimester terminations with fetal ages from 14 to 25 weeks and maternal ages from 14 to 37 years. The average mass of tissues for analysis was about 170 g for the fetus and 90 g for the placenta. Levels of $^{239/240}$Pu were measured in collaboration with the Atomic Weapons Establishment, Aldermaston, using the sensitive method of thermal ionisation mass spectrometry. The values obtained were below or close to the limit of detection even in pooled samples but the results indicate concentrations of a few μ Bq kg^{-1} compared with average maternal whole body concentrations of about 1 mBq kg^{-1}. Concentrations of ^{210}Po measured by alpha-spectrometry, shown in the Table, were about three to four orders of magnitude greater than those of $^{239/240}$Pu. The Table also shows results for ^{238}U and ^{232}Th measured by mass spectrometry.

Origin	Tissue	Concentration, mBq kg^{-1}			
		^{210}Po	^{210}Pb	^{238}U	^{232}Th
Oxfordshire	Fetus	3.6 - 59	<7.9 - 31	2.3 - 6.9	0.13 - 1.0
	Placenta	6.0 - 119	<10 - 69	5.3 - 7.4	0.17 - 1.0
Cumbria	Fetus	3.1 - 43	<2 - 40	0.13 - 1.6	0.15 - 0.54
	Placenta	21 - 147	<5 - 36	0.45 - 2.3	0.24 - 1.3

2. Animal data

Measurements of the distribution of ^{210}Po, ^{238}Pu and ^{241}Am in maternal tissues and fetoplacental tissues (decidua, placental trophoblast, yolk sac and embryo/fetus) of rats and guinea pigs were made at different stages of gestation. The nuclides were administered systemically in citrate solution, three days previously in rats and 7 days previously in guinea pigs; ^{238}Pu and ^{241}Am were administered together to the same animals to facilitate direct comparison. The amount transferred was greatest after administration at later stages of gestation. For example, in rats at 17.5 days of gestation, each fetoplacental unit (FPU) accounted for about 0.3% of administered activity of ^{210}Po and ^{238}Pu and about 0.02% of ^{241}Am; about 1 - 2% of the activity in the FPU was present in the fetus for each nuclide. The yolk sac was shown to accumulate both ^{210}Po and ^{238}Pu, accounting for about 25% of FPU activity at 12.5 days of gestation. For ^{241}Am, total uptake by each FPU at 12.5 days of gestation was about four times lower than that of ^{238}Pu and the proportion retained by the yolk sac was about ten times lower than for ^{238}Pu. The concentration of ^{210}Po and ^{238}Pu in the rat yolk sac at day 12.5 was similar to that in maternal liver at about 4% g^{-1} and 2% g^{-1}, respectively; the concentration of ^{241}Am was about 40 times less than that of ^{238}Pu.

The transfer of ^{210}Po to each FPU in guinea pigs in late gestation, on day 57, was about ten times greater than in the rat; 3 to 4 FPU each containing about 3% of injected activity in the guinea pig compared with 9 to 10 FPU each containing about 0.3% of injected activity in the rat. The distribution of activity in the FPU was also different in the two species with a greater proportion retained in the placental trophoblast and a smaller proportion in the yolk sac of guinea pigs compared to rats.

In a collaborative study between NRPB and CEA, the transfer of ^{239}Pu, ^{241}Am, ^{237}Np and ^{210}Po to the fetus in late gestation is being studied in a primate species, the baboon. Preliminary results for ^{239}Pu and ^{241}Am indicate higher levels of transfer to the fetus and accumulation in the placenta than comparable values for rats and guinea-pigs but generally similar concentrations in fetal tissues.

Retention in the placenta at one week after administration accounted for about 10% of injected ^{239}Pu with transfer to the fetus of about 3 - 5%. Values for ^{241}Am were about an order of magnitude lower.

Comparisons have been made between the short-term transfer of ^{239}Pu and ^{241}Am to the fetus of rats and guinea pigs with transfer from existing maternal deposits. Results for guinea-pigs in late gestation indicate that the total transfer to 3 - 4 fetuses accounted for about 0.03% of ^{238}Pu activity administered to the mother at one month before conception whereas transfer to the fetuses after administration 7 days previously during pregnancy was about 1.6%. The corresponding values for ^{241}Am were 0.007% from existing deposits and 0.8% after administration 7 days previously.

Autoradiographic studies of fetal tissue sections from rats and guinea-pigs in late gestation showed the specific uptake of ^{238}Pu in liver and bone while the distribution of ^{210}Po was fairly uniform. Studies of the distribution of ^{210}Po in rat tissues at earlier stages of gestation have shown that, like Pu, it is concentrated in the yolk sac from the time of its formation. In addition, as for Pu, association of activity with the developing hind-gut was observed. Because of uncertainties in concentrations determined for low masses of tissues in early gestation, autoradiographic techniques are being used to measure ^{238}Pu concentrations in the rat blastocyst, egg cylinder and yolk sac by track counting. Autoradiographic studies using a beta emitter, ^{241}Pu, are also in progress to obtain information on the microdistribution of Pu in relation to sensitive cells in the yolk sac and other tissues. Results for alpha track distribution indicate that concentrations of ^{238}Pu in the blastocyst are higher than in the surrounding decidua by about a factor of two while ^{210}Po concentrations in the blastocyst appear lower. Concentrations of ^{238}Pu in the egg cylinder determined by track counting were about a factor of two lower than radiochemical measurements; results for ^{210}Po obtained by the two methods were very similar.

3. Dose estimates

Estimates of doses to the human fetus are very largely reliant on extrapolation of animal data. However, the results obtained for ^{210}Po concentrations in human fetal bone in late gestation (University of Bristol) were more than an order of magnitude lower than corresponding values reported for children. Measurements of $^{239/240}$Pu in human fetal tissues showed that average concentrations around mid-term were more than an order of magnitude lower than average maternal tissue concentrations. This finding differs from previous reports of about equal concentrations of $^{239/240}$Pu in fetus and mother (U.S. NUREG/CR-5631, 1990) but the results reported here for ^{210}Po and $^{239/240}$Pu are consistent with the extent of placental discrimination shown in animals.

The animal data have been used to estimate doses to the human fetus from intakes of ^{210}Po, ^{239}Pu and ^{241}Am, concentrating on the calculation of doses to haemopoietic tissues. Account has been taken of the different sites of haemopoiesis during embryonic and fetal development. The first

population of haemopoietic stem cells originate outside the embryo in the blood islands of the yolk sac, or even at the earlier egg cylinder stage. Once the extra-embryonic and embryonic circulations become connected, stem cells appear in the developing liver, then the spleen and finally the bone marrow. Whether yolk sac cells are precursors of all definitive haemopoietic stem cells remains to be established but the approach we have adopted is to include in utero doses to the blastocyst/egg cylinder, yolk sac, liver and bone marrow by comparing results for concentrations of the nuclides in these tissues with the corresponding maternal liver concentrations. The Table shows the concentration ratios used and the periods of human gestation to which they were applied. Doses were calculated for the chronic maternal intake by ingestion of 4.8 kBq of ^{210}Po and 1.8 kBq of either ^{239}Pu or ^{241}Am, corresponding to a committed effective dose of 1 mSv to the mother. The estimated in utero doses to haemopoietic tissue were about 140 μ Sv for ^{210}Po, 2 μ Sv for ^{239}Pu and 0.4 uSv for ^{241}Am compared with red bone marrow doses to the mother in the year of 380 μ Sv for ^{210}Po and 33 μ Sv for ^{239}Pu and ^{241}Am. It should be recognised that these estimates of fetal doses are based on a range of results from animal experiments and are subject to uncertainties inherent in their application to man. However, they serve to indicate relationships between fetal and maternal doses.

Equivalent dose to haemopoietic tissues of the embryo and fetus after chronic maternal ingestion of 4.8 kBq ^{210}Po, 1.8 kBq ^{239}Pu or ^{241}Am in the year of pregnancy

		^{210}Po		^{239}Pu		^{241}Am	
Tissue	Gestation period (weeks)	Concn ratio	Equivalent dose (μSv)	Concn. ratio	Equivalent dose (μSv)	Concn. ratio	Equivalent dose (μSv)
Blastocyst/ egg cylinder	0 - 2.5	1	1.4	0.1	0 04	0.01	0.004
Yolk sac	2 5 - 6	2	57	2	1.4	0.05	0 04
Liver	6 - 12	0 1	7	0.01	0 02	0.001	0.002
Bone marrow	12 - 38	0.1	71	0 02	0.7	0.001	0.4

Concn. ratios are fetal tissue : maternal liver ratios from animal data.

For ^{239}Pu and ^{241}Am, because of their long physical and biological half-lives, an important consideration is the activity present in the offspring at birth and the committed equivalent dose to red bone marrow in the child and mother. The total dose to haemopoietic tissue in the offspring to age 70 years was calculated as about 22 μ Sv for ^{239}Pu and about 4 μ Sv for ^{241}Am compared with maternal doses to red bone marrow of 1.4 mSv for both nuclides. For ^{210}Po, because of its short physical and biological half-lives, consideration of activity in the offspring at birth and committed doses to the child and mother make negligible differences to dose estimates.

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Project 2

Head of project: *Dr. Henshaw*

Objectives for the reporting period

This project has sought to measure levels of natural α-activity in the human fetus in autopsy and temination tissues, using alpha-sensitive plastic track detectors.

Progress achieved including publications

1. Tissue Collection

During the project fetal tissue samples from 67 cases were collected. Samples of fetal liver, spleen, thymus, vertebra, umbilical cord and corresponding placenta were sought, but in many cases not all samples are available. The majority of tissues were obtained from Southmead Hospital, Bristol, but six cases have been obtained from West Cumberland Hospital, Whitehaven from mothers living in West Cumbria and four from the Kiev/Chernobyl region (see below). Figure 1 shows a histogram of fetal ages which range from 18 weeks gestation to 39 days postnatal.

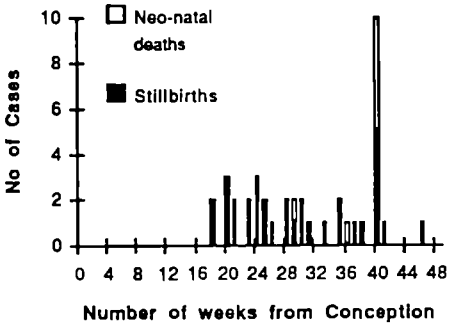

Figure 1 - Fetal tissue ages

1.1 Fetal tissues from Chernobyl, Ukraine

There is obvious interest in looking at transplacental transfer and absolute levels of transuranic alpha-emitters (and indeed fission products such as ^{131}Cs and ^{90}Sr) in fetal tissues obtained from the region around Chernobyl. In May and December 1991 and in June 1992 visits to Kiev were made by members of the Bristol group organized by Ms. Susan Kilburg of the Rush Presbyterian St Lukes Medical Centre, Chicago who is setting up a study of child health in the region. This will be linked to a similar study in Bristol under Professor Jean Golding in the Univesity Institute of Child Health. Professor Tamara Zadorzhnaja, Chief Infantile Pathologist at the Kiev Research Institute of Paediatrics has to date supplied for analysis in Bristol, samples from 16 termination cases and 53 placentas from healthy births. Tissues from 50 of these cases were from former residents close to the Chernobyl accident in 1986.

We are now seeking funding for a full project in this area to obtain a steady supply of tissues and to allow Soviet scientists to visit Bristol on a collaborative basis. Using a small travel grant from the British Council Progessor Zadorzhnaja and two of her colleagues will visit Bristol University this September. We have arranged with Austrian Airlines for air freight of tissue samples between Kiev and London Heathrow at fairly low cost. In future work this should speed up the supply of tissues for analysis. We have also suggested that Professor Zadorzhnaja collects teeth from the study group from all ages for analysis. We ourselves can analyse for total alpha and search for "hot" particles. Bristol University has a sensitive gamma detector currently in use as part of post-Chernobyl monitoring in the UK. This will be used for assay of ^{131}Cs in teeth and in fetal tissues samples. Scientists at University College Dublin and the Environmental Sciences Division, AEA Technology Harwell (with whom we are collaborating on a UK survey of radioactivity in children's teeth) have expressed interest in analysing the teeth respectively for plutonium and strontium.

1.2 Alpha-activity in Placenta

Forty two whole placentas from healthy births have also been obtained with information on mother's age and smoking history. Details are given in figure 2.

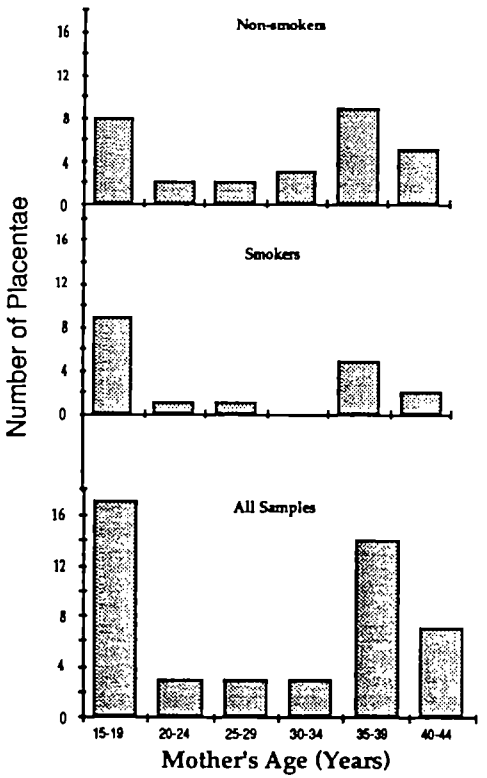

Figure 2

Note that we have deliberately sought samples from the youngest and the oldest mothers. These samples are all being stored for at least one year and analyses are not yet available. It will be of interest to determine whether there are any variations of levels as a function of age and smoking history. For example, cigarettes have been shown to contain excess ^{210}Po and there is some evidence that excess levels exist in the lung and the bloodstream of smokers (Little *et al* 1965, Henshaw *et al* 1984). Studies carried out at NRPB have shown low transplacental transfer of ^{210}Po in mouse and it will be interesting to see if similar information can be gleaned for the human case.

2. Analysis

In analysing these data we have been unable to resolve the activities present in soft fetal tissues, although activity is resolvable in the fetal skeleton. The main limiting factor is the level of background tracks on the autoradiographs. The project has therefore necessitated further developments of the separation of background from signal tracks in order to record natural levels of α-activity in small, <5g, unconcentrated tissue samples.

The sources of background are illustrated in figure 3. This shows a computer simulation of pre-etched and signal tracks. The left hand track originates from an α-particle crossing the initial plastic surface. This is a background track which is revealed by both the pre-etch, removing ≈44 μm of surface and the sample etch removing a further ≈11 μm of surface. The right hand track originates from the sample which crosses the post pre-etch surface and is revealed only by the sample etch. The middle tracks originate from latent α-particle tracks within the body of the plastic which are revealed partly by the pre-etch and subsequently by the sample etch. Whereas the left and right hand etch tracks are readily distinguishable, the middle tracks may fall in the size envelope of sample tracks and be indistinguishable as background tracks. Such tracks within the body of the plastic can originate either from intrinsic impurities in the plastic or from radon diffusing out of the casting glass during the high temperature polymerisation process. We have found wide variations in the background levels in blank plastics stored as controls with fetal tissue autoradiographs such that our ability to resolve signal from background on individual samples is impaired.

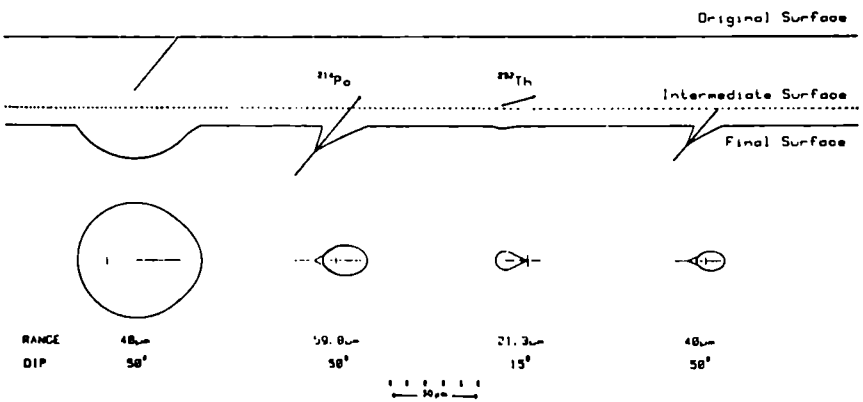

Figure 3

A method has been developed for assessing the background on each individual tissue autoradiograph. The background tracks such as in figure 3 left may be counted under a microfiche reader. On background control plastics the number of such tracks have been shown to correlate with the number of apparent real events. This is illustrated in figure 4,

bottom, which suggests that the casting glass is the predominant source of background. The plots from all autoradiographs from soft tissues: placenta, umbilical cord, liver, spleen and thymus are similar to that for the background plates, demonstrating that activity is not resolvable from background. In contrast, the plot for fetal vertebrae (top right) shows a group of points well separated from background. The corresponding activity values are discussed below.

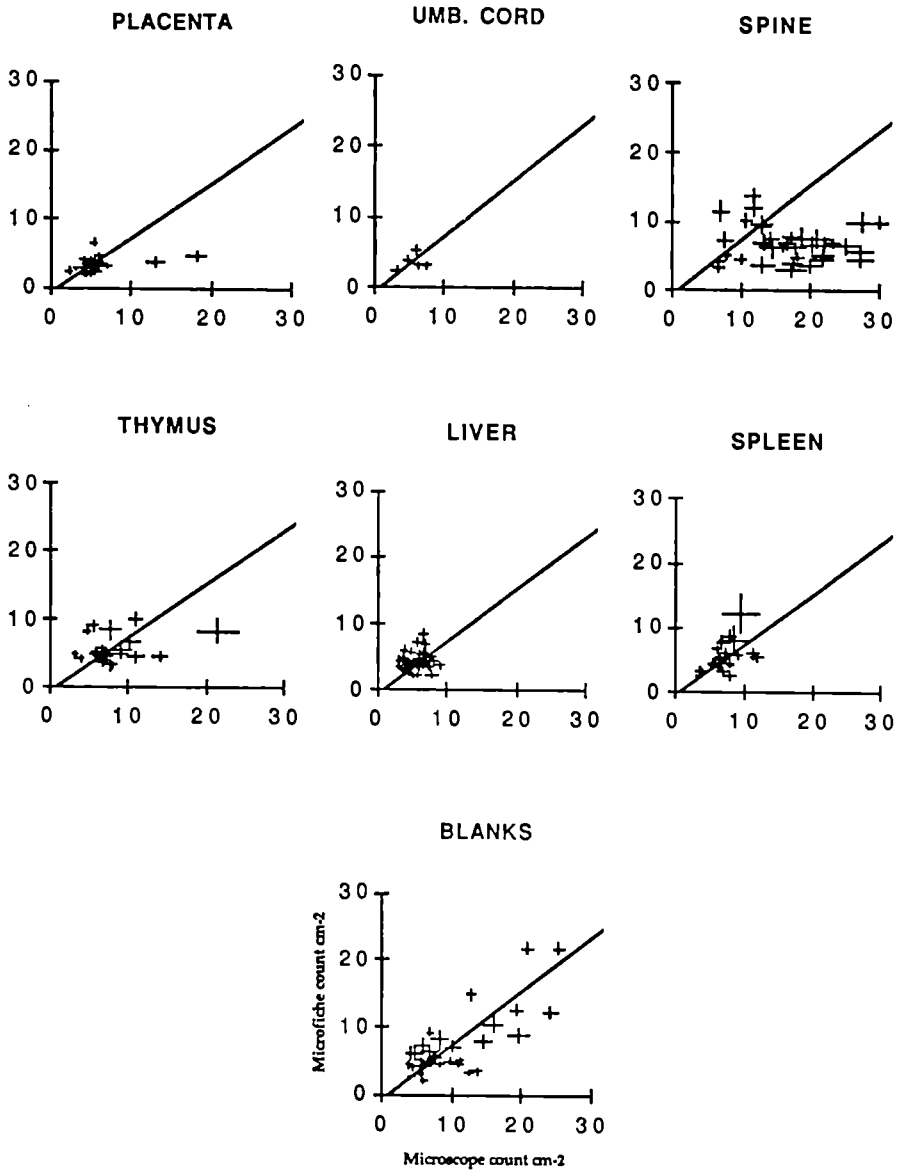

Figure 4 - Scatter diagrams comparing background pre-etch α-particle tracks with apparent event tracks.

Analysis of these very low levels of activity in small unconcentrated samples require manual scanning of the autoradiographs. This remains a lengthy procedure. For example, a sample spread across a TASTRAK (CR-39) plate of area 36 cm^2 will take between one and two days to scan. In the case of the soft tissues we aim to maximise the area of spread as this is proportional to the resolution attainable. In all cases at least two plates per sample are used, one either side, and in several cases the size of sample available provides four plates. The area per plate for fetal vertebrae is lower, around 10 cm^2 per plate.

3. Results

A detection limit for each autoradiograph has been obtained using the above procedure and found to lie in the range 30-70mBq.kg^{-1}. Activity has been measured in fetal vertebrae and values range from the detection limit to 0.45 Bq.kg^{-1}. These are shown in figure 5 where the activity on the outer vertebral surface (OS) appears to be slightly higher than on the inner surface (IS). Two corrections need to be applied to these data if we assume that it is ^{210}Pb and not ^{210}Po that is transferred to the fetus: (i) for ingrowth of ^{210}Po form ^{210}Pb in the autoradiograph itself and (ii) for ingrowth of ^{210}Po in the fetus itself. The latter is difficult to assess but one approach is to assume that ^{210}Pb is transferred to the fetus at a rate proportional to that for calcium from the mother's skeleton. Details of these corrections have not yet been worked out, but provisional estimates suggest fetal activities of approximately 25% of the values in figure 5.
We have also determined the level of ^{226}Ra in fetal spine with provisional values ranging from the detection limit (≈8mBq.kg^{-1}) up to 41 mBq.kg^{-1}.

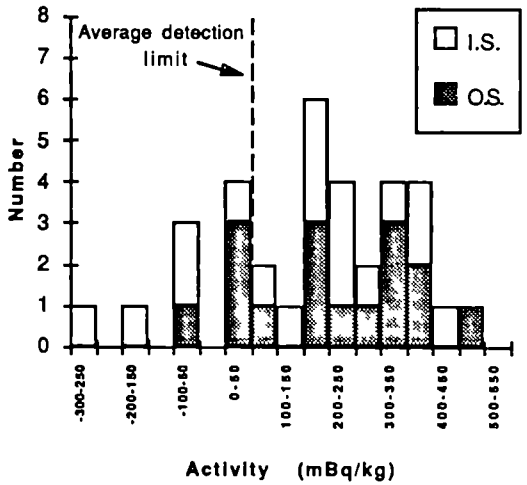

Figure 5 - Total activity on α-autoradiographs of fetal vertebrae

The analysis of a set of samples completed in December 1991 revealed that the level of α-activity from ^{210}Po in fetal spine appeared to show an association with distance of mothers residence from the sea at Avonmouth on the Severn Estuary. In figure 6 the p-value is 0.01 when all the data are included and 0.05 when the values below detection threshold are

excluded. An association of leukaemia incidence with estuaries has been shown by Alexander *et al* (1990) and the same authors (1991) have shown evidence of an increased solid tumour risk close to a tin smelter associated with the emission of ^{210}Po, in Capper Pass near Kingston-upon-Hull. Several industries exist at Avonmouth including a zinc smelter. Pollution in the area is being investigated and it will be interesting to see whether the association persists in further data.

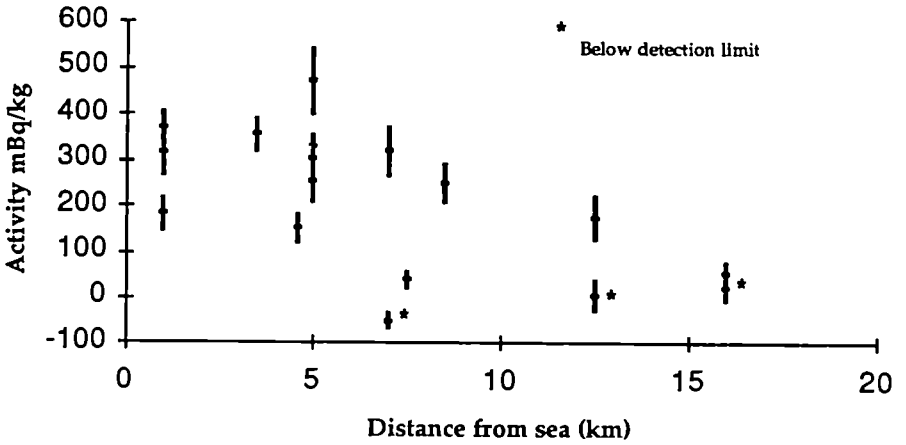

Figure 6 - Fetal vertebral activity vs. distance from sea of mother's residence

During the period from January 1st 1992 to June 30th tissues from 12 further cases have been analysed but the analyses have not yet been carried through to the complete stage of the data shown in figure 5 and figure 6. For the Bristol cases, although we have obtained the current address of the mother we have yet to get full information of the address during the pregnancy. In addition although the manual microscope scanning has been carried out, the microfiche analysis, for local background, is not complete on some of these cases as this involves a second stage of manual analysis.

Accordingly, figure 7 shows a histogram of activities in fetal bone for all cases for which the microscope scanning is complete. Some values are therefore preliminary. The activity from the Kiev case (one case only: mother believed to be a former resident of Pripyat) is at the higher end of the distribution for Bristol samples.

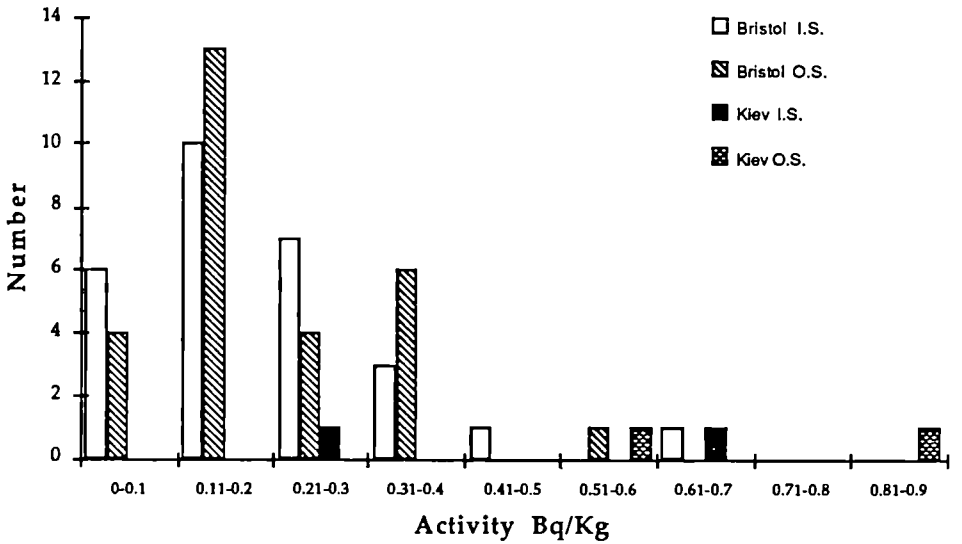

Figure 7 - Histogram of fetal activities in Bristol and Kiev samples: note that the Kiev values are all obtained from one case

4. Discussion

This remains an on-going project and further analysis of tissues is needed to establish both the activity levels in the fetus as a function of fetal age and the provisional findings of an apparent association between fetal skeletal activity and proximity to the Severn Estuary. Analysis of fetal tissues from around Chernobyl will be of interest in view of the possibility of detectable levels of plutonium being present. Separately it may be possible to analyse levels of caesium and strontium in these samples. Analysis of placentas may be impaired by the resolution attainable using track detection techniques. However, the level of ^{210}Po in placenta as a function of mothers smoking history is of interest and other techniques such as radiochemistry could usefully be employed on such determinations. A model of fetal transfer is being developed in this group and this will be extended in further work.

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2. Alexander FE, McKinney PA and Cartwright RA; *The pattern of childhood and related adult malignancies near Kingston-upon-Hull.* Journal of Public Health Medicine 1991, Vol. 13 No. 2. 96-100.

3. Henshaw DL, Heyward KJ, Thomas JP and Fews AP. *Comparison of the α-activity in the blood of smokers and non-smokers.* Nuclear tracks and Radiation Measurements.

Project 3

Head of project: *Dr. Coffigny*

Objectives for the reporting period

The aim of this project is to estimate the irradiation doses delivered to the embryo or the fetus after internal contamination by radionuclides. For that purpose, we determine a dose-effect relationship between the irradiation doses delivered by protracted external irradiation during the whole intra-uterine life and the biological effects measured on different radiosensitive target organs. Thus, the irradiation doses delivered after internal contamination could be estimated from the measurement of the induced biological effects.

The effects of protracted gamma or neutron irradiation during the whole gestation of rat were studied at short term (end of gestation), with the prenatal mortality and the body and the brain weights as parameters, and at long term (90 day-old) with the body, the brain and the gonads weights completed by the histology of both organs. In adult rats, the effects of protracted gamma and neutron irradiation on brain and gonads are compared as relevant biodosimeter.

Progress achieved

1. Methodology

Rats were irradiated from day 1 to day 21 of gestation (>23 hours per day). With the ^{60}Co gamma exposure the dose-rates were 0.03, 0.10, 0.25 and 0.375 Gy/day i.e. a cumulative dose of 0.60, 2.00, 5.00 and 7.50 Gy respectively. With the ^{252}Cf neutron exposure the dose-rates were 0.015, 0.03, 0.05, 0.10 and 0.15 Gy/day i.e a cumulative dose of 0.30, 0.60, 1.00, 2.00 and 3.00 Gy respectively.

For each experimental point, animals came from 3 litters or more. At the end of gestation, one part of pregnant rats were killed by an overdose of anesthetic. The mortality of embryos and fetuses was scored with a distinction between pre-implantation death (difference between the number of corpora lutea and the number of implantation points) and post-implantation death (difference between the number of living fetuses and the number of implantation points). Fetus and placenta were weighed and the whole head was immersed in 10% of Becker fixative after incision of the skull. After some days when tissues were hardened, the brain was dissected out and weighed before inclusion for histology.

In the long term study, the other part of pregnant rats were allowed to go to parturition. In 3 month-old females and males, the body, the cerebrum (forebrain + midbrain) and hindbrain were freshly weighed and the cerebrum was fixed for the histological study. The tissue sections were coloured with hematoxylin and eosin or with toluidine blue. Testis and ovary were weighed and fixed. Testis sections were coloured with hematoxylin and picro-indigo-carmin and ovary sections with hematoxylin and eosin.

2. Results

2.1 Early effects of protracted irradiations

2.1.1 Pre and post-implantation deaths

Pre-implantation deaths were not significantly increased by irradiations. Only post-implantation deaths were increased with irradiations (Table 1).

Table 1 - % of mortality on day 21 of gestation after protracted gamma or neutron irradiation during the whole gestation.

DOSE-RATES (Gy/day)	GAMMA	NEUTRON
0	10.7	10.7
0.015		16.5
0.03	16.0	5.7
0.05		39.3
0.10	13.5	36.0
0.15		73.7
0.25	19.6	
0.375	22.3	

2.1.2 Fetal and placenta weights

The body (Figure 1) and placenta weights decreased with increasing dose-rates or cumulative doses of gamma irradiation. With neutron irradiation, the values of body weight dropped with dose-rates higher than 0.03 Gy/day.

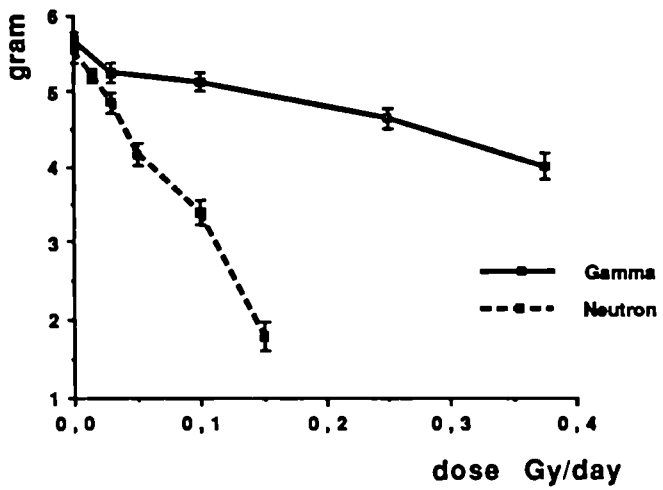

Figure 1 - Fetal body weights after different protracted gamma or neutron irradiations

2.1.3 Fetal brain weight and histology

The fetal brain weight followed the same pattern as the body weight after irradiations. No gross malformation was observed on brain sections.

2.2 Late effects of protracted irradiations

2.2.1 Body weight

In gamma irradiated rats, the body weights were not significantly different from the control ones except with 0.37 Gy/day. In neutron irradiated males, the body weights dropped with dose-rates higher than 0.05 Gy/day (Figure 2) but in females this decrease was less important.

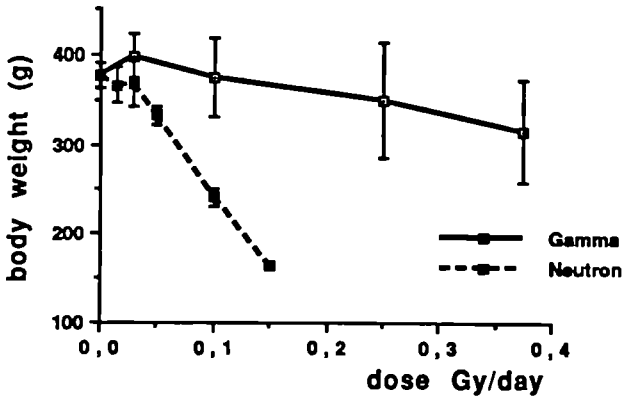

Figure 2 - Adult males body weights after different protracted gamma or neutron irradiations

2.2.2 Brain weight and histology

Females and males cerebrum weights decreased with increasing doses and dose-rates of gamma irradiation. The decrease was more important in neutron irradiated animals with as little as 0.015 Gy/day in females (Figure 3B) and 0.03 Gy/day in males (Figure 3A). But the relative cerebrum weights were similarly reduced with both irradiations. The relative hindbrain weights were normal in gamma and neutron irradiated animals.
No gross malformation was observed in brains.

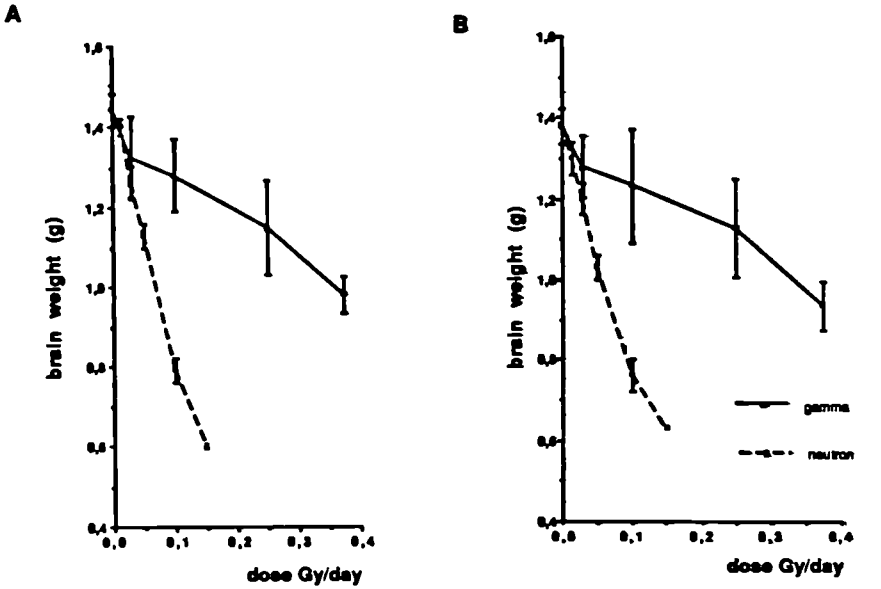

Figure 3 - Male (A) and female (B) adult cerebrum weights after different protracted gamma or neutron irradiations

2.2.3 Gonad weights and histology

Testis

Significant testis weight decrease was observed with the lowest dose of neutron exposure (0.015 Gy/day) and only from 0.10 Gy/day gamma rays onwards. The drop of weight was so important that with 0.10 Gy/day of both kind of exposure, testis was free of germ cells and no more very radiosensible cells were present. As suggested by weight pattern, higher dose of neutron killed supporting cells involving extra-weight decrease in comparison with the gamma exposure decrease.

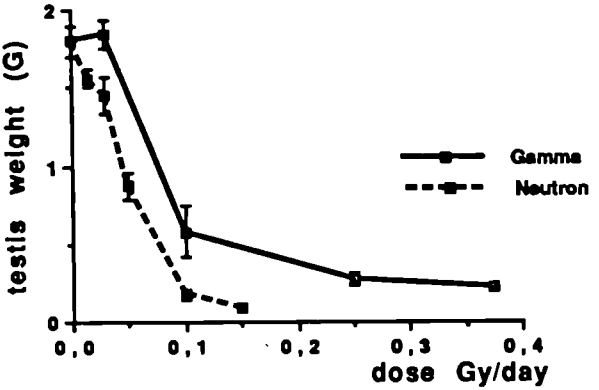

Figure 4 - Testis weight after different protracted gamma or neutron irradiations

Ovary

Ovary weight clearly decreased with dose as low as 0.10 Gy/day gamma rays or 0.05 Gy/day neutron (figure 4). However, with 0.10 Gy/day neutron or 0.25 and 0.37 Gy/day gamma rays no follicule was observed in ovary.

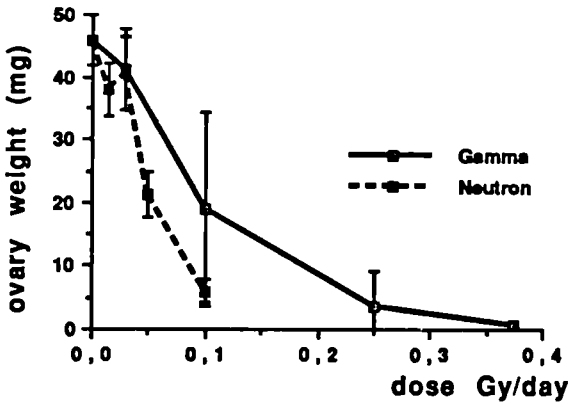

Figure 5 - Ovary weight after different protracted gamma or neutron irradiations

3. Discussion

All studied parameters indicate a good dose-effect relationship which allows estimation of irradiation dose received during fetal radionuclides contamination. Fetal body weight is a sensitive parameter during the whole intra-uterine life but this is no more verified in adult after growth compensation in gamma irradiated animals. Conversely, cerebrum weight is a more accurate parameter in the logn term study specially with the highest doses. However, this model is limited by animals survival. The germ cells in gonads are easily killed but no more sensitive cells are present to allow for measurement of doses and dose-rates beyond 0.10 Gy/day. The brain and gonad parameters are working only during organs development in the second half of gestation. Conversely, fetal body weight and mortality are of interest to estimate radiation dose received during the whole gestation.

The ^{252}Cf neutron exposures are more effective than gamma rays. The RBE value is different with the end-point studied. This value was 6 with prenatal mortality (dose-rate of 0.15 Gy/day) and fetal body weight, and 4 with adult cerebrum weight as targets.

The linear aspect of dose-effect curves indicates no dose-rate effect in the range of dose-rates compatible with the animal survival. The no linear aspect of gonad curves with dose-rate beyond 0.10 Gy/day is the consequence of killing a second cell population, the supporting cells, when no germ cells are surviving.

4. Conclusion

The prenatal mortality and fetal body weight (early effect) are good parameters to estimate the dose of exposure received during the whole intra-uterine life. The RBE value is 6.

The gonad weight and histology, and the cerebrum weight are the best parameters for the long term effect study. The RBE value is 4.

No dose-rate effect compatible with animals survival occurs with protracted gamma or neutron irradiation during gestation.

Other research group (s) collaborating actively on this project

Dr. J.D. Harrison, NRPB, UK
Dr. D.L. Henshaw, Bristol University, UK

Publications

Coffigny, H., Beauvallet, M., *Effects of gamma and neutron protracted irradiation during the whole gestation of rat. EULEP Newsletter*, 1992, 67, 24.

Coffigny, H., Beauvallet, M., *Effects of gamma and neutron protracted irradiation during the whole gestation of rat. 24th Annual Meeting of the European Society for Radiation Biology*, Erfurt, Germany, October 4-8, 1992.

III

RISKS AND MANAGEMENT OF RADIATION PROTECTION

Assessment of human exposure and risks

THE RISKS OF RADIATION WORK: ANALYSIS OF REGISTRY DATA

Contract Bi6-213 - Sector C11

1) *Stather*, NRPB

Summary of project global objectives and achievements

The UK's National Registry for Radiation Workers (NRRW) is a long-term epidemiological study of those exposed to ionising radiation in the course of their work and for whom radiation dose records are kept. Data from the NRRW are being analysed with the following aims.

(1) To determine whether there is any evidence of differences in the cause of and the age at death of workers exposed to different levels of radiation, and if any differences are found whether it seems likely that they can be attributed to radiation.

(2) If any differences are found which seem likely to be attributed to radiation, to estimate the magnitude of the risk.

(3) To estimate bounds to the possible risk for particular types of malignancy, such as leukaemia.

(4) To compare the mortality experience of radiation workers with national mortality data, and also that of other industrial groups for whom data exist.

Project 1

Head of project: *Dr. Stather*

Objectives for the reporting period

To perform the first analysis of the NRRW. To prepare a report describing the results of the analysis. To prepare a paper summarising the findings for publication in a refereed journal.

Progress achieved including publications

The first analysis of the NRRW has been completed, based on a cohort of 95,217 workers in the UK nuclear industry. The results have been published in the British Medical Journal, as well as an NRPB report (see Publications below). The following is an outline of the study results.

The population studied is summarised in Table 1. Rather more than 40,000 of the 95,000 participants have been included in other studies of radiation workers and these groups contribute two thirds of the collective dose and two thirds of the total of 6,660 deaths.

Standardised mortality ratios (SMRs) were calculated to compare the mortality of radiation workers with the general population of England and Wales. The SMR for all causes of death was 85, significantly below 100 at the 0.1% level. The SMR for all malignant neoplasms (86) was similarly below 100. This is a manisfestation of the expected Healthy Worker Effect. The main results from the test for trend with dose are shown in Table 2. For all known causes of death except cancers the excess relative risk is almost exactly zero. For all malignant neoplasms the estimated excess RR is above zero, although the excess does not reach statistical significance ($p = 0.10$). For all neoplasms of the haematopoietic system the estimated excess RR is positive but not significant ($p = 0.3$). For all leukaemias the excess RR is again positive and closer to statistical significance ($p = 0.10$). When attention is focused on leukaemias except CLL the positive excess RR reaches statistical significance ($p = 0.03$).

Projection models allow the values of excess relative risk to be extrapolated to lifetime risks for a working population. Table 3 shows lifetime risk estimates derived from the NRRW, the values recommended by ICRP, and data from a study of US nuclear workers. The ICRP values were derived by applying a DDREF (dose and dose rate effectiveness factor) of 2 to the Japanese atomic bomb survivor data. The American study did not find an association between radiation and either all cancers or leukaemias, although the statistical uncertainties are large. In fact, if the US data are pooled with the NRRW, the resulting risk estimates are very close to those of ICRP, though the confidence intervals are still wide. The lifetime risk estimate from the combined studies for all malignant neoplasms is 4.9% Sv^{-1} (90% CI < 0, 18) and for leukaemia 0.3% Sv^{-1} (< 0, 1.04). In view of the large statistical uncertainties there is presently insufficient evidence to require a revision of risk estimates.

Future analyses will include both longer follow-up and additional groups of radiation workers. These should provide more powerful evidence on the risks of occupational exposure to radiation.

Publications

1. G.M. Kendall and C.R. Muirhead. First analysis of the National Registry for Radiation Workers. Radiation Protection Bulletin 128 5-10 (1992).
2. G.M. Kendall, C.R. Muirhead, B.H. MacGibbon, J.A. O'Hagan, A.J. Conquest, A.A. Goodill, B.K. Butland, T.P. Fell, D.A. Jackson, M.A. Webb, R.G.E. Haylock, J.M. Thomas and T.J. Silk. Mortality and Occupational Exposure to Radiation: first analysis of the National Registry for Radiation Workers. British Medical Journal 304 220-225 (1992).
3. G.M. Kendall, C.R. Muirhead, B.H. MacGibbon, J.A. O'Hagan, A.J. Conquest, A.A. Goodill, B.K. Butland, T.P. Fell, D.A. Jackson, M.A. Webb, R.G.E. Haylock, J.M. Thomas and T.J. Silk. First analysis of the National Registry for Radiation Workers: Occupational exposure to ionising radiation and mortality. NRPB-R251. London, HMSO (1992).
4. G.M. Kendall, C.R. Muirhead and B.H. MacGibbon. Leukaemia risks: fact or fiction. Nuclear Engineering International 37 42-44 (1992).

Table 1 Study population by dose category and employer

	Number of workers		Collective Dose	Mean Dose
	Total	>100 mSv	man Sv	mSv
British Nuclear Fuels	25617	4847	1805	70.4
Ministry of Defence (MoD)				
- Atomic Weapons Establishment	10241	154	85	8.3
- Defence Radiological Protection Service	27246	876	381	14.0
Nuclear Electric	8199	480	198	24.1
UK Atomic Energy Authority	23914	1912	730	30.5
TOTAL	95217	8269	3198	33.6

Table 2 Results of selected tests for trend

	1-sided P-value	Excess RR, Sv^{-1} (90% CI)
All known causes except cancers	0.49	0.01 (-0.30, 0.36)
All malignant neoplasms	0.10	0.47 (-0.12, 1.20)
Lymphatic/haematopoietic	0.30	0.61 (-0.87, 3.43)
Leukaemia	0.10	2.29 (-0.32, 8.37)
Leukaemia (except CLL)	0.03	4.28 (0.40, 13.6)

Table 3 Lifetime Risk Estimates % Sv^{-1} (with 90%) CI) from Atomic Bomb Survivors, the NRRW and US Nuclear Workers

	ICRP	NRRW	US Workers†
All malignant neoplasms	4* (3, 5)	10 (< 0, 26)	< 0 (< 0, 8.2)
Leukaemia	0.4* (0.3, 0.55)	0.76 (0.07, 2.4)	< 0 (< 0, 0.60)

* Derived by applying a DDREF of 2 to the Japanese survivor data
† Gilbert et al (Radiat. Res., 1989)

STATISTICAL RESULTS OF THE PERSONAL DOSIMETRY SERVICE AT THE GSF

Contract Bi7-0053-D - Sector C11

1) *Regulla, Schraube* , GSF Neuherberg

Summary of project global objectives and achievements

The GSF Personal Dosimetry Service is the largest of the 5 official services in the FRG. Actually, up to 145.500 occupationally radiation exposed persons are monitored monthly by this service. The collected data basis is intended to be used for some studies on the dose distribution to the occupationally exposed population.

The first aim of the project is to indicate the trends in personal and collective doses on the available data base and to correlate it to the state structure (Bayern, Hessen, Baden-Württemberg and Schleswig-Holstein) and professional groups.

The second aim is to assess individual life time doses in view of the already implemented limits for the effective lifetime dose in the FRG.

Objectives for the reporting period

For a eleven years period, the dose data of the occupationally exposed people in 3 respectively 4 German states are analyzed with respect to the state where the workers are registerd and with respect to the professional grouping. In order to support the feasibility of the 400 mSv life time dose limit, a retrospective 7 years survey is made for a subgroup of persons for which all personal data are available and which are uninterruptedly surveyed by the GSF service.

Progress achieved

1. Trends in individual and collective dose

During the past 11 years the number of occuptionally exposed persons surveyed by the GSF personal dosimetry service increased steadily between 1980 to 1988 from 58.000 to 90.000 and in 1990 to 145.500 (in roughly 10.000 enterprises) because of the additional responsibility for a fourth German State. The relative portions of the main professional groups remained essentially constant.

It was observed that only between 15 and 20% of all persons received a dose of more than 0.1mSv at least once during one year. The resulting average annual dose in 1982 for these persons was for the workers in industry and research by a factor of 3 larger than for the workers in the medicine branch (fig. 1), but dropped to a factor 1.5 until 1990. Generally, the average dose decreased steadily since 1982 (with an exception in 1987) what may be attributed to an increasingly careful handling of radioactive sources and materials. Among those working in the medicine branch, the nuclear medicine subgroup received the relatively highest average dose during the past eleven years. But also here, a steadily decreasing radiation exposure is observed. In fig.2, the average annual doses over all professional groups are summarized with respect to the country in which the workers were registered. The dose distribution per country is influenced by the following circumstances: In Hessen, the comparably oldest power stations are situated and nuclear processing companies are present. In Bayern and Schleswig-Holstein there are a total of 8 power stations with a mean age of only 8 years, and no nuclear industry is present. It is observed that the pronounced differences between the countries in the early 1980s disappear in the late 1980s.

The collective doses in the German countries decreased sightly in the past 11 years and amounted in 1990 to approximately equally 14 manSv each in the countries Bayern and Baden-Württemberg, to 10 manSv in Hessen and to 2 manSv in Schleswig-Holstein.

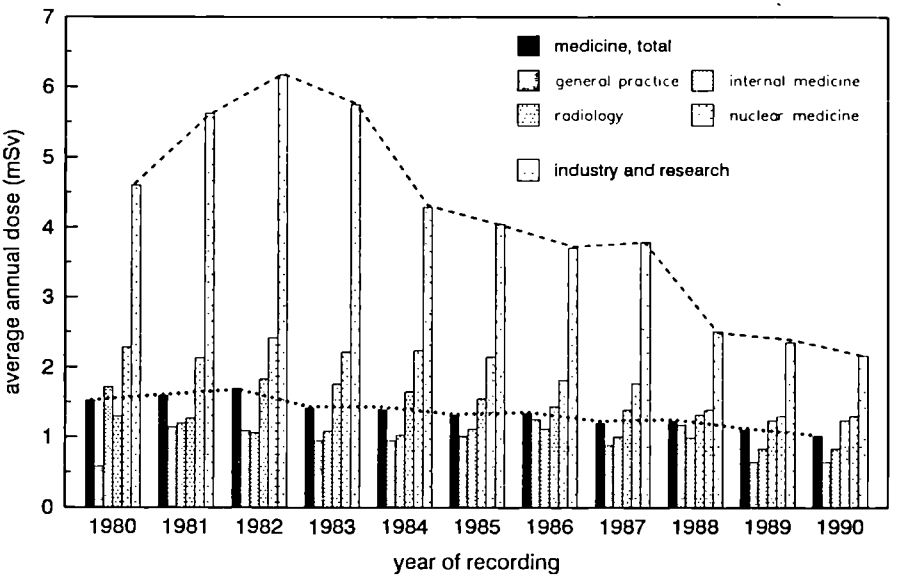

Fig.1: Average annual individual dose for all recorded values H>0.1mSv with respect to the main occupational groups "medicine" and "industry and research", and some subgroups

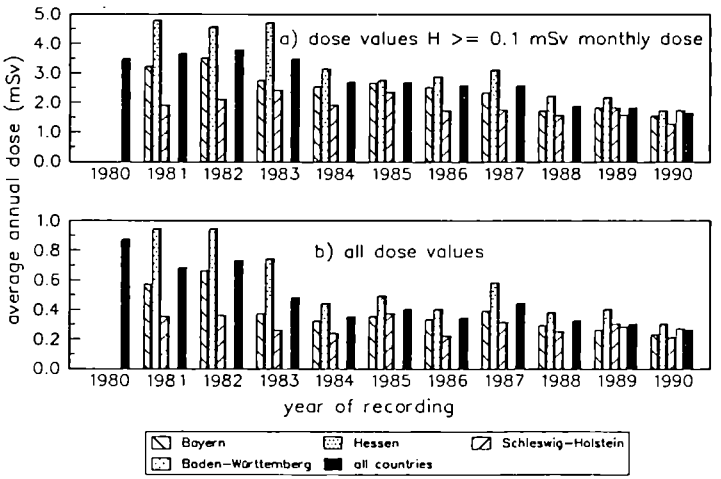

Fig.2: Average annual individual dose with respect to the country of registration

2. Individual life time dose

The individual life time dose in the Germany is limited to 400mSv, i.e., an average dose of 10mSv per year of occupation. The intention is to estimate whether this limit is followed taking into account the exposures in the past. The greatest problems are connected with the fact that i) by far not for all persons the date of birth is available, ii) a change of the place of occupation to another German country in which the GSF is not responsible, results in a loss of information to the GSF service on further doses received by the specific person.

Therefore, it is necessary to draw conclusions only from average statistical behaviours during a limited observation time. A number of 18.000 persons could be identified for which dose dose records were available without any time gap during a 7 years time period. At 43% of the persons of this group, the total recorded 7 years dose was $>=0.1$mSv, at 1.1% it was $>=70$mSv. 76% out of the latter number came from the nuclear power and processing branch, 6% from conventional industry and 17% from medicine. An important observation was that only exceptionally the 70mSv were due to a single exposure, in the most cases, however, due to a continuous dose collection. This means that already in advance to the introduction of the life time dose limit of 400mSv, the extrapolation of the individual annual dose does not exceed this limit.

Another important observation was that over the past 11 years period the relative number of all people which received an annual dose of 10mSv and more, decreased from 2% in 1980 to 0.33% in 1990, where 90% were employed in industry and 10% in medicine (fig.3).

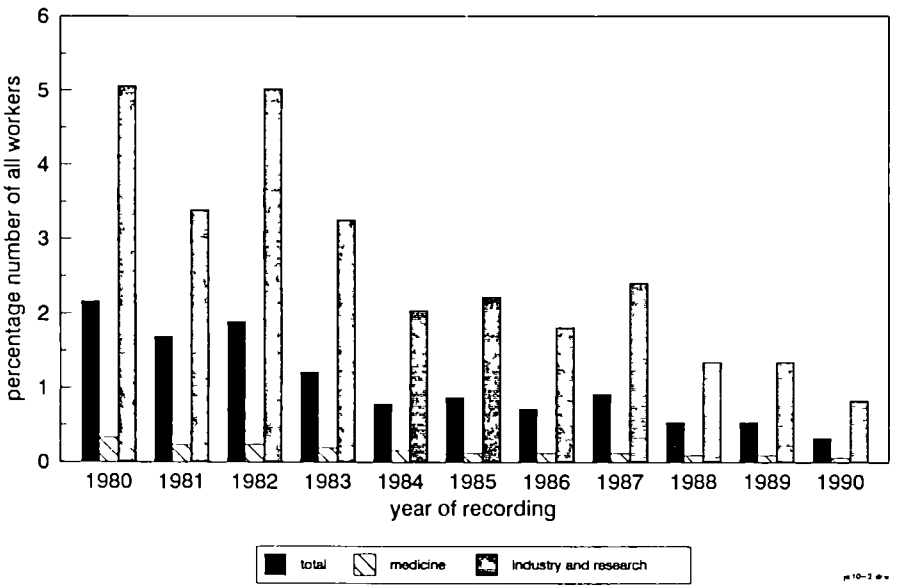

Fig.3: Relative number of all workers with average annual individual dose H > 10mSv

PROCEDURES TO ASSESS INTAKES OF RADIONUCLIDES FROM SAMPLES OF AIRBORNE RADIOACTIVITY AND STATISTICAL STUDIES OF RADIATION RISKS

Contract Bi6-116 - Sector C11

1) *Stather*, NRPB

Summary of project global objectives and achievements

See projects 1, 2, 3.

Project 1

Head of project: *J.W. Stather*

Objectives for the reporting period

To derive a model that will relate the effective dose equivalent received per unit exposure to radon in air to parameters including the unattached fraction of potential alpha-energy, the equilibrium factor, the aerosol size distribution, aerosol concentration, plate-out velocities and ventilation in both domestic and mine environments.

Progress achieved including publications

The dose equivalent rate to the basal cells of the skin due to the plate-out of radon daughters was calculated to be 2 μSv under specified standard environmental conditions: basal cell depth, 50 μm; radon concentration in air, 20 Bq m^{-3}; unattached fraction of polonium-218, 50%; indoor occupancy, 90%; no movement; no electrostatic fields. A number of parameters, having wide ranges of value, affect the dose to skin, the most important being radon gas concentration in air and electrostatic charge on the individual. The range of multiplying factors arising from known variability in the parameters is shown in Table 1.

Table 1

Multiplying factors modifying the dose to basal cells of skin from plate-out of radon daughters

Parameter	Range of multiplying factors
Depth of basal cells of the skin	0 to 2
Radon concentration in air	0.1 to 500
Aerosol conditions	0.1 to 2
Concentration of small ions in air	1 to 10
Air movement	1 to 10
Movement of individual	1 to 10
Electrostatic charge on person	1 to 200
Electrostatic charge on objects	0.5 to 10
Humidity	0.5 to 1

Although working with positively charged visual display units can, under certain circumstances, increase the dose to skin from plated out radon daughters, such increase is small compared to that caused by the parameters in Table 1.

A six channel, parallel, multi-screen diffusion battery, utilising silicon diffused junction detectors to detect alpha particle emissions from filters downstream from the screens, was designed and constructed at NRPB. This instrument has been used to determine the activity size distribution of the aerosol in the atmosphere of mines and homes to which radon (^{222}Rn) daughters are attached. The original diffusion battery has been modified so that it is capable of resolving the unattached fraction of radon daughters having diameters in the range 0.5-3 nm, and details of the modified instrument are given in Table 2. The diffusion battery has performed well in side-by-side intercomparisons with aerosol sizing equipment at the US Department of Energy's Environmental Measurements Laboratory, New York, in an intercomparison under realistic conditions in a mine at Limoge, France, and in a study at the University of Illinois at Urbana.

Table 2
Details of the NRPB six-channel parallel diffusion battery.

Channel	Mesh No.	Wire diameter (μm)	Solid fraction (%)	Number of screens
0	--	--	--	None
1	100	35	29	1
2	400	24	30	1
3	400	24	30	4
4	400	24	30	14
5	400	24	30	45

Figure 1 below shows a cross section through one channel of the diffusion battery.

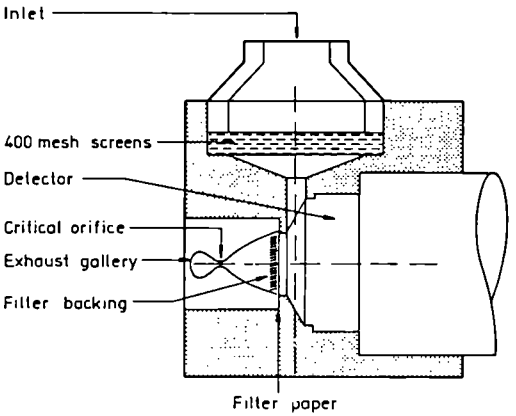

Figure 1. Cross section through one diffusion battery channel.

Previously reported measurements of unattached fraction of potential alpha energy concentration (PAEC), f_p, in homes using the diffusion battery have demonstrated values in the range 0.04 to 0.34. The results of measurements in a kitchen while cooking was in progress yielded a mode having an activity median diameter of 11 nm. Particles in this mode were classified as being unattached radon daughter. This is now recognised as being in error, unattached radon daughters being unlikely to exist in a form having diameters much in excess of 3 nm. The mode at activity sizes around 11 nm arises from cooking activities; further measurements have confirmed that in living rooms close to kitchens, a mode between 6 and 14 nm occurs during, and for some time after, cooking activities. In all cases the accumulation mode in the activity size distributions measured has a modal diameter in the range 110 nm to 130 nm.

Aerosol conditions in above ground workplaces such as schools are similar to those in homes. Limited data has been obtained on activity size distributions of radon daughters in mines. Whereas in homes, using currently accepted lung dosimetry models, it has been shown that average radon gas concentration is a better estimate of dose to lung than is measurement of average total PAEC, this is not the case in mines. In homes, factors affecting equilibrium factor, F, and unattached fraction, f_p, act in opposite senses so that increasing f_p, which would increase dose to lung, is offset by falling F, tending to reduce dose. In mines, because of high aerosol concentration, independent of varying ventilation conditions, f_p is always low, rarely exceeding 0.02. In homes an annual average radon concentration of 20 Bq m^{-3} results in an effective dose equivalent of 1 mSv.

When the ICRP Task Group on Lung Dosimetry finalises the new model to be used for radon daughter dosimetry, the results from the measurements made during this contract will be used to determine any concomitant changes in the relationship between radon gas concentration in indoor air and effective dose.

Publications

Miles J C H, Factors affecting skin doses due to radon daughters, NRPB-R197, HMSO, London,

Strong J C, The size of attached and unattached radon daughters in room air, J. Aerosol Sci., 19, 1327-1330, 1988

James A C, Strong J C, Cliff K D and Stranden E, The significance of equilibrium and attachment in radon daughter dosimetry, Radiation protection Dosimetry, 24, 451-455, 1988

Strong J C, Design of the NRPB activity size measuring system and results, Presented at the on workshop attached and unattached radon decay products, University of Illinois at Urbana, April 1989

Strong J C, The particle size distribution of Technegas and its influence on regional lung deposition, Nuclear Medicine Communications, 10, 425-430, 1989

Hopke P K, Ramamurthi M, Knutson E O, Tu K W, Scofield P, Holub R F, Cheng Y S, Su Y F, Winklmayr W, Strong J C, Solomon S, and Reineking A, The measurement of activity-weighted size distributions of radon progeny: methods and laboratory intercomparison studies, To be published in Health Physics.

Project 2

Head of project: *J.W. Stather*

Objectives for the reporting period

To measure the filtration efficiency of the human nose for sub-micron particles in the size range of the natural radon daughter aerosol and to establish a model to predict deposition as a function of particle size and flow rate. To determine the effect of airway dimensions on deposition and its dependence on age. To determine the sites and magnitudes of deposition within the nasal passages in order to assess doses to epithelial tissues.

Progress achieved including publications

The lung dose delivered following inhalation of radioactive aerosols is significantly affected by deposition of aerosols in the nasal and oral airways. In the case of doses due to radon daughters, the deposition may be different depending on whether the daughters are attached to natural aerosols. The efficiency of the human nose as a filter of small aerosol particles has been investigated using hollow anatomical casts. Penetration through the nasal airways has been measured using monodisperse sodium chloride particles and silver particles with diameters in the range 5 to 150 nanometres. A polydisperse condensation aerosol was generated from sodium chloride or silver using a tube furnace. The required particle sizes were selected with an electrostatic classifier (TSI, model 3071).

The average fractional penetrations of particles in the above size range were measured at flow rates of 5, 11.5 and 18 litres per minute and found to be 0.4 0.46 and 0.51, respectively. The results were compared with a deposition tube model and showed good agreement. With this model to represent penetration as a function of particle size, the equivalent diffusion diameter of unattached polonium-218 was found in these tests to be approximately 2 nm. It can be concluded that the fraction of unattached radon daughters that deposits in the human nose is approximately 0.5, with relatively little dependence on flow rate over the normal respiratory range. Likewise, it can be concluded that radon daughter activity carried by particles larger than about 10 nm diameter penetrates the nasal passages without loss. These experimental data are consistent with the single value of nasal deposition measured for 5 nm particles in human subjects by Schiller (PhD thesis, JW Goethe Universitat, Frankfurt 1985).

The experimental apparatus shown in Figure 1 was used with a thorium-228 source to expose a nasal cast to unattached lead-212 atoms. Exposures of several hours duration were carried out at three different flow rates to give about 150 kBq of deposited activity in each case. The distribution of lead-212 activity within the exposed cast was measured using a gamma camera at the Department of Nuclear Medicine, Radcliffe Infirmary, Oxford. The gamma camera image was divided into two fields of interest, corresponding to the anterior and posterior regions of the nose. These correspond to sites of deposition where material clears forwards to the nostrils and backwards to the pharynx. The proportion of activity deposited in the anterior region was found to have a constant value of about 65% for the three flow rates, 5, 12 and 19 1 min^{-1}.

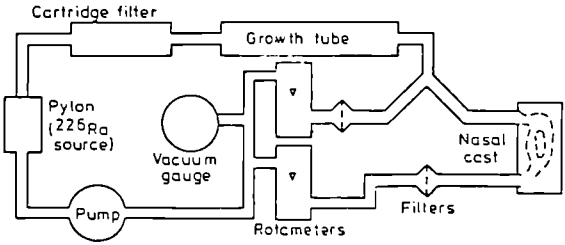

Figure 1: Schematic diagram of the apparatus used to measured penetration of unattached Po-218 through the nasal cast.

In order to investigate the deposition of unattached radon daughters in the nasal and oral airways in more detail, five plastic casts of human upper airways have been used. One was a cast from an adult at autopsy, and the others were fabricated from sheets of polymethyl methacrylate, the airway outlines having been obtained form nuclear magnetic resonance imaging (NMRI). Polonium-218 was generated by passing filtered air containing radon through a growth tube. Half of the air from the growth tube was passed through a reference filter, and half through a cast followed by an identical filter. The airflows were monitored using rotameters and vacuum gauges. Particle sizes were estimated by replacing the filters with a stainless steel mesh and filter, and measuring the deposition of particles on them. Comparison of the measured deposition with the expected deposition as a function of particle size allowed the polonium-218 aerosol size to be determined. The results of the measurements are shown in the table.

Cast	Flow, litre/m	Diameter, nm	Penetration,
NRMI Model, 2.5 year old, both nasal passages	4.9	1.25	25
	9	0.95	24
	18	0.85	28
NMRI model, 6 year old, both nasal passages	6.4	1.04	42
	9	0.95	37
NMRI model, adult A, both nasal passages	4	1.30	30
	10	0.96	37
	20	0.82	40
NMRI model, adult B, both nasal passages	4	1.30	30
	10	0.92	29
	20	0.80	29
Adult B, one nasal pas	19	0.92	37
NMRI model, adult B, mouth	4	1.28	50
	10	0.92	31
	20	0.79	50
Moulded cast, one nasal passage	5	1.40	36
	11	1.10	35
	18	1.10	39

The data show substantial deposition of unattached radon daughters in the human nasal and oral airways, which need to be taken into account when estimating radon daughter doses to the lower regions of the respiratory tract. The penetration through the oral cavity of the sectioned cast was similar to that through the nasal casts, implying that the lung dose from unattached radon daughters is not strongly dependent on the manner of breathing either by nose or mouth.

A recent development in the production of radioactive tagged submicron particles has been the introduction of the Technegas Generator (Tetley Technologies, New South Wales). This equipment has been designed to generate an aerosol suitable for lung ventilation studies using a gamma camera. For such studies, a proportion of the aerosol must deposit in deep lung, and for this to occur, the particle size must be in the submicron range. Early reports suggested that the particle size was between 5 and 10 nm diameter, an ideal size for studying the spatial deposition in a nasal cast. With the multichannel diffusion battery developed in Project 1 of this research contract, the Tc-99m aerosol size distribution was measured.

The results suggest that the size varies little with the period between generation and use: the AMD for all measurements was 140 nm on the average with a GSD of 1.5; it would appear therefore that this aerosol could only be of limited use in studying deposition in a nasal cast. A trial using the total radioactive aerosol was carried out with a gamma camera at the Royal Free Hospital in London. The images of the cast obtained were of very high quality and would allow the deposition sites for this size of aerosol to be determined. For this polydisperse aerosol, and an air flowrate of 10 litres per minute through the nasal cast, most of the activity was deposited in the inferior turbinate region with smaller fractions in the region of the nasal valve, middle turbinate, and nasopharynx. However, there seems to be no possibility of simple modification to the equipment which would alter the size distribution of the aerosol over the large range of particle sizes that are required (1 to 250 nm).

Publications

Strong, J C and Swift, D L. Deposition of "unattached" radon daughters in models of human nasal and oral airways. In Indoor radon and lung cancer: reality or myth? Proceedings of the 29th Hanford Symposium, 1990, Richland USA.

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James, A C and Roy, M. Dosimetric Lung Models. In: Age-related factors in radionuclide metabolism and dosimetry, ed. G B Gerber. 95-108. CEC, Brussels Martinus Nijhoff, Lancaster (1987).

Project 3

Head of project: *J.W. Stather*

Objectives for the reporting period

To develop the technique of alpha particle registration in CR 39 to the stage where it is suitable for routine assay of long lived alpha activity collected on personal air sampler filters.

Progress achieved including publications

Personal Air Samplers (PAS) are currently used for routine individual monitoring for workers who are risk of exceeding 30% of the annual limit on intake (ALI) of long-lived alpha-emitters. The activity on the filters is measured at present using alpha drawer counters. In monitoring chronic exposures to plutonium, however, the sensitivity of the technique is unsatisfactorily low: the minimum detectable activity is equivalent to about 0.1 ALI. The technique of alpha-track registration on CR-39 plastic has the potential for measuring significantly lower levels of activity and providing more information about the aerosols to which the activity is attached.

Personal air sampler filters used by staff working with uranium and plutonium at AWE Aldermaston were assayed by placing them in contact with CR-39 for several weeks, then etching the CR-39 in sodium hydroxide solution. Tracks were then visible under the microscope. It was demonstrated that low levels of activity on the filters could be detected by this technique. Some of the filters were remeasured using a surface barrier detector to assess their activity. It is estimated that the alpha autoradiography technique is at least five times more sensitive than the technique used routinely.

The PAS filter holder used at Aldermaston has a 6mm diameter inlet orifice. Aerosols of more than 400nm diameter tend to deposit near the centre of the 25mm diameter filter, while smaller aerosols deposit over the full area of the filter. The possibility of estimating the fraction of the aerosol greater than 400nm was investigated. Such knowledge would be useful in estimating lung doses.

It was shown that on most filters the track density within a 5mm radius of the centre of the autoradiograph was a factor of 10 or more greater than the track density elsewhere. This implies that most of the activity is attached to aerosols of 400nm or more in aerodynamic size. In some cases where an individual aerosol was sufficiently active, an identifiable cluster of tracks was formed on the autoradiograph. This was found only on autoradiographs of PAS filters from workers exposed to plutonium: those from workers exposed to uranium showed no clusters of tracks. In many cases the number of tracks in a cluster was too high to allow the tracks to be counted. The same filters were therefore re-assayed, this time with a 1.5mm spacer between each filter and the CR-39. Under these conditions, overlapping tracks were avoided, but it was still possible to identify individual active particles.

For autoradiography to be a practical alternative to electronic counting of alpha emissions from PAS filters, an automatic track counting system is required. To this end, tests were carried out on a Cytoscan 110 image analysis system developed by the Medical Research Council Population Cytogenetics Unit at Edinburgh, UK. Autoradiographs etched for different periods were examined, showing that the Cytoscan could identify and count tracks after a comparatively short etching time, 4 hours at 80°C in 20% NaOH. The use of short etching times is important to minimise problems caused by overlapping tracks in areas with more than 200 tracks per mm^2. A

short etching time also gives tracks with a large ratio between the lengths of the major and minor axes, thus allowing the image analyser to determine the direction of the major axis. When many tracks have originated from a single aerosol, the major axes of the tracks point to the centre of the cluster, so this technique may allow the position and activity of individual aerosol particles to be determined.

The Population Cytogenetics Unit at Edinburgh was contracted to develop software to enable the Cytoscan to automatically identify and record the position of each track on a detector, together with various other parameters such as area, grey level, lengths of perimeter and major and minor axes, and the direction of major axis. Three versions of the software were written and tested. The first version was found to operate unreliably on the NRPB Cytoscan hardware, but most of the operating faults were corrected in the second version. The software was tested on autoradiographs etched for various lengths of time and with a range of track densities. These tests demonstrated that the software could identify tracks correctly from their shape, even when they varied widely in size, and could record the required parameters of accepted tracks. Spurious images were rejected reliably.

Various difficulties with the technique remained, some of which were overcome in the third version of the software. Improvements were made to allow easier control of the parameters to be measured. A variable scanning rate could be set to allow for varying track densities and avoid data overflow at high densities. Data output from scanning was also modified to facilitate analysis of the data. These changes allowed some collection and analysis of data, but considerable difficulties remained. Automatic focus was unreliable and operation of the image analyser was slow and required understanding of the mode of operation of the Cytoscan. Minor operator errors and unidentified causes resulted in the system crashing, with loss of data and long delays. It was decided that the system was not suitable for routine use.

NRPB purchased a Quantimet 520 image analyser from Cambridge Instruments for other work on etched tracks, and the potential of this machine for analysing autoradiographs was investigated. It proved to be more suitable for the task on the Cytoscan. in particular because it could be controlled using a version of BASIC. Programs for analysis of autoradiographs could be written and modified by NRPB staff, resulting in much better progress. Subsequent analysis in this report is based on Quantimet results.

In order to allow clusters of tracks to be investigated in more detail, artificial clusters were created using an americium-241 alpha particle source. The source was masked using a 0.1mm thick foil with a 0.5mm hole. Exposures were carried out with a spacer between the source and the CR 39, as before. Studies of the spread of tracks as a function of spacer thickness showed that a 0.7mm spacer was sufficient to avoid overlapping without spreading the tracks too much.

Autoradiographs were made with different exposure times of the americium source to determine whether tracks could be identified as belonging to a cluster, so that the activity of individual aerosols could be determined. For each track on an autoradiograph its x and y coordinates, area, roundness and angles of minimum and maximum width (feret angles) were determined. Analysis showed that, as expected, tracks close to the centre of a cluster were round, and tracks around the edges of clusters were elongated. The minimum feret angle was found to be a more accurate guide to the direction of tracks than maximum feret angle. The minimum feret angles for tracks on the edge of a cluster were compared with the expected track angle determined by transforming the x, y coordinates of tracks to polar coordinates centred on the cluster. The results showed that although there was a broad correlation, individual tracks may have minimum feret angles reported that would be of little use in determining whether it was a member of a cluster.

A notable feature of the results was that an order of magnitude more tracks were reported at 0° or 90° feret angle than at other angles, although the tracks were randomly distributed. This is probably caused in part by the fact that the image is analysed on the basis of square pixels, which have their smallest dimension at 0° or 90°. The effect might be reduced by using a greater magnification, but this would cause difficulties in maintaining focus and would greatly extend counting times.

The conclusions of the project may therefore be summarised as follows:

1 Autoradiography of PAS filters could provide a sensitivity at least a factor of five greater than present counting techniques.

2 Activity attached to aerosols of greater than 400mm could be assessed separately.

3 The dynamic range of the technique is limited by tracks overlapping in the centre of the autoradiograph on high activity samples. These could be remeasured by exposing them to CR-39 for a shorter period.

4 Even with automatic image analysis, however, the technique is considerably more labour-intensive than present counting techniques.

5 Clusters of tracks are difficult to identify among evenly spread tracks unless there is a large difference in track density.

6 Quality control of etched-track counting (in particular when high magnification makes automatic focusing difficult) would pose significant problems for the technique.

7 The technique entails a delay of several weeks before obtaining a result.

8 Although autoradiography of PAS filters provides useful extra information, its drawbacks make it unsuitable for routine use.

Publications

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RADON SOURCES AND MODELS (NRPB ASSOCIATION)

Contract Bi6-347f - Sector C12

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3) *Damkjær*, Univ. Denmark-Tech - 4) *Majborn* , Risoe National Laboratory
5) *Wouters* , CSTC/WTCB - 6) *de Jong* , TNO-Arnhem
7) *Ball* , NERC (BGS) - 8) *Hubbard/Enflo* , Nat. Inst. of Rad. Protec. (SSI)
9) *Proukakis* , Univ. Athens - School of Medicine

Summary of project global objectives and achievements

Global Objectives

To develop and test techniques for identifying areas with a potential for high radon concentrations in homes, both on a large scale and for individual building sites.

To improve the understanding of, and develop mathematical models of, the movement of radon from the ground to sub-floor spaces and into buildings.

To develop and test countermeasures against radon in homes using laboratory and field studies.

Global achievements

NRPB has studied the effectiveness of practical radon remedial measures in 150 homes. Measurements were made for three-month periods in two locations in each homes before and after installation of remedial measures. The results were corrected for seasonal variations to estimate the reduction in annual average radon concentration in each home resulting from countermeasures. The countermeasures adopted were classified according to householders' replies to questionnaires. The study showed that subfloor depressurisation was the most effective and reliable radon reduction technique, generally reducing radon levels by an order of magnitude. The next most effective technique was positive ventilation, if applied in homes with limited natural ventilation. NRPB also assisted NERC in mapping the potential for high radon concentrations in homes.

KVI has constructed and tested a laboratory facility to measure radon transport in soil as a function of soil parameters. A cylindrical vessel 2m high and 2m in diameter was designed and constructed. A sand of uniform grain size was chosen for filling the vessel because of its sharp transition from saturated to dry conditions. In order to monitor conditions in the vessel a multifunctional probe was designed in collaboration with the Technical University of Denmark. Codes developed at CSTC and at KVI were used to calculate shape factors for the probe for use in air pressure and air flow measurements under different conditions. The vessel was gradually filled with sand with dummy probes in place. After overcoming difficulties over the insertion of vertical probes, tests were carried out indicating that the inhomogeneity of the sand was small. Initial measurements of radon concentrations in the vessel give results higher than expected, possibly due to dependence of emanation rate on humidity.

The Technical University of Denmark has developed a technique for radon source mapping of small areas. A set of drilling tools to allow sampling and measurements to depths of 5 metres has been designed and manufactured. A permeability probe suitable for measurements in soil has been designed in collaboration with KVI. A calibration of the probe has been carried out in dry sand and compared with the results of calculations by CSTC, showing good agreement between measurement and calculation. Two test areas were mapped: the Risoe test site and the site of one of the SSI test houses. The results of measurements in 29 boreholes showed that the Risoe site, with mixed moraine deposits, had permeabilities varying over four orders of magnitude. The SSI site, on the edge of an esker, displayed high permeabilities on the side towards the esker and low permeabilities associated with a clay layer on the other side. Etched track detectors were applied to the measurement of radon emanation from soil samples and to in-situ measurements of radon concentrations in boreholes.

Risoe has developed a numerical model of radon transport and entry and has established a test structure for experimental studies of radon transport under field conditions. The test structure consists of a 40 litre cylinder placed in an excavation 0.52 m deep. The dimensions of the structure were chosen on the basis of the results from initial calculations of soil gas flow by CSTC and by the Risoe Section for Mechanical Systems, both using commercial heat-transfer codes. The structure is fully instrumented including probes installed to allow the Technical University of Denmark to make in-situ permeability measurements. The model is a two-dimensional numerical model of the finite-difference type. It can be applied to the test structure, to real houses and to soil probes. Steady state experiments have been conducted at the test structure and the results compared with results from model calculations based on the measured soil parameters. The ability of the model to describe the combined diffusive and advective flow was verified. However, the results indicated that further work is needed to allow entry rates to be calculated where soils are inhomogeneous.

CSTC has applied a three-dimensional finite difference code to model soil gas movement and to predict the performance of radon remedial measures. Calculations with this model can take into account indoor-outdoor pressure differences, joints and cracks in the floor, permeabilities of soils and building materials, and the presence of countermeasures. The code calculates pressure fields and flow rates. Calculations on the experimental configurations of KVI, Risoe and the Technical University of Denmark were performed, and used for different purposes by these institutes, demonstrating the utility of the model. CSTC also used a multi-compartment model to calculate interzone airflows and radon concentrations in real buildings. Practical radon countermeasures were studied for use in a school with high radon levels. Following tests, mechanical ventilation systems producing an overpressure were installed in two classrooms, achieving a substantial radon reduction. In a second school, sealing of soil gas entry routes and improved ventilation under floors was sufficient to reduce radon concentrations.

TNO has developed a mathematical model with four sub-modules dealing with radon entry from soil, exhalation of construction materials, air infiltration and transport, and calculation of doses to individuals. The model divides both the house and the soil into different compartments, each with its own values for the relevant parameters. This allows inhomogeneities, including water content of the soil, to be taken into account. Calculations

have shown that the variation of exhalation rate with soil permeability is limited owing to depletion of radon in soil gas at high permeabilities. Results from the model were compared with data from the KVI test house. This shows that although the agreement was good for much of the time, at other times significant discrepancies occurred. Planned practical work by TNO on a radon test facility was not completed because the laboratory was moved to a different site during the contract period. The opportunity was taken to refine the design of the test facility.

In order to develop radon potential mapping techniques, the geology of two areas of the UK was studied in detail by NERC and compared with results of NRPB measurements in homes. One of the areas chosen was underlain by Carboniferous Limestone, Mudstone and other rocks, while the other was underlain by Hercynian Granite intruded into Carboniferous and Permo-Triassic rocks. Detailed measurements were made of radon in soil gas, gamma ray spectra and uranium and radium levels in soils. In both areas there were statistically significant correlations between lithology and radon in soil gas, and between radon in soil gas and radon in homes. The best geological predictor of radon in homes was radon in soil gas. Reliance on other suggested parameters, such as the distribution of uranium in rock, soil and alluvium can give rise to erroneous conclusions, since high values of radon in soil gas and dwellings have been observed over rocks with low uranium abundances.

SSI collected and analysed data from two research houses which were instrumented to allow the factors that determine radon concentrations to be monitored. Initial modelling and analysis was carried out on one of the houses, with a suspended wooden floor and an internal structure which can be treated as a single air zone. In order to examine the effects of temperature differences in detail, analysis was confined to data from days with little or no wind. In winter the temperature differences between indoors and outdoors caused two competing effects: an increased flow of soil gas, high in radon, and an increased flow of outdoor air, low in radon. In addition the stack effect caused mixing of the indoor air. In both of the research houses the balance of these effects led to lower indoor radon concentrations at large indoor/outdoor temperature differences. An airflow model based on these effects has been used to predict radon concentrations. In periods with little wind the modelled radon concentration is in close agreement with the measured values.

The University of Athens has surveyed radon levels in Greek homes using etched track detectors and compared the results with radium-226 concentrations in surface soil. The correlation coefficient found was 0.38. The area with the highest radon levels in homes was found to be northern Greece, with a mean of about 200 Bq m^{-3}. In order to reduce errors and allow more rapid assessments, an automatic image analyser has been installed to count etched tracks. The University of Athens detectors have been calibrated by NRPB.

Project 1

Head of project: *J.C.H. Miles*

Objectives for the reporting period

To investigate the effectiveness and durability of practical radon remedial measures in existing homes and preventive measures in new homes. To assist the British Geological Survey (NERC) in the development of radon potential mapping, using data on geology, radon and other isotopes in soil, and radon in homes and mines.

Progress achieved including publications

Following radon measurements by NRPB in about 100,000 homes in the UK, some 14,000 householders have been informed that the radon level in their home exceeds the UK Action Level of 200 Bq m^{-3}. They were advised that they should take remedial action and given a booklet explaining the various radon reduction techniques. Householders in 143 homes with particularly high radon levels were referred to the Building Research Establishment (BRE) for individual advice on radon reduction techniques. So far about 500 householders are known to have had remedial measures installed.

Where remedial work has been completed and the householder requests it, NRPB has provided follow-up monitoring of radon levels to determine how effective the remedial work has been. In general, follow-up monitoring is provided only where the remedial action taken is considered to be likely to produce a significant and sustainable reduction in radon levels; simply opening windows more frequently, for example, is not regarded as a sustainable means of reducing radon levels. The radon monitoring follows the same procedure as used initially to assess whether homes are above the Action Level. Two etched track detectors are exposed for three-months, one in the living area and one in an occupied bedroom, and the results corrected to account for the season of exposure. At present there are 340 homes for which NRPB has provided follow-up monitors, and results are available for 154.

Six main radon remedial techniques have been used, sometimes in combination:

1. Subfloor depressurisation (usually under concrete-on-ground floors) is effected by excavating a cavity or sump beneath the floor to which is connected a pipe and in-line fan, the exhaust of the fan being discharged to the atmosphere outside the building.

2. Whole house positive ventilation is usually achieved by installing a fan in the roof space so as to draw air from the loft and, after filtering, pass the air into the living space. These units have been marketed in the UK for many years as a means of ameliorating problems with condensation in homes. The fan power is commonly 65 W, but this is not sufficient to reverse the pressure difference across the ground floor, except in unusual circumstances. The device will, however, reduce the underpressure in the house, so

reducing the amount of soil gas drawn in. It may also increase the ventilation rate somewhat and thus cause a reduction in radon concentration simply by dilution.

3. Increased natural ventilation of the void under suspended timber or concrete floors is achieved simply by increasing the number of air grilles in the walls surrounding the void. This is seldom sufficient to bring about a large reduction in radon levels: homes with suspended timber floors have proved more difficult to remedy than those with concrete-on-ground floors.

4. Mechanical ventilation of the void under suspended timber or concrete floors is generally required if reductions in radon levels greater than a factor of three are necessary. This should be designed to provide a uniform flow of air across the sub-floor space with no dead spaces.

5. Sealing of cracks in solid floors and of gaps around service entries can be moderately effective, but it is labour-intensive and hence costly when carried out by contractors. Most contractors seal only readily accessible cracks and gaps, before installing one of the other methods as the main remedy; we know of no case of a contractor attempting sealing alone as a remedy. Extensive sealing is the first choice of the enthusiastic do-it-yourself householder.

6. Suspended timber floors may be sealed by covering them with a membrane of polythene or similar material. This has been done in 13 cases reported here, but such action is no longer advocated as there is a possibility of altering the moisture condition of the timbers so as to be conducive to dry rot.

Householders were provided with a questionnaire to identify the remedial techniques they had applied. The replies were entered in a database together with information on house type and results of radon measurements before and after remediation. Analysis of the results shows the effectiveness of the different techniques (see Table 1). The radon reduction ratio is the ratio of the best estimate of the annual average radon level in the home before remedial work was undertaken, to that obtaining after the work was completed. In this table, arithmetic average and standard deviation and their geometric counterparts are given as in no category are the results represented well by a normal or lognormal distribution. The arithmetic average, however, is often distorted by a few very high values and the geometric mean is closer to the result most likely to be achieved. The 'other' category includes those where more than one method was applied, e.g. positive pressurisation and subfloor depressurisation, or positive pressurisation and increased natural ventilation of the underfloor void.

Table 1 shows that where the technique is appropriate, subfloor depressurisation is by far the most effective remedial measure, generally producing reductions by an order of magnitude or more. Passive techniques generally produce poor results with reductions less than a factor of two. Positive ventilation can produce significant reductions in radon concentrations, but it can only be effective in homes with limited natural ventilation. In order to test the long-term durability of these remedial measures, a programme of regular annual radon measurements is being carried out in selected houses.

Table 1. Radon reduction ratios for different methods of radon remediation.

METHOD	N	Arithmetic average	SD	GM	GSD	Range
Subfloor depressurisation	41	17	15	11	3.0	1.0 to 66
Positive ventilation	35	4.0	4.9	2.8	2.2	1.0 to 24
Natural ventilation of subfloor void	15	2.0	1.1	1.8	1.6	1.0 to 4.8
Mechanical ventilation of subfloor void	8	3.4	2.9	2.5	2.2	1.0 to 9.8
Sealing of cracks and service entries	19	2.1	1.4	1.7	1.8	1.0 to 5.7
Sealing of timber floor with membrane	13	2.5	1.8	2.1	1.9	1.0 to 6.6
Other	23					1.0 to 6.0

In order to assist NERC in mapping radon potential, a method was developed for transferring data on radon in homes in a way that preserves detailed geographical information (for correlation with geology) without compromising the confidentiality of the results. Data was transferred in this way for the area of Derbyshire under investigation by NERC. Later, 67,000 results of measurements in southwest England were transferred in 5 km grid square format. Various calibrations and radon measurements were also carried out to assist the NERC work.

Publications

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Cliff, KD and Stephen,R. The effectiveness of radon reduction techniques in UK houses. In preparation.

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Project 2

Head of project: *Dr. R.J. de Meijer*

Objectives for the reporting period

To construct and test a laboratory setup to measure, under controlled conditions, radon transport in soil as a function of soil parameters.

Progress achieved including publications

Prior to the submission of the proposal a first order design of the vessel was made at the KVI and offered for bids to industry since design and manufacturing of such a vessel were beyond the capacity of the KVI workshop. During the design stage several difficulties were encountered by the company that led to considerable delay and were finally solved with assistance of the design department of the KVI. For both parties the scheduled time was exceeded considerably. During the construction of the vessel some minor problems were encountered and solved. In April 1991 the vessel was tested and accepted at the company and transported to the KVI.

The 2m high, 2m diameter, cylindrical vessel is closed off with a lid. The lid is placed in a water lock and is adjustable in height. In the wall 14 entries are made for probes all pointing to the center of the vessel. The deviations from the desired positions is in the center in no case more than 0.5 cm. The positioning was obtained by design requirements on the accuracy in mounting the flanges in the wall of the vessel and by placing sleeves on the inside of the wall that can be slightly adjusted in position. The time that the vessel was designed and constructed was used to design the multi-functional probes in collaboration with A. Damkjaer from Lyngby. For the permeability measurements and the soil gas sampling a stainless steel mesh cylindrical air filter was chosen, manufactured at Fujiplate in Japan. Also here delay occurred because the set of filters had to be returned twice since they did not meet the specifled diameter; each manufacturing period lasted 8-10 weeks.

In collaboration with the department of Fysische Geografie and Bodemkunde (FGB) (department of soil sciences and hydrology), pressure transducers for measuring the capillary suction by the pores were ordered. In the testing it was found that the temperature drift of these transducers was larger than specified and not acceptable for our purposes. The transducers were sent back and the manufacturing of the new ones lasted 12 weeks, including testing. The new set of transducers met the specifications. A water pressure transducer of a different type, to be used for measuring the water level in the vessel, was tested and recalibrated . The water level can be determined with a precision of approximately 1 cm, accurate enough for interpretation of measurements of radon profiles as a function of water level.

To reduce the number of parameters in our investigation the preference was for a soil with a sharp transition from totally saturated with water to arid. A soil type that is known to have such a small transition range is sand with a rather uniform grain-size distribution. Also for radon concentration profiles a measurable concentration of radon should be

present in the pores of the soil. This concentration may be estimated from the radium concentration, radon emanation factor, density and porosity of the soil.

To find a suitable soil type for the vessel experiments we measured the grain-size distribution, water-retention curve, porosity, hydraulic conductivity, intrinsic permeability, fraction organic matter, density, radium and thorium content, and radon and thoron emanation factor of various sand types. On basis of these measurements the choice was made for a classified filter sand from a commercial firm with a specified grain-size range of 0.25-0.50 mm. From these measurements it is clear that this filter sand indeed has a rather uniform grain-size distribution and a small transition range from "wet" to arid. The other measured parameters of the filter sand are compiled in Table 1. From these parameters it was estimated that in equilibrium the radon concentration in the air volume of the soil pores of the dry filter sand is approximately 700 Bq m^{-3}. This concentration is high enough to be accurately measured with conventional Lucas cells.

Table 1: Specifications of filter sand

porosity	0.36 ± 0.02
bulk dry density (Mg m^{-3})	1.76 ± 0.09
hydraulic conductivity (m^2 Pa^{-1} s^{-1})	(4.75 ± 0.12) 10^{-8}
intrinsic permeability (m^2)	(6.22 ± 0.16) 10^{-11}
fraction organic matter (%)	0.15 ± 0.01
radium content (Bq kg^{-1})	3.68 ± 0.13
thorium content (Bq kg^{-1})	3.3 ± 0.2
radon emanation factor	0.040 ± 0.019
thoron emanation factor	0.021 ± 0.007

Parallel to these measurements, air pressure and air flow measurements with and around the multi-functional probe positioned in a cylinder filled with the filter sand were performed. From these measurements the resistance of the sand around the probe was calculated as function of the diameter of the cylinder and the height of the sand. The shape factors of the different configurations were calculated both with a code developed at BBCI (Dr. P. Cohilis) and a code developed at KVI. From a comparison between the results of the calculations, it could be concluded that the two codes gave, within a few percent, the same result. Using these numerically calculated shape factors a linear relation that follows from theory was fitted to the measured resistances using the permeability of the sand as a free

parameter. From a comparison with the data shows that theory describes the data well except for the 12 cm diameter cylinder were a deviation of theory from measurement of 20% is found. The latter might be caused by a systematically more compact filling of the 12 cm diameter cylinder which seems not impossible considering the smaller diameter makes the cylinder more difficult accessible for filling. The intrinsic permeability of the filter sand that was calculated from the fit was $(7.2 \pm 0.3)\ 10^{-11}\ m^2$. For some of the cylinders a pressure field measurement was carried out and from this values of the intrinsic permeability of the sand were calculated that were within 15% of the previous found value. Finally we concluded that as the agreement between numerical calculations and measurements in the investigated cylindrical geometries of sand is fairly good, the same procedure can probably be applied to calculate the shape factors of the probes in the vessel geometry.

Approximating the cylindrical air filter of the probe by a rotational ellipsoid, we also calculated analytically both shape factors of the probes in the vessel geometry and pressure fields around them. From this approximate analysis it was found that for the probes at lower depths the shape factor is somewhat higher than for the deeper probes. For all probes the shape factor is estimated to be between 0.25 and 0.30 m. From the pressure field calculations it was estimated that in a permeability measurement the permeability of a spherical region with radius of approximately 20 cm around the center of the air filter is measured. Measurements were performed to experimentally determine the shape factors of the probes in the vessel geometry. The results of these measurements are presently analysed.

In September 1991 the vessel was filled with sand in steps of 10 to 15 cm layers each time compacted by bringing up the water level and subsequent draining. In this way it was hoped to obtain a uniform sand body in the vessel. Before reaching the level at which the probes are to be inserted a sleeve containing a dummy probe was mounted. This dummy closed off the sleeve such that water was not running out of the vessel.

At several levels of filling pressure field measurements were carried out to check the homogeneity of the distribution of the sand. After complete filling of the tank it was noticed that the sand had become too compact to manually insert a vertical pressure probe to the bottom and that even replacing the dummy probes by real ones caused difficulties. The latter problem was solved by drilling holes in the sand with a diameter somewhat smaller than the probes. The first problem was more complex. After making a construction to gently hammer the vertical probe into the sand it was found that irregular and irreproducible pressure profiles were measured. These irregularities could be traced to blocking of the small openings in the probe head by sand grains and were eventually solved by inserting the vertical probes while forcing air through the probe into the sand.

The pressure field measurements indicate that the inhomogeneity of the sand is small. Hence we conclude that we were successful in setting up a laboratory setup that will allow to study radon transport in soil under well controlled conditions. The various aspects of the properties of the vessel, the instrumentation, and the properties of the sand were documented in six Technical Documents. The first preparatory measurements of radon concentrations in soil gas have been started and indicate that these concentrations are somewhat higher than expected from the dried sand. This result indicates that parallel to the measurements in the vessel a study has to be made of the humidity dependence of radon emanation in the sand.

These measurements together with a measurement of the time dependent ingrowth of radon in soil gas are the first steps that will be undertaken in the continuation of this project.

Parallel to the instrumental development and preliminary measurements computer codes were written and tested. As mentioned above a code for pressure field calculations was written and compared to the one of BBCI. From Rogers and Associates Engineering Corporation (RAEC) in Salt Lake City, USA, a one-dimensional code for radon transport (RAETRAN) was obtained. This programme was modified by us to accommodate the boundary conditions in the vessel. This programme and its 3-D successor, presently being developed by RAEC, will be validated in the proposed continuation of the project.

Publications and reports covering work of the reporting period

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van der Graaf, E.R., Heijs, S., de Meijer, R.J., Put, L.W., and Mulder, H.F.H.M., *A facility to study the transport of radon in soil under controlled conditions,* Presented at the "Fifth Int. Symp. on the Natural Radiation Environment", September 22-28, 1991, Salzburg, Austria, accepted for publication in Radiat. Prot. Dosim.

van der Graaf, E.R., de Meijer, R.J., *Calibration, stability at room temperature and temperature drift of a* water *pressure transducer used for measuring the water level in the radon vessel,* KVI internal report Tech. Doc. KVI/RV-01, May 1992.

van der Graaf, E.R., de Meijer, R.J., *Calibration, stability at room temperature and temperature drift of ten miniature water pressure transducers used for measuring pore water content of the sand in the radon vessel,* KVI internal report Tech. Doc. KVI/RV-02, May 1992.

van der Graaf, E.R., de Meijer, R.J., *Orientation of the radon vessel and determination of the positions of the multi-functional measuring probes,* KVI internal report Tech. Doc. KVI/RV-03, May 1992.

van der Graaf, E.R., Heijs, S., de Meijer, R.J., Put, L.W., Mulder, H.F.H.M., *The choice of soil type for radon vessel experiments,* KVI internal report Tech. Doc. KVI/RV-04, May 1992.

van der Graaf, E.R., Cohilis, P., ten Have, R., de Meijer, R.J., Stapel, K., *Pressure fields in sand,* KVI internal report Tech. Doc. KVI/RV-05, May 1992.

van der Graaf, E.R., de Meijer, R.J., *Calculation of shape factors of and pressure fields around an ellipsoidal permeability probe in some simple geometries,* KVI internal report Tech. Doc. KVI/RV-06, June 1992.

Project 3

Head of project: *A. Damkjær*

Objectives for the reporting period

To develop a technique for radon source characterisation of a local site. This includes the design of a small-diameter drilling and soil-sampling equipment and the construction and calibration of equipment for in-situ measurements of the gas permeability of soils. In addition the objective is to apply the track etch technique for radon emanation measurements of small soil samples, and for measurements of radon in soil gas.

The aim is to perform a comprehensive "radon source mapping" of the soil on one or more suitable test sites.

Progress achieved including publications

1. Drilling tools and techniques

A set of small-diameter drilling tools is designed and tested. It includes one 16 mm and two 20 mm spiral drills which are used for soft sediments, and two 20 mm widia bits for hardened or stony deposits. The drills are welded to 12 mm bore shafts. A set of extention rods allows for depths down to 5 metres. Two soil samplers, capable of removing 25 cm^3 samples of soft soil from depths down to 4 metres have been made. Accessories like chisel and hauling tools have proven indispensable.
The borehole is established with a hand held electrical drilling machine of heavy duty quality. Figures 1a to 1d show the sequence of operations used to place the permeability probe in the soil. The 20 mm borehole is supplied with 50 cm^3 bentonite/water jelly placed at the bottom (fig. 1a). The plastic casing tube closed with a piston at the front end is pressed into the borehole. This causes the bentonite to flow upwards between the casing and the soil, thus sealing this passage for any gas flow (fig. 1b). The piston is opend and removed. The 16 mm bit is lowered through the casing, and a hole for the probe head is drilled 17 cm beyond the casing tube (fig. 1c). The permeability probe is inserted through the casing and the probe head is positioned below the casing. Finally the passage between the casing and the probe shaft is closed above ground with a rubber collar (fig. 1d).
This procedure prevents any leakage along the probe shaft to the surface. It gives a high degree of mechanical protection to the probe head and a minimum disturbance to the strata in close vicinity of the measuring position.

2. Gas permeability of soils

A permeability probe is constructed and tested. The design was coordinated with KVI, The Netherlands, in order to facilitate comparative measurements. Figure 2 shows the probe head which consists of a perforated steel tube tightly wrapped with two layers of finely meshed stainless steel net. During operation air is injected through the hollow probe shaft into the probe head, from where it flows into the soil.

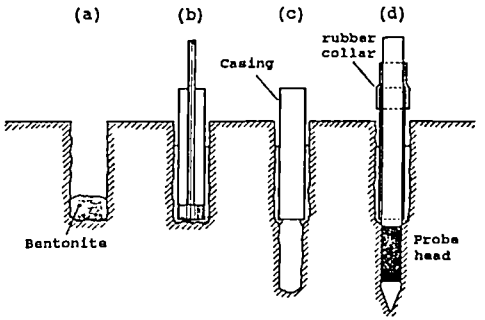

Figure 1 - Sequence of operations

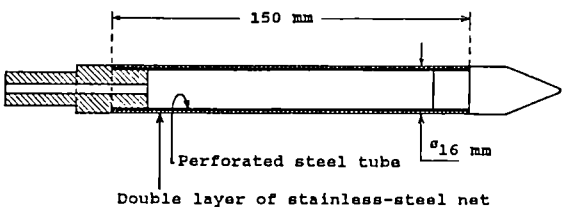

Figure 2 - Permeability probe

The associated instrumentation is mounted in a portable box. It contains an air pump, two flow monitors (Sierra's "Top=Track", 0-50 ml/min and 0-500 ml/min), and two manometers (Micatrone's MG-1000, 0-100 Pa and 0-1000 Pa). The permeability measurements are performed by recording the pressure difference between the probe head and the soil surface and the corresponding flow rate in a steady state situation. With the present probe head the instrumentation allows for a permeability measurements in the range from $2 \cdot 10^{-10}$ m^2 to $2 \cdot 10^{-15}$ m^2.
The permeability probe was calibrated in a 200 liter vessel filled with dry quartz sand of known permeability. The shape factor for the probe in the vessel was measured and the result compared to the theoretical shape factor calculated by CSTC, Belgium. The measured and the calculated shape factors were found

to agree, both yielding a shape factor equal to 87% of the theoretical shape factor for the probe buried at the same depth in a semi-infinite medium. The theoretical shape factor for the semi-infinite medium was therefore adopted as the shape factor to be used for the field measurements.

3. Radon emanation and radon in soil gas

A simple and efficient method for measurement of the radon emanation is developed. The technique is aimed at the small soil samples obtained during the drilling. The 50 gram sample is placed in a glass vial and covered with a diffusion membrane of PVC. The vial is placed in a 150 cm^3 autoclave with a track etch detector (Kodak LR 115 II) on the inside wall. A desiccant in the autoclave prevents water condensation on the track etch detector. After a growth period of 3 weeks the autoclave is opend and the track etch detector is developed and counted on an automatic track counter. The water content of the sample is determined by weighting and drying.

The track etch technique has also been considered for in-situ measurements of the radon concentration in soil gas. A small, open container, which fits into the borehole casing, has been made. The container is supplied with a track etch detector and a desiccant and the container is closed with a diffusion membrane. The container is placed at the bottom of the borehole and the casing is sealed imidiately above the container. After a few days the detector is removed and the exposure is determined.

4. Results and discussion

The techniques described above were used for radon source mappings of two test sites: One was the radon test facility at Risø National Laboratory, Denmark, the other was the site of one of the radon test houses of SSI, Sweden.
In the mapping of the Risø site, a total of 29 useable boreholes have been established and more than 90 soil samples were analyzed for geological composition and for radon emanation. The results show a site characterised by moraine deposits covered with 0.5 metre of soil of organic matters and sand. The moraine deposits exhibit a rather complex picture with mixed clay,silt, and sand deposits. The permeability of the soil have been measured in all the useable boreholes and values from 10^{-15} m^2 to $1.4 \cdot 10^{-11}$ m^2 were found. The pattern of permeability values agrees well with the geological analysis of the soil samples.
The radon concentration in the soil gas was measured with track etch detectors in a few of the boreholes. However, the sealing of the casing tube above the detector container appeared in some cases to be insufficient. This method of measuring the radon concentration in the soil gas therefore need more attention before it is operable.

The mapping of the SSI site, which is placed on the edge of an escher, involved the establishment of 5 boreholes, 4 of which were suitable for permeability measurements. A total of 19 soil

samples were analyzed for geological composition and for radon emanation. The results show that the half SW side of the test house foundation seems to be in direct contact with the high permeable ($k=7.2\cdot10^{-11}$ m^2) homogeneous sand/gravel deposits of the escher, while the other half NE side is more or less "closed" by a clay layer($k=1.2\cdot10^{-14}$ m^2), which here comes to the surface.

Publications

Damkjær, A., Korsbech, U. A Small-diameter Probe for In-situ Measurements of Gas Permeability of Soils. Fifth International Symposium on the Natural Radiation Environment, Salzburg, 22-28 September 1991. (To be published in Radiation Protection Dosimetry).

Korsbech, U., Damkjær, A. Radon-Geological Mapping of two Test Sites. Department of Electrophysics, Technical University of Denmark, R-65, May 1992.

Project 4

Head of project: *B. Majborn*

Objectives for the reporting period

- To develop a numerical model of radon transport in soil and entry into houses.
- To perform related experimental studies.
- To compare the experimental results with results of model calculations based on measured soil parameters.

The aim of the work is to obtain a better understanding of radon transport in soil and entry into houses.

Progress achieved including publications

A numerical model of radon transport and entry has been developed, and a test structure for experimental studies of radon transport under field conditions has been established at Risø National Laboratory. Experimental results obtained at the test structure have been compared with results of model calculations.

1. Model

The developed model is a two-dimensional numerical model of the finite-difference type for studying steady-state transport of soil gas and radon in soil and entry into houses. The calculations are performed in two steps. Firstly, the movement of soil gas is determined in response to an indoor-outdoor pressure difference. Secondly, the model solves the radon transport equation that involves generation, decay, combined advective and diffusive transport, and partitioning of radon between the gas phase and the aqueous phase. The model is flexible and can be used for the Risø test structure, for real houses, and e.g. for soil probes. The model has been implemented on a personal computer and on a VAX-8700. On a personal computer the model can handle grids with up to 10000 nodes. It has been subjected to a number of tests concerning the mathematical correctness. The verifications have focused on the ability of the model to solve two-dimensional heat-flow problems and one-dimensional radon transport problems for which solutions are known. In addition the model has been tested against other numerical models.

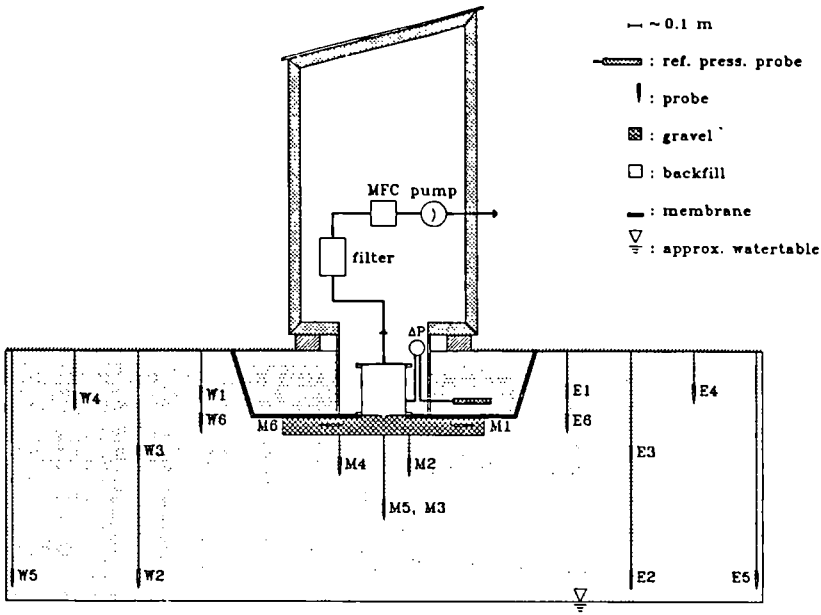

Figure 1: Cross-sectional view of the radon test structure.

2. Test structure

A test structure for experimental studies of radon transport under field conditions has been established at Risø National Laboratory. A cross-sectional view of the structure is shown in Figure 1. The structure consists of a 40 litre, stainless-steel cylinder placed in a 0.52 m deep quadratic excavation with a side length of 2.4 m. The excavation is lined with an airtight membrane, and soil gas enters the cylinder through a changeable interface in the bottom. Below the cylinder, a capillary breaking layer of highly permeable gravel has been placed. This layer has a thickness of 0.15 m and a side length of 1.5 m. The permeability of the gravel was measured in the laboratory to be $4 \cdot 10^{-9}$ m^2. The chosen dimensions of the structure were partly based on initial calculations of the soil-gas flow performed by CSTC/WTCB, Belgium, and by the Section for Mechanical Systems at Risø, both using commercial heat-transfer codes. A shelter for instrumentation is placed on top of the structure. The instrumentation includes: 2 continuous radon monitors, 2 differential pressure gauges, 6 thermometers, and gauges for wind, rain and atmospheric pressure. Data are logged onto a personal computer every 10 minutes. The (de)pressurization of the cylinder is set by a mass-flow controlled pump. A reference probe for the pressure measurements is located in the backfilled gravel within the excavation.

In the vicinity of the structure a total of 26 simple pipe-end probes of an inner diameter of 17 mm have been installed in a parallel project undertaken by the Technical University of Denmark (DTH). Moreover, two simple probes are located in the gravel below the cylinder. 22 of the probes are pair-wise located symmetrically on the east and west or north and south sides of the structure. Six probes are located below the structure. The probes serve several

purposes: Firstly, the drilling of the probe holes has provided soil samples for measurements by DTH of radon emanation and moisture, and for a general characterization of the site geology. Secondly, in-situ permeability measurements have been made by DTH by means of a specially designed small-diameter probe that fits into the probe holes. Finally, we have used the probes for mapping pressure and radon fields manually, the latter by means of conventional scintillation cells. All probes are sealed off when not in use. The site is located on clayey till, which is a common type of surface soil in Denmark. At the site, the till was found to be covered by a top layer of 40 to 50 cm of sandy soil. The water table was found at a depth of about 2 metres. The measured permeabilities range from below 10^{-15} m^2 to $1.4 \cdot 10^{-11}$ m^2.

3. Results and discussion

Steady-state experiments have been conducted at the test structure. Four aspects were investigated: total flow resistance, pressure couplings, and radon concentrations under diffusive and advective conditions. Pressure couplings and radon concentrations were measured at 19 probe locations.

The relation between the steady-state depressurization and the soil-gas entry rate into the cylinder, i.e. the flow resistance, was found to be $1.5 \cdot 10^5$ $Pa \cdot s \cdot m^{-3}$ for depressurizations up to 60 Pa. The pressure couplings, i.e. the depressurizations at the probe locations normalized with respect to the depressurization of the cylinder, were found to be in the range from 75% to 92% for the probes located below the structure, whereas they were lower than 15% for the other probes. When the cylinder was depressurized, the radon concentration field in the soil was influenced such that a significant radon depletion was observed at the probe locations nearest to the structure in response to the imposed flow of soil gas.

The experimental results were compared with results of model calculations based on the measured soil parameters. For most of the probe locations the measured and calculated values of the pressure couplings, the normalized radon concentration fields under diffusive and advective conditions, and the degree of radon depletion were in reasonable agreement. This verifies the ability of the model to describe the combined diffusive and advective radon transport, which is a key element of the model. However, the model significantly underestimated the soil-gas and radon entry rates. Even if the soil was assumed to be homogeneous and to have a permeability equal to the highest of the measured values, the predicted soil-gas entry rate was still a factor of two lower than measured. This indicates that even a rather extensive characterization of the soil may be insufficient for correctly predicting soil-gas and radon entry rates in the case of inhomogeneous soils (which often occur in practice). As a part of our further work, we intend to investigate how detailed both soil characterization and modelling need to be to account for soil inhomogeneities.

Publications

Andersen, C.E., Søgaard-Hansen, J. and Majborn, B. Radon Entry into a Simple Test Structure. Fifth International Symposium on the Natural Radiation Environment, Salzburg, 22-28 September 1991. (To be published in Radiation Protection Dosimetry).

Andersen, C.E. Entry of Soil Gas and Radon into Houses. Risø-R-623(EN), April 1992.

Project 5

Head of project: *P. Wouters*

Objectives for the reporting period

The aims concerning more specifically the contribution of the Belgian Building Research Institute (CSTC-WTCB) to the program were the following:

1. the improvement of the understanding of the movement of radon from ground to sub-floor spaces and into buildings, and the development of mathematical models in this field

2. the development and test of remedial actions against radon in buildings, using laboratory and field studies.

In particular, the objectives related to the first aim were to develop or to adapt, in the framework of radon, tools to predict soil-gas flow rates between the ground and the building, and tools to predict air flow rates and pollutant transport between building zones. Concerning the in-situ studies, the objective was to perform various measurements, in one or more buildings, in order to define and evaluate remedial techniques and to achieve a better understanding of radon transport in buildings.

Progress achieved including publications

The description of the work carried out and of the results obtained during the 1990-1992 period is presented below according to the above presentation of the objectives:

1 Understanding and modelling of the gas movement

1.1 Modelling of the movement of soil gas from the ground to sub-floor spaces and into buildings

The possibility of using a particular three-dimensional finite difference code to model the soil-gas movement and to predict the performance of radon remedial actions was considered. This code, named TRISCO, is a commercially available code normally used for solving heat transfer problems. We have well delimited the domain of validity of this model in the framework of the radon problem, with the following main hypothesis: 1)the radon transport from soil into a building occurs mainly by pressure-driven air flow, 2)the air flow under the slab is supposed to be laminar, 3)the steady-state condition is adopted. Calculations with this model can take into account the indoor-outdoor pressure differences, the presence of joints

and cracks in the floor-slab, the soil and materials permeabilities, the presence of mitigation systems,... The code calculates pressure fields and flow rates and delivers alphanumerical and graphical (two and three dimensions) outputs.

Sample calculations were done concerning a house without basement and with an entry route for soil gas: the floor-wall joint. A particular subslab depressurisation system was included in the calculations. Because one can take into account all the details of the configuration in a very simple way, and because of the simple and useful outputs, the code appears to be particularly well suited for the design and the evaluation of remedial actions (subfloor ventilation strategies) against radon in buildings (1).

The model was also used to perform calculations adapted to the experimental configurations of KVI (The Netherlands), RISO (Denmark) and Technical University of Denmark (2). The results of the calculations were used for different purposes by these institutes, in relation with their research. These results were successfully compared to laboratory measurements performed by the Technical University of Denmark and by KVI, demonstrating the possibilities of the model and its utility in the framework of radon research (3,4).

1.2 Modelling air flow rates and radon transport between building zones

Several important parameters may influence the radon transport within a building. This transport is related to the movement of air which, in turn, is due to pressure differentials that occur in the building and across the building envelope, as a result of a combination of wind effect, stack effect and the operation of mechanical ventilation systems. The air infiltration and ventilation, and consequently the pollutant transport and the pollutant concentrations in the rooms, will depend on these climatic and operational conditions as well as on the building characteristics (airtightness, number and distribution of flow paths, ...) and on the occupants behaviour (use of open fires for example).

The number and the complexity of these factors imply that complex simulations with multi-cell computer codes are necessary to obtain a rather good picture of air infiltration and ventilation behaviour in real buildings and for real weather conditions, and to understand and predict the transport of pollutants. That's why a preliminary study was made on the possibility of using a particular computer program, named VENCON, for the case of radon (5).

This program takes all the above mentioned parameters into account and models indoor interzone airflows as well as pollutant concentrations. Sample calculations were made concerning a rowhouse supposed to have a constant radon source in the basement. Some adaptations should be made, in the future, in order to allow the model to take into account some of the peculiarities of the radon problem. However, the results of the preliminary calculations already illustrate the possibilities of the used code and demonstrate that models of this type are powerful instruments. They allow the study, for real situations, of the impact of a number

of factors on the indoor air quality (especially from the radon point of view) and on the performances of systems aimed to influence the pattern of air flow within a building in order to ensure low radon concentrations in habitable zones. This kind of model should be intensively used in the future to perform studies in the framework of the radon problems in buildings.

2. On-site studies

Several measurements were made in a school well known for its high radon concentrations. The degree of permeability to air of the studied zone of the building was measured using the pressurization method. The airtightness of the inner walls of the various rooms was also evaluated. Measurements of tracer gas (N_2O injected in the basement) concentrations in different rooms for different experimental conditions were made, in function of time, together with radon concentration measurements (6). This study allowed us to present some conclusions concerning the radon entry paths and the influence of a number of factors on the measured concentrations. As a consequence of these conclusions, two mechanical ventilation systems producing an over-pressure in the rooms and improving the global ventilation were installed and tested in two classrooms. Their use was completely successful in achieving radon reduction (7). The possibility of using a sub-slab depressurisation system was also evaluated, and it was shown that this method could also be applied to reduce radon levels in the school (8). But it is the method based on the pressurisation of the rooms which was suggested to the school authorities (9). One of the reasons is that the pressurization fans also improve the general indoor air quality of that school, as shown by CO_2 concentration measurements.

Measurements were also made in a second school, very different from the other one, with crawl spaces beneath the part of the building in which high radon levels were measured. Pressurisation measurements were made in this school, especially in the crawl spaces. A few important entry routes for gas coming from the crawl spaces into the rooms were detected. Remedial actions were proposed to the school authorities, mainly the sealing of the most important entry routes and the ventilation of the crawl spaces. The effectiveness of these countermeasures was evaluated on part of the building. The current results indicate that a natural ventilation of the crawl spaces, together with the sailing of entries, successfully reduces the radon levels inside the school (10). When it works, this solution is an attractive alternative to the mechanical ventilation of the crawl spaces.

These case-studies allow for a better understanding of the factors affecting the performances of the tested radon countermeasures. This kind of studies will be continued in the future. Measurements have just started in two dwellings presenting high radon levels.

Publications

1. P.Cohilis, P.Wouters and D.L'Heureux, "Prediction of the performance of various strategies of subfloor ventilation as remedial action for radon problems", Proceedings of the 11th AIVC Conference, Belgirate, Italy, 1990

2. P.Cohilis, P.Wouters and D.L'Heureux, "Use of a 2-D code to execute model calculations adapted to three particular experimental configurations used in the framework of radon research", CSTC-WTCB internal report,1991

3. P.Cohilis, P.Wouters and D.L'Heureux, "Use of a finite difference code for the prediction of the ability of subfloor ventilation strategies to reduce indoor radon concentrations", submitted to *Radiation Protection Dosimetry* as part of the 5th International Symposium on the Natural Radiation Environment, Salzburg, Austria, 1991

4. E.R. van der Graaf, P.Cohilis, R. ten Have, R.J. de Meijer and C. Stapel, "Pressure fields in sand", Tech. Doc. KVI/RV-05, 1992

5. P.Cohilis, P.Wouters and L.Vandaele, "Radon and ventilation: preliminary calculations illustrating the possibilities of a multi-cell model predicting air movement in buildings", CSTC-WTCB internal report, 1992

6. P.Cohilis, P.Wouters, J.Verheyden, L.Vandaele, R.Bossicard, D.L'Heureux, and P.Voordecker, "A case-study concerning radon problems in schools: Libramont-Belgium", CSTC-WTCB internal report, 1990

7. P.Cohilis, P.Wouters and P.Voordecker, "Use of ventilation systems (pressurization fans) to reduce radon concentrations in a school of Libramont (south of Belgium)", CSTC-WTCB internal report, 1991

8. P.Cohilis, P.Wouters and P.Voordecker, "Radon problems in schools: evaluation of the subslab depressurization technique in a school of Libramont (south of Belgium)", CSTC-WTCB internal report, 1992

9. P.Cohilis, P.Wouters and P.Voordecker, "Radon reduction in a belgian school: from research to application", Proceedings of the 1992 International Symposium on Radon and Radon Reduction Technology, Minneapolis, USA, 1992

10. P.Cohilis, P.Wouters and P.Voordecker, "Radon reduction in buildings: the case of two belgian schools", submitted to the International Conference on Building Design, Technology & Occupant Well-Being in Temperate Climates, Brussels, Belgium, 1993

Project 6

Head of project: *Ir. Peter de Jong*

Objectives for the reporting period

As the concentrations of radon and decay products in a dwelling are influenced by an interplay of many parameters, it was proposed to study the effect of remedial actions in a test structure on a semi-laboratory scale. In this test structure most of the parameters involved can be controlled. Any resulting change, detected in the radon concentration, would then be directly related to a known change in a parameter value. The research programme covers the following:
- design, setup and validation of the test structure,
- testing of remedial actions to limit the concentration in the under-floor space or the entry rate, together with the determination of the radon concentration distribution,
- development of predictive mathematical models of the indoor radon concentration and entry rates.

Progress achieved including publications

Of the contemplated objectives only a part could be realized during the validity term of the contract. The reason for the delay was that the panel working on radon research had to move from Delft to Arnhem due to a reorganization within TNO. The move included the transfer of the measuring equipment which, due to the lower permitted floor load, implied significant structural adaptations of the laboratory. It is anticipated that the new facilities will be available within three months. In the meantime a feasibility study has been completed, dealing with the experimental possibilities of a semi-laboratory test structure. The report discusses the following subjects:
- the suitability of the test structure for the validation of model calculations
- the suitability for studying the effectiveness of different types of counter-measures to reduce radon concentrations under controlled conditions
- other possibilities, including permeability measurements and pressure-controlled diffusion

On the basis of the subjects considered, a set of requirements has been formulated with regard to civil engineering provisions. Most of the experiments can be performed in a so-called basic design, consisting of a crawl space with a room on top. The dimensions of such a structure are roughly 2 x 3 x 3.2 m (l x w x h). The construction will be such that the ground floor can be replaced. To investigate the contribution to the radiation dose of radon transport through the cavity, the construction can be provided with a cavity wall. Apart from technical feasibility, the report also focuses on the required provisions and the measuring equipment to be applied. This study is an excellent basis for both design and execution of the work plan. Although the preparatory work has taken more time than was anticipated, it underlines the importance and the innovative character of the experiments to be conducted. Meanwhile this project is incorporated into a larger research programme, which will be co-sponsored by the Dutch Government as part of the strategic radon research programme STRATEGO. For this programme to be successful, however, it is essential that the remaining EC funds continue to be available and can be transferred to the next funding period.

In view of the number of parameters involved, the availability of mathematical models to calculate indoor radon concentrations is essential, not only to serve as a predictive tool for

complicated situations, but also to identify the gaps in our knowledge. The model developed at TNO consists of different sub-modules dealing with:
- radon entry from the soil,
- exhalation from the construction materials,
- air infiltration and transport, and
- calculation of doses to individuals.

In the model not only the house but also the soil is divided into different compartments. The soil compartments consist of horizontal layers, underneath and beside the construction respectively, each having its own value for radium concentration, emanating power, diffusion coefficient, porosity, density and thickness. This approach offers the opportunity to take soil inhomogeneities (including water content) into account. The pressure-driven transport is based on wind velocity and the temperature difference between the crawl space and outside, on the basis whereof the driving force and the resulting air flow is calculated. At this moment the permeability is considered to be homogeneously distributed. In the joint example (Figure 1), the area exhalation rate of the soil in the crawl space due to diffusion and advection is calculated as a function of soil permeability. Although the exhalation rate shows an increase as permeability increases, this is only a limited value due to the high degree of radon depletion (indicated in the right scale of Figure 1). The slight depth of the foundation of some tens of centimetres plays an important role in the depletion process. When a concrete layer is fitted onto the crawl space floor, an extra diffusion barrier is introduced, in combination with a reduction of the infiltrating air flow, depending on the quality of the floor. In the example a 40% reduction is adopted.

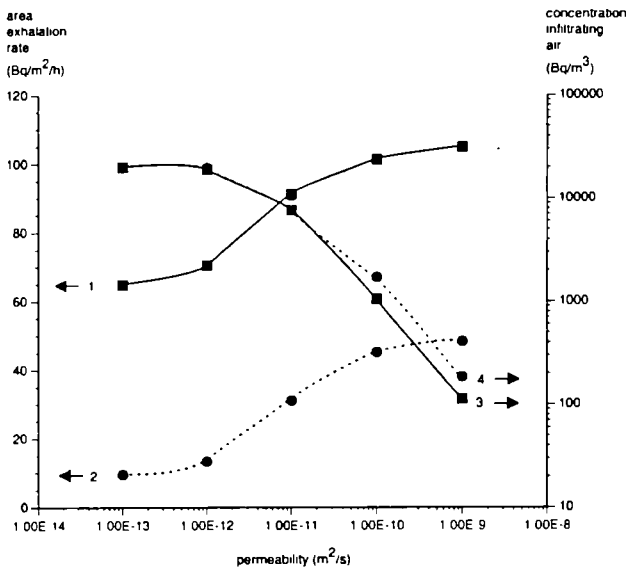

Figure 1 Calculated area exhalation rate and radon concentration of the infiltrating air as a function of soil permeability, using the following parameter values:
D_{eff} (soil) = 10^{-6} m^2/s; c (∞) = 20 kBq/m^3; v_{wind} = 2 m/s; ΔT=10 C.
Curves 1 and 3: bare soil floor
Curves 2 and 4: 20 cm of concrete floor (L=15 cm)

In the air infiltration and transport model, the dwelling is divided into individual rooms which are interconnected via leaking paths. The model calculates ventilation flows, pressure differences and the transport of radon. The most important input parameters are:
- weather conditions (wind velocity, wind direction, temperature)
- site data (wind shielding)
- building characteristics (building shape, dimensions, openings in the building envelope)
- data connected to the inside of the structure (temperature distribution, openings and leakage across internal zones, mechanical ventilation)

The model can calculate the air exchange between the different compartments of the house as well as the flows through the building envelope, ground floor and cavity wall. At the moment it is assumed that the radon concentration is perfectly and instantly mixed within each compartment, although there is a possibility to introduce sub-compartments.

During the course of the project a start was made with the comparison of computed data and measured data from the KVI test house. Figure 2 shows the ratio of the two series as a function of time. During certain periods significant discrepancies were found between the measured and modelled radon concentrations for reasons which are not quite clear at the moment. A further evaluation is in progress and is among the objectives of the next research period, as is a comparison with other data sets.

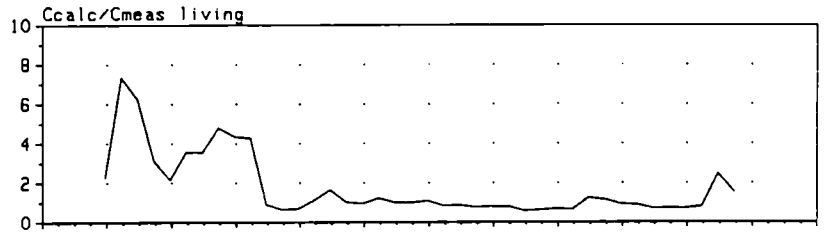

Figure 2 Comparison of calculated and measured radon concentration in a living room as a function of time.

The module dealing with the calculation of the radiation dose to a resident is not yet fully elaborated, although some sub-parts are already available, including:
- a three-room compartment code, modelling not only the radon isotopes but also their decay products taking the aerosol concentration, plate out (attached, unattached), recoil and transport into account;
- a sub-module describing the behaviour of a resident in respect of the residence time in certain rooms, as a function of time, in combination with time-dependent use of windows;

The models described use a large number of input parameters, which enables wide application but makes it practically impossible to quantitatively assess all of them. Therefore, it is of paramount importance to select and classify those input parameters that significantly influence the radon concentration, as proposed for the next funding period.

Reports
De Jong, P.
Experimental possibilities of a laboratory dwelling
Report RD-E/9202-303 (1992).

De Jong, P., Ackers, J.G. and Phaff, J.C.
Radon modelling: theoretical background and examples of calculations
Report RD-E/9207 - 309 (1992).

Project 7

Head of Project: *Dr. T.K. Ball*

Objectives for the reporting period

1. Objectives

The aims and objectives of project were to develop radon potential mapping techniques. To investigate the roles that existing geologigal and geochemical data sets; new measurements of soil and bed-rock radioelement concentrations; and in particular the determination of soil gas radon levels, might have to the efficient recognition of zones of high radon values in houses. The NRPB have selected an "Action Level" of 200 Bq/m^3 Rn in house air, above which action is recommended to reduce the concentration. It is tedious and expensive to test every dwelling in the housing stock for radon levels. Since most radon is generated within the ground, there are advantages in basing house surveys upon the geology, provided there is consistent radon generated by specific geological features. If this is so, then geochemical survey methods can be of enormous advantage in assigning priorities in any housing survey. It is equally important at an early planning stage to identify areas where domestic radon levels are likely to be low.

2. Summary of progress

The 1622yr half life of ^{226}Ra, the parent of ^{222}Rn, is significant in terms of recent geological events, for example the 10,000 - 12,000 years since the end of the glaciation in Northern Europe.

Radium in the secondary environment can behave quite differently from the parent uranium and is generally less mobile. Some granites, such as that in the Okehampton area, have uraninite weathered near surface, the uranium removed, but most of the radium left in situ. In consequence radon can escape easily into the disperse phase. The movement of radon into intergranular space in rocks depends upon the specific surface area of the mineral, imperfections in its lattice, its density and the nature of the intergranular space. Once in the intergranular zone, wheter radon is transported depends on the nature of the disperse phase and the permeability of the host rock. In the gas phase, radon transport is often dependent on carrier gases, whilst microclimatic effects within cavernous limestones can result in large quantities of radon-rich air being transported.

3. Radioactivity and lithology

Two areas were examined to test the possibilities of producing radon distribution maps. These areas contained constrasting lithologies, typical of many European rock types. In addition, they were known to have a large proportion of houses exceeding the Action Level. The chosen areas were based on Geological Survey maps Chapel-en-le Frith and Okehampton (Figure 1).

4. Geology of study areas

The Chapel-en-le Frith area is underlain by a range of rocks of Carboniferous age (Figure 2). Dinantian limestones with basic intrusive and extrusive igneous rocks are overlain by

Namurian black mudstones and sandstones, in turn succeeded by Westphalian Coal Measures comprising interbedded coals, mudstones and sandstones. Uraniferous concentrations are known to exist in the limestone marginal reef facies, the lower Namurian pyritic black shales and in relatively narrow marine bands (<1%) within the Westphalian (7). The whole area was glaciated, with boulder clay and glacio-fluvial sands and gravels deposited in the valleys.

The Okehampton map sheet covers an area partly underlain by the Hercynian Dartmoor Granite, intruded into carboniferous cherts with limestones and black shales (the Meldon Formation) and a very thick sequence of grey shales and sandstones (Crackington and Bude Formations). There are also Permo-Triassic breccia conglomerates, mudstones and igneous rocks. Uranium values are high in the granite, cherts within the metamorphic aureole and in some of the carboniferous black shales. The sedimentary rocks have been intensely folded and there are major faults trending NW-SE. The area lay south of the limit of the main Pleistocene glaciation, but periglacial weathering occurred and local ice features are seen on the higher ground. Patches of deep Tertiary weathering are preserved.

5. Methodology

In each area, orientation surveys ware followed by sampling along traverses designed to test the following:

1. Was it possible to assign discrete radioelement concentrations in relation to the know geological features.

2. Bearing in mind the well known variability of soil gas radon due to weather conditions could it be established that the variations due to geological factors were greater than those due to weather effects?

Sampling traverses were designed to investigate each rock formation, to assess the overall radon variability. Sample intervals depended upon the nature of the topography and the complexity of the geology. In all cases, detailed geological maps were available at scales of 1:10000 or 1:10560. At each site the following measurements were made:

a. A sample of soil gas was taken through a hollow spike at 50 cm depth into a Lucas cell and the activity of radon and thoron determined.

b. A gamma spectrometer was used to measure the photopeak intensity of ^{40}k, ^{214}Bi and ^{208}Tl in the field. These measurements enable the total radon and thoron activities in the soil to be estimated. Soils along certain traverses were analysed for uranium and radium to determine the influence of these components.

6. Results

6.1 Chapel-en-le-Frith area

Radon in soil gas was found to vary with lithology. Statistical analysis shows highly significant differences for radon emanation over the various lithologies. The soil gas radon values are also independent of the uranium concentration in the bed-rock. The limestones typically exhibit ranges of 1-10ppm U whilst the basan Namurian mudstones have 10-60ppm U. The highest soil gas radon occurs over the Dinantian reef limestones and where the Namurian mudstones overlie the reefs. The non-reef limestones also give rise to high radon in soil gas, whilst radon from the less permeable Namurian mudstones is moderate. The Westphalian outcrop is characterised by isolated high levels radon in soil gas over marine bands.

6.2 Okehampton Area

Here again, consistent and statistically highly significant differences exist between the soil gas values associated with different rock types. The highest values occur over the granite and the Meldon Formation. These lithologies are characterised by over 30% of the houses being above the Action Level compared to 10-30% of the houses on the other rock types being affected.

7. Discussion

Soil gas entry is the most important factor governing radon in buildings. Thus of all the individual radioelement parameters measured it would be expected that the most appropriate would be the radon in soil gas measurement and there is increasing evidence to support this conclusion. Figure 2 shows the relationship between house levels and average soil gas radon for 5km squares in the Okehampton area. The correlation coefficient is about 0.89. Despite fewer data, limestone areas have a different regression line with a lower gradient. Data from gamma spectrometric and stream sediment and hydrogeochemical surveys can also be incorporated in a survey, but these other approaches must be used with caution. The ^{214}Bi photopeak intensity is not necessarily related to the amount of labile radon and uranium anomalies in drainage samples can be misleading since high values of radon in soil gas and in houses may be related to rocks in which the uranium content is low. Consequentely, soil gas surveys based on adeguate geological knowledge, must be regarded as the most efficient means of estimating the radon potential of an area. The survey must cover the ground adequately, and should pay particular attention to those rock formations which underlie zones of high population density. Each rock formation, and its variants should be tested several times and some traverses should be repeated to test the variability. Typical sites should be monitored daily to determine variability due to weather.

In cool temperate climates the best time for the survey is during the spring to autumn months when the soils are less wet and are thus more permeable. Soil gas surveys at these times relate better to the dry conditions beneath houses during the winter months when domestic radon levels are highest.

8. Conclusion

Soil gas radon determinations have been found to be the most efficient and least expensive survey method for radon distribution mapping. Reliance on other suggested parameters, such as the distribution of uranium in rock, soil and alluvium can give rise to erroneous conclusions, since high values of radon in soil gas and dwellings have been observed over rocks with low uranium abundances.

Publications

Ball, T.K, Cameron, D.G., Colman, T.B, in press, Aspects of Radon Potential Mapping in Britain. Proceedings of the Fifth International Symposium on the Natural Radiation Environment, Radiation Protection Dosimetry.

Ball, T.K, and Miles, J.C.H, in press, Geological/geochemical factors affecting the radon concentrations in homes in Cornwall and Devon, Environmental Geochemistry and Health.

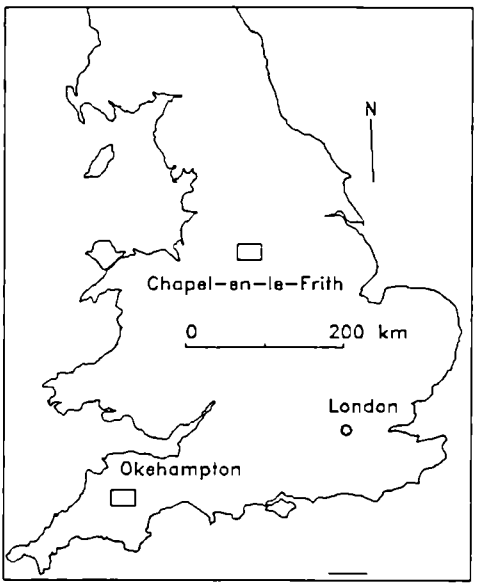

Figure 1

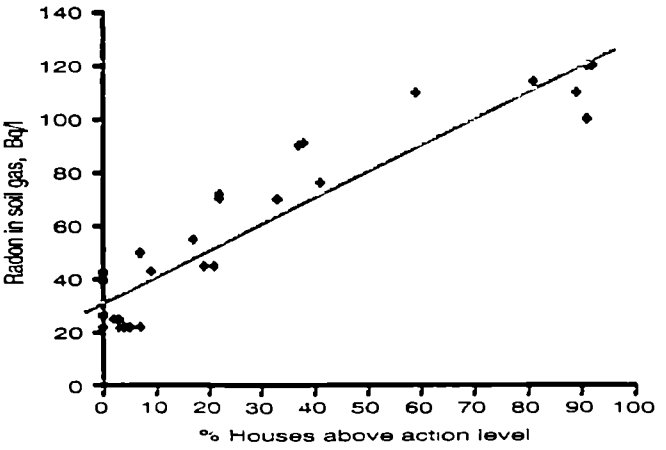

Figure 2

Project 8

Heads of project: *Lynn M. Hubbard, Anita Enflo*

Objectives for the reporting period

Our research focuses on developing a systematic comparison and better understanding of the behavior of radon in dwellings under different conditions. Physical models are used to understand how weather and house dynamics affect radon-containing soil gas entry compared to outdoor air entry into buildings, and the movement of radon between indoor zones, using data from real houses as input to the models. During the funding period from March 1990 to June 1992 the project has had two overall objectives: a systematic collection of experimental data from test houses and a theoretical modelling of the behavior of radon gas indoors.

The ongoing motivation for our research is to obtain sufficient understanding of the radon dynamics associated with buildings to be able to simplify the prediction of indoor radon concentrations and to prescribe adequate mitigation at a minimum cost to the household energy consumption. To this end the current research has had one objective of adding continuously recorded data from two Swedish research homes to an international data set of detailed measurements on houses in different countries of different construction types and geological environments. Homes which have been measured in the United States, the Netherlands, and Sweden have had similar parameters measured as a time series using similar measurement protocols.

Ultimately, consistent physical models should be able to describe the observed radon dynamics in the different environments. Models of radon entry and movement indoors are used in our research to study the different physical mechanisms driving the observed time-dependent behavior of radon. Another long term goal motivating our research is to understand the physics well enough to simplify the models to include only mechanisms and terms which are most relevant. To this end, one question addressed in the current study period has been to determine how much of the time and in what way temperature dependent mechanisms driving radon entry and movement indoors describe the radon dynamics in the two Swedish research homes.

Progress achieved including publications

During the funding period 1990-1992 we have collected and systematically catalogued continuous time series data over an approximate 1 1/2 year period from two research houses near Stockholm, Sweden. Parameters recorded include environmental temperatures in a variety of locations indoors and outdoors and in the soil, pressure differences across the building shell in a variety of locations, and radon gas concentrations in different indoor and subfloor zones. Radon progeny concentrations indoors and soil gas radon are also measured during regular intervals. Perfluorocarbon tracer gas measurements have occasionally been performed in each house to obtain integrated inter-zone airflows and ventilation rates.

The two research houses both have natural draught ventilation with hot water heated radiators in House (labeled) 901 and electrically heated radiators in House 902. They lie in

different geological environments and soil types. House 901 lies on morain which contains significant amounts of clay and House 902 lies on the edge of an esker over very sandy soil which partially includes a clay layer. Both houses have indoor radon concentrations which average between 150-250 Bq/m3 in the living level and the source of radon is the soil gas. Both houses have exposed dirt floor crawlspaces and, in one of the houses, an adjoining finished basement. House 901 was instrumented in March, 1990, and data collection continued until January 1992. House 902 was instrumented in October 1990 and data collection is ongoing.

As stated above, one of our long term objectives is to understand the physics well enough to simplify the models to include only mechanisms and terms which are most relevant. One of our research homes, House 902, provides a physical structure which can be treated as a single indoor zone during the winter months (ref. 1), thus simplifying the theoretical modelling of the airflows. In addition, although it is quite clear that in general the main mechanisms creating pressure differences across building shells are due to a combination of temperature differences, the wind, and the effect of indoor air distribution systems, if data can be obtained with one or two of these effects nulled then the remaining physics can be studied undisturbed in more detail. The two research homes have no indoor air distribution systems, and therefore no pressure differences due to them. In addition, our initial modelling and analysis of the collected data has eliminated from the data set days when the wind blew, focusing on non-windy days when the temperature dependent mechanisms driving the radon dynamics act independently of the wind effects. This occurred on approximately 50% of the days during a 7 month period spanning fall, winter, and spring months.

The resulting data set allows us to look in more detail at the effect of temperature on radon behavior indoors. There are three primary mechanisms by which temperature affects the radon dynamics indoors. Increased airflows across the building shell resulting from increased indoor-outdoor temperature differences during cold weather will: 1)increase the airflow rate from the outdoor air which tends to drive the indoor radon concentration down, and, 2)increase the flow of radon-containing soil gas into the house which tends to drive the radon concentration up. We call these the ventilation effect and the radon source effect. They are two components of the total quantity of air infiltrating a house. They are not entirely separate components, because as the ventilation increases with increasing temperature differences, the increased flow of soil gas usually contains a component of diluting outdoor air which gets flushed through the soil. Thus, an increased flow of soil gas into the house does not automatically imply an increased flow of radon gas also. That depends on where the increased flow is coming from: whether it draws from a larger volume of soil gas and thus radon gas or whether it also draws from the (relatively) radon-free outdoor air.

A third mechanism which depends on temperature differences can be called a mixing effect. During the cold months, in natural draught ventilated homes, the stack flow indoors tends to bring the air and thus radon from the lower levels to the higher levels. This mixing is so efficient in research house 902 that during winter months there is virtually no difference between the radon concentrations downstairs versus upstairs. During warmer months, as the airflow upward is much less, the radon concentration downstairs becomes significantly greater than the value upstairs (ref. 2).

Both Swedish research houses in this study exemplify buildings in which the indoor

radon is closely coupled to changes in outdoor temperature. (Because the indoor temperature stays relatively constant, discussing changes in outdoor temperature is the same as discussing changes in the indoor-outdoor temperature difference.) Figure 1 shows a typical response at House 901 of indoor radon with outdoor temperature on non-windy days during Janurary, 1991, with a rather dramatic increase in radon with temperature on both of days 9 and 10. This pattern has been repeated in both houses consistently during our measurement period.

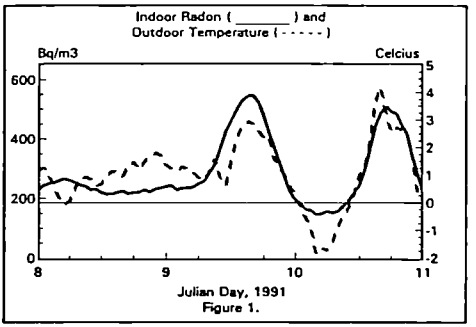

Figure 1.

It is generally believed that as the outdoor temperature decreases, the increased flow into the house from the soil gas leads to an increase in indoor radon concentration, and this is one reason for the increased wintertime indoor radon levels which are so commonly reported. This is in general not true if the house has been kept in the same operating configuration, (e.g., with the windows closed), and particularly not true in homes with natural draught ventilation. Both research houses discussed here show the opposite trend: a general increase in indoor radon with increasing outdoor temperture, as shown in figure 2.

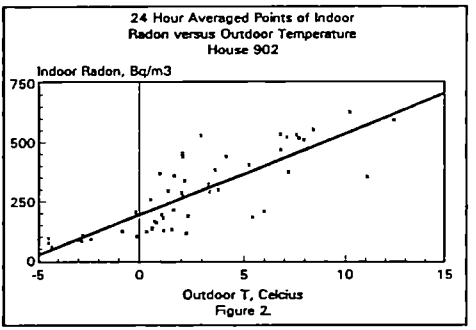

Figure 2.

Although the indoor radon increases with outdoor tempertature on a seasonal time scale in these houses, the daily pattern in house 901 shows the opposite pattern. On an hourly time scale, the radon concentration in house 902 follows the outdoor temperature profile, as in the seasonal data, while the radon concentration at house 901 displays the opposite profile. The three mechanisms mentioned above can explain this behavior, a discussion of which can be found in reference 2. During the next funding period, experiments are planned to better elucidate these mechanisms, as well as the role of difffusion of radon into the crawlspace.

We have a working radon flow model which takes as input time-varying airflows and predicts the time-varying radon concentrations in each specified indoor zone. We have developed a simple and useful formalism for modelling the airflows as a function of indoor-outdoor temperature differences, treating the air infiltrating from the soil gas separately from the air infiltrating from the outdoor air, so that radon entry and concentration indoors can be followed. The model is described in reference 2. The motivation for modelling the airflows from measured parameters, such as temperature differences or the wind, which create the pressure differences instead of the measured pressure differences themselves, is that, for example, temperatures are easier to measure accurately and more macroscopic than site-specific pressure measurements. It is also more desirable to model radon entry from the basic physics which causes the pressure differences driving the airflows. Of course, measured pressure differences can also be used as input to the model to determine the airflows.

Figure 3 compares the measured to the modelled indoor radon concentrations at House 901 during a 12 day period during which there was little wind. The results depend on the measured time varying crawlspace radon concentration, the measured hourly temperatures outside, in the crawlspace, and indoors, and the resulting modelled airflows as input to the radon flow model. The modelled radon concentration is in close agreement with the measured values, verifying the use of the model in future studies.

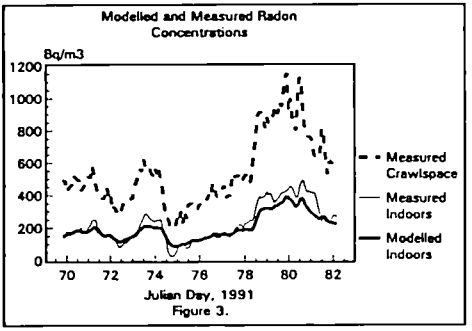

Figure 3.

The research discussed here is a part of a study aimed at characterizing the two components of airflow into houses which are relevent to radon dynamics: outdoor air and soil gas. We hope to understand better how environmental and physical parameters affect these two components of air infiltration. Reference 2 focuses on the temperature dependent mechanisms, showing data from two research houses and introducing a formalism for modelling the data. Current work is focused on using the model to study the effect of the different temperature dependent mechanisms discussed herein on the indoor radon concentration, on the role of the house leakage distribution, and on characterizing the interaction of the house with the soil physics.

A collaboration with another project in this contract, Dr. Anders Damkjaer from the Technical University of Denmark, has resulted in soil permeability measurements at different locations around research house 902 and soil mapping of the site. This data will be used in the next funding period for modelling soil gas entry rates in collaboration with the researchers

from Riso National Laboratory in Denmark and CSTC in Belgium, also in this contract.

Publications completed within reporting period

1. Hubbard, L.M., Hagberg,N., Enflo, A., Swedjemark, G.A., Radon Dynamics in Swedish Dwellings: A Status Report., presented at and in the procedings of the USEPA 1991 International Symposium on Radon and Radon Reduction Technology, Philadelphia, USA, April 1991.

2. Hubbard, L.M., Hagberg, N., Enflo, A., Temperature Effect on Radon Dynamics in Two Swedish Dwellings, presented at the Fifth International Symposium on the Natural Radiation Environment, Salzburg, Austria, September, 1991 and accepted for publication in the journal used for the symposium proceedings **Radiation Protection Dosimetry**.

Project 9

Head of project: *Prof. C. Proukakis*

Objectives for the reporting period

1. Establish an alpha track detector measuring capability in Greece. Quality assurance of the radon data by intercalibrations and intercomparisons between the collaborating laboratories.
2. Carry-out measurements and analyze the results
3. Gamma-spectroscopic analysis of surface soil samples
4. Evaluate the results and investigate the probable correlation between indoor radon concentration and Ra-226 concentration in the substrate soil.
5. Installation of an Image Analysis System for automated counting of Radon detectors

Progress achieved

1. The Medical Physics Department during the reporting period has installed 500 Rn-222 detectors of different manufacture (Terradex, University College Dublin, Medical Physics Laboratory) in many locations inside Greece.

   We have calibrated our detectors in collaboration with NRPB according to known concentration levels. The calibration accuracy was estimated to be + 15%.

   Intercomparison between greek and american (Terradex) detectors was made in order to ascertain the method's quality assurance.

2. The results from the measurements of Rn-222 indoors concentration performed in different locations are presented in table I.

TABLE I

Rn-222 concentration	Number of detectors	% of dwellings
$<50 Bq/m^3$	355	71%
$50\text{-}100 Bq/m^3$	83	16,6%
$100\text{-}200 Bq/m^3$	43	8,6%
$200\text{-}400 Bq/m^3$	11	2,2%
$400\text{-}1000 Bq/m^3$	6	1,2%
$>1000 Bq/m^3$	2	0,4%

3. Soil samples were selected from the above locations and were analyzed in the National Technical University of Athens employing the hight resolution Ge detectors set-ups where the Ra-226 radioactivity was measured.

4. Having a total of 97 experimental points (Rn-222 indoor air concentration, Ra-226 radioactivity in the surface soil) an investiqation on possible correlation of the two quantities was attempted. The correlation coefficient is 0,38.

   The area with the highest values of Rn-222 indoor air concentration is in Northern Greece (mean value: 206,98 Bq/m^3). The Ra-226 soil concentration in this area is significantly higher (>40Bq/Kg) than the average value of greek soils (mean value: 26Bq/Kg, std.der. 19Bq/Kg, sample size 717) according to the National Technical University of Athens.

5. The detector measurements were carried out until now with the use of a microscope. This method is time consuming and it introduces a large subjective error since it is based on optical observations.

   For this reason an Image Analysis System has been installed in Medical Physics Laboratory in order to obtain the measurements automatically.

ASSESSMENT AND MANAGEMENT OF RADIATION EXPOSURE AND RISKS FROM NATURAL AND MAN-MADE RADIATION SOURCES

Contract Bi6-114 - Sector C12

1) *Kollas* , NCSR "Democritos"

Summary of project global objectives and achievements

This is a continuation of a former contract, with CEC support only to the Project 1 concerning natural radioactivity studies, with emphasis to the indoor radon problems and studies related to them. Therefore, the title does not represent exactly the activities during the period 1990-1992.

The general target of Project 1 is to improve the knowledge on the internal exposure of the Greek population to the decay products of ^{222}Rn and to provide methodological support to the Greek authorities in the implementation of any future measures related to the control and reduction of this exposure.

A basic objective of the Project was the introduction of the track-etch detector technology in the Environmental Radioactivity Laboratory for determination of the integrated exposure to ^{222}Rn indoors. This concerned the whole circle of the method, in order to enable fully independent indoor radon studies and surveys in the future. A pilot indoor radon survey in the region of Athens was planned. The experience derived from this survey had to be used for future investigations of other regions of Greece.

A second objective was to improve the knowledge about the sources of indoor radon in Greece, which included:

1. Continuation and completion of the survey of natural radioactivity in the Greek soils. This would provide information on the main source of indoor radon - ^{226}Ra in the soil - and point out the regions where enhanced indoor radon concentrations are expected to occur. In addition, this survey would result in external dose rate mapping of the country, by use of the complete set of analysis data, which include a sufficient number of radionuclides of the ^{238}U and ^{232}Th series, as well as ^{40}K.

2. Development of methodologies and construction of devices for field and laboratory measurements of the exhalation rate of radon from soil and building materials. A related pilot study of the building materials used in the wider Athens region was planned.

3. Development of methodology and construction of device for field determination of the "radon availability" of the soil, which can be defined as the product of the soil gas concentration of radon and the soil permeability. This type of measurements is expected to provide more reliable indication of the potentially "hot spot" indoor radon regions, as compared with the data on ^{226}Ra in soil.

Project 1

Head of project: *Dr. P. Kritidis*

Objectives for the reporting period

Since Project 1 was the only one supported by the CEC after 1990, its objectives coincide with those presented in the previous page.

Progress achieved including publications

1. The work related to the introduction of the track-etch detector methodology included:

1.1. The development of a user-friendly method for manual determination of the track density, based on the magnified projection of the etched surface (KODAK LR-115 type detector) on a 40x40 cm half-transparent screen, after suitable blue-colour filtering and the "quasi-linear" track counting in 1x40 cm bands, which minimises the double- and skip-counting effects.

1.2. The study of the personal variations of the "counting sensitivity" and the introduction of personal sensitivity coefficients to correct for these variations.

1.3. The construction of a small calibration chamber, suitable for simultaneous exposure of up to 8 measuring pots or several tens of unprotected films.

1.4. The determination of optimal etching conditions (duration, etching solution density and temperature etc.) in order to minimise the low limit of detection and to achieve maximum repeatability of the results. The sensitivity achieved is 1.5 (counted tracks cm^{-2}) per (Bq month m^{-3}), while the low limit of detection (2σ of the background) is below 10 Bq month m^{-3}.

1.5. The selection of suitable, light-protected metal pots for housing the detector films, in order to avoid the effect of non-homogeneous deposition of the short-lived decay products due to static electricity, as well as the contrast degradation in the case of prolonged film exposure to light.

The results of this methodology work have been reported in (1), and also in two CEC radon contractors' meetings organised during 1990.

A pilot survey of the indoor radon concentrations in the wider Athens region is in progress. Near 150 detectors were distributed and exposed during the winter 6-month period October 1991 - March 1992. The statistical treatment of the data has not been completed yet, but one can note that no case of exceeding the CEC recommended

remedial action level has been observed.

2. The first phase of the survey of the natural radioactivity of the Greek soils has been completed. About 600 samples covering the whole country have been analysed, after appropriate treatment, by use of high-resolution gamma-spectrometry. The specific activities of the major gamma-emitting radionuclides of the uranium and thorium series, as well as of ^{40}K have been determined.

Paired measurements of the external exposition rate and the soil radioactivity have been made in several tens of selected areas with homogeneous soil content and "2σ geometry" of the surface, in order to test the theoretical relations used to calculate the external dose rate based on the data of the specific activities of the terrestrial source-radionuclides.

A statistical analysis of the results has been performed and the regional averages and variations, as well as the country averages after area- and population weighting have been determined.

The results of these studies have been reported in (2-5, 8,9) and constitute the basic material of the Thesis (5). They were also used (together with data from the Technical University of Athens) to provide external dose rate data to the NRPB group preparing the "Radiation Atlas" of Europe. Some general results are shown in Fig.1 and Fig.2.

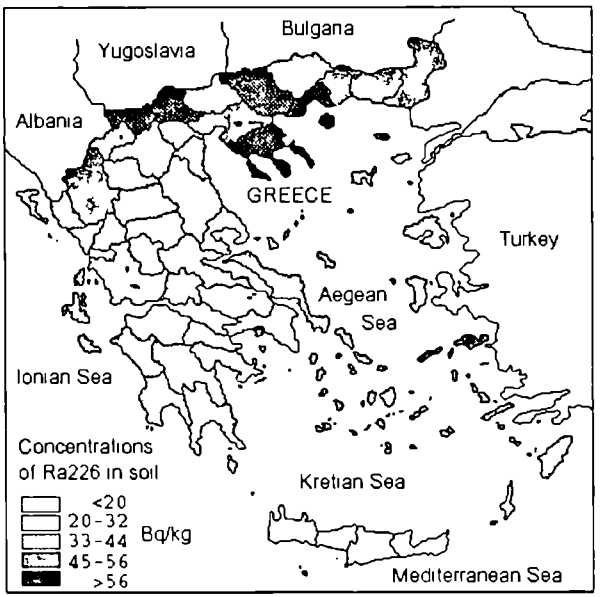

Figure 1 - Regional averages of the concentrations of 226Ra in the Greek soils

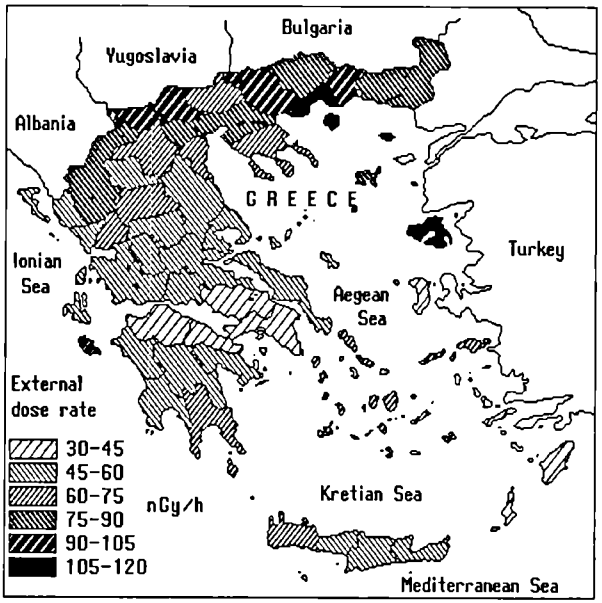

Figure 2 - Regional averages of the external dose rate due to the gamma-ray emission of the terrestrial natural radionuclides

3. A new version of a laboratory device for determination of the exhalation rate of radon has been developed and calibrated. Determination of exhalation rates down to 10^{-5} Bq s^{-1} is possible for samples of up to 4 l volume. The device can also be used as alternative calibration chamber for track-etch detectors. The sensitivity of the system allows to test various materials, pots etc. for radon leakage. A study of the exhalation rate of ^{222}Rn from various building materials widely used in Greece is in progress.

4. A pilot soil gas sampling-and-measuring device has been constructed and tested under various conditions of soil density, humidity, constitution, etc. The results demonstrated an unexpected (by us) high range of variation of the product (soil gas radon concentration) x (soil permeability). This does not allow the establishment of a reliable single set of sampling parameters, but rather indicates the need of at least two devices, one applicable in the case of low-permeability and low-radon content soil gas and another - in cases that the product of these quantities is more than 2 orders of magnitude higher. This work will continue during the next 2-year period.

Publications

1. Kamenopoulou V. and Kritidis P., *"A methodology for determination of radon concentrations in the air of Greek houses with track detectors"*. Proc. I Nation. Congr. of Radiation Protection, Athens, 24-26.10.1990 (in press, in Greek).

2. Probonas M. and Kritidis P., *"A study of the natural radioactivity of the Greek soils"*. Proc. I Nation. Congr. of Radiation Protection, Athens, 24-26.10.1990 (in press, in Greek).

3. Kritidis P., *"Ionising radiations in the environment - quantities and variations"*. Proc. I Nation. Congr. of Radiation Protection, Athens, 24-26.10.1990 (in press, in Greek).

4. Florou H. and Kritidis P., *"Natural radioactivity in environmental samples from an island of volcanic origin"*. Marine Pollution Bulletin **22, No 8**, p.p. 417-419 (1991).

5. Probonas M. *"The exposure of the Greek population to gamma-rays of terrestrial origin"*, Thesis (submitted to Medical School of the Athens University).

6. Kritidis P., *"A radiological study of the Greek radon spas"*, Proc. Intern. Symp. on Radon and Radon Reduction Technology, Philadelphia (USA), 2-5.04.1991 (in press).

7. Kritidis P. and Kollas J., *"Individual and social risk due to natural and artificial environmental radioactivity in Greece"*, Radiat. Prot. Dosim. (in press, Proceedings of the NRE V, Salzburg, Austria, Sept. 1991).

8. Probonas M. and Kritidis P., *"A study of the natural radioactivity of the Greek soils as factor of radiological exposure of the population"*, Proc. II Nation. Congr. of Environmental Science and Technology, Mytilini, Sept. 1991, pp. 534-543 (in Greek).

9. Probonas M. and Kritidis P., *"The exposure of the Greek population to gamma-radiation of terrestrial origin"*, Radiat. Prot. Dosim. (in press).

10. Florou H. and Kritidis P., *"Gamma radiation measurements and dose rate in the coastal areas of a volcanic island - Aegean Sea - Greece"*, Radiat. Prot. Dosim. (in press, Proceedings of the NRE V, Salzburg, Austria, Sept. 1991).

NATURAL EXPOSURE FROM RADON AND RADON PROGENY IN SPANISH HOUSES. II PART

Contract Bi6-314 - Sector C12

1) *Quindós Poncela* , Universidad de Santander

Summary of project global objectives and achievements

The measurements of radon levels in Spanish houses started in October, - 1988 within the CEC Contract B16-0314-E entitled "Natural exposure from radon and radon progeny in Spanish houses" and was prolonged as II Part, until December, 1991. The global objectives of the Project are:

a.- Determination of radon gas levels in Spain to evaluate the actual status relative to this field.

b.- Selection of areas of Spain with high radon levels in houses.

c.- Study of the relationship between the measurements of passive dosemeters and an instantaneous method employing modified Lucas cells developed in our laboratory.

d.- Measurement of radioactivity in soils and building materials in order to correlate them with the presence of radon in houses.

e.- Evaluation of the external dose from the radium, thorium and potasium content in soils and building materials.

f.- Study of the relationship between the external dose derived from the radioactivity of soils and building materials and the experimental results from a portable monitor.

g.- Correlate the geographical distribution of lung cancer in Spain with the presence of radon in the houses.

h.- Measurement of radon progeny using a grab sampling method, the WL and the equilibrium factor in a group of houses of selected areas in Spain.

i.- Study of sources of radon in houses in selected areas with special emphasis in soils, building materials and water through the measurement of exhalation rate from soils and building materials and the evaluation of radon in water.

Progress achieved

1. Methodology

During the period of the Research Project more than 3,000 measurements of radon levels in Spanish houses, including a broad regional survey in our region, Cantabria, have been successfully completed. The first

stage of the project involved the measurement of radon gas in 1,600 houses using the modified Lucas cells developed in our laboratory and calibrated in October, 1987 at the National Radiological Protection Board (NRPB), UK. The detection limit for these cells was evaluated at about 10 $Bq.m^{-3}$ for a counting time of 15 minutes. Taking into account the seasonal and diurnal variations of the radon concentration and in order to make our instantaneous measurements as similar as possible to time averaged values, we conducted our survey during the winter period and collected the samples in the early hours in the morning. Fig I shows the location of sampling points along the country, each point represen---ting an average of approximately 30 individual measurements of radon gas in houses. A questionnaire was distributed in order to complete relevant data of the houses such as ventilation system, building materials, habits of inhabitants, etc. From this first survey we identified the areas in the country with high indoor radon levels and obtained a "provisional" average radon concentration in Spanish houses. In a second phase, we placed more than 600 passive integrating detectors from Terradex, USA, and from the NRPB, UK, in order to compare results with our previous measurements and to achieve a "real" national average for radon gas. After an exposure period of 3-4 months, the detector were recovered and shipped to the manufacturer for analysis. When the detectors were put in place and removed grab samples were also taken using the technique described above and were used to derive an average value for comparison with the value obtained from the passive measurements.

As we describe in more detail in the article published in Health Physics, no significant differences were found between the two results and our provisional value could be adopted with a small correction as a good average for radon in Spanish houses.

For the measurement of radioactivity in soils and building materials in more than 1,000 samples collected all over the country, and to measure radon content in water, gamma spectrometry was used.

In order to validate our results and establish a quality control of the measurements, we coordinated an International Exercise of Intercomparison which we chose the portable monitor used by Dr. Green from NRPB, UK, for the national survey in England, our device also being calibrated at his laboratory.

Measurements of exhalation from soils and building materials were carried

out by adoption of an accumulator method. Finally, continuous measurement of both radon gas using cells and working level with a WL-Meter, (Thomsom- Nielsen), USA, has made it possible to evaluate the equilibrium factor for a small sample of Spanish houses.

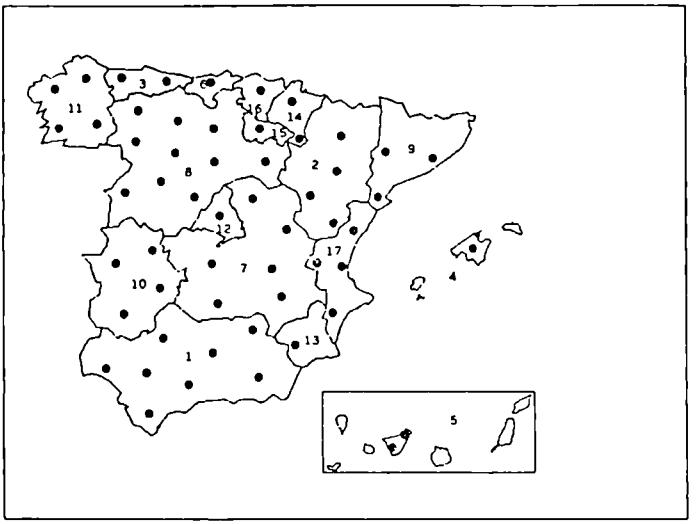

Figure I

2. Results

The results obtained from this Research are explained in more detail in the publications cited at the end of this Final Report. Each part of the research has led to the publication of a specific paper. The following Figures and Tables summarize our results. The Fig II shows the log-normal distribution of indoor radon concentrations. The geometric mean and geometric standard deviation as well as the range and number of measurements for each region of Spain are shown in Table I. Fig III shows the percentages of houses that fall within certain radon concentration intervals. About 13% of the houses have levels above the action level recommended by Environmental Protection Agency, EPA, USA, and 4% of them above 400 $Bq.m^{-3}$ as reported by the Commission of the European Communities, CEC, for existing buildings. However, this latter percentage increases significantly in the west of the country, as shown in Fig IV, where high radon levels were detected.

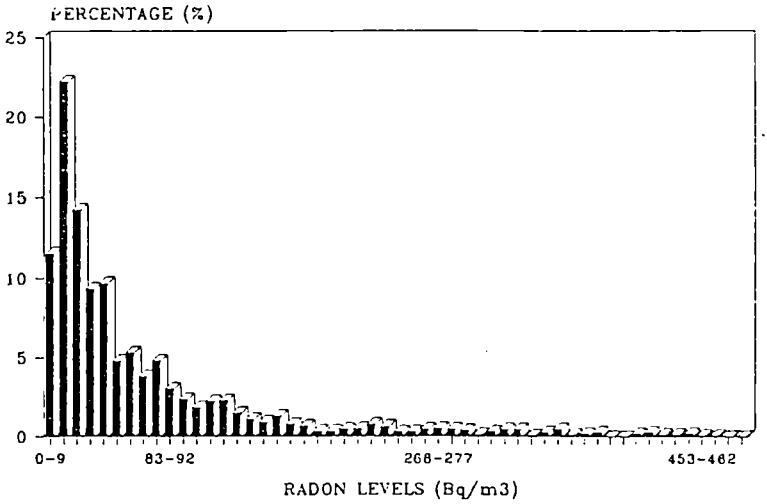

Figure II

Table I

REGION CODE	Region Name	G.M (Bq.m-3)	S.D	N° of measurements
1	Andalucia	263	35	250
2	Aragon	329	35	142
3	Asturias	426	28	74
4	Baleares	272	21	27
5	Canarias	599	49	52
6	Cantabria	411	30	87
7	Castilla-Mancha	426	25	188
8	Castilla-Leon	703	48	310
9	Cataluña	229	39	88
10	Extremadura	898	25	171
11	Galicia	1176	24	172
12	Madrid	949	21	67
13	Murciana	154	35	41
14	Navarra	198	24	69
15	La Rioja	185	30	52
16	Pais Vasco	202	35	69
17	Pais Valen	176	26	144
SPAIN		427	37	2003

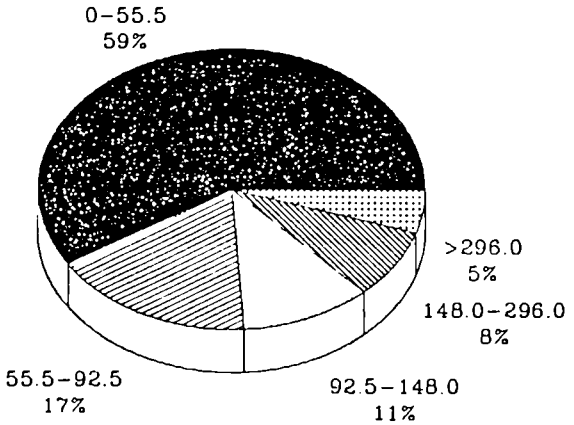

Figure III

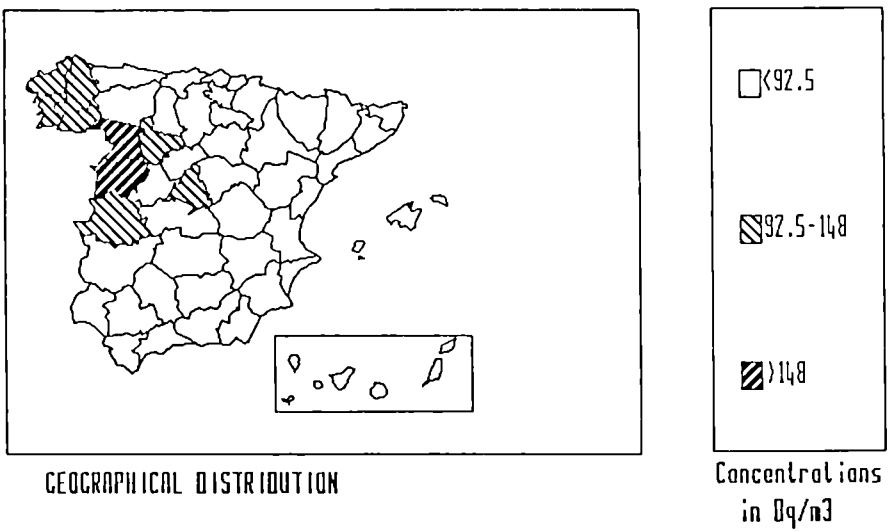

Figure IV

For the radioactivity of soils, Table II gives a summary of the survey results, after the intercomparision, for the 17 autonoumous regions in Spain. Directly related with theses measurements are the values shown in Table III for the external gamma rays corresponding to each region. The average geometric mean value for the terrestrial gamma ray dose rate was 38.4 $nGy.h^{-1}$ corresponding to the regions of Valencia (Pais Valenciano) and Madrid, respectively, and depending directly on their

different geologic formation. The Table also gives data for the total number of measurements for each region as well as surface area and population in 1985.

From the individual arithmetic mean values for the different regions we calculated a population-weighted average for the terrestrial gamma-ray dose rates of 47.1 $nGy.h^{-1}$.

In an attempt to determine the usefulness of "in situ" gamma radiation measurements in identifying areas with high indoor radon levels, Figure V shows the values obtained for terrestrial gamma radiation. Comparing this with Figure IV, we found that no meaningful relationship can be established between the two parameters. This is because other parameters such as soil permeability, craks or pressure differences, have an important influence on the radon exhalation processes that control radon levels in houses; it may not, therefore, be directly related to terrestrial gamma radiation emitted from the same soil. On the other hand, as can be seen from the data of Table II, a closer relationship was found between the radioactivity of soils and the distribution of radon in houses.

Table II

REGION	A.M (Bq/kG)			G.M (Bq/Kg)			S.D		
	Ra	Th	K	Ra	Th	K	Ra	Th	K
Andalucia	29.0	30.0	436	26.3	25.5	351	1.58	1.83	2.08
Aragon	37.5	36.8	518	35.5	34.1	469	1.44	1.52	1.72
Asturias	43.7	44.5	410	37.0	40.9	350	1.76	1.54	1.96
Baleares	36.5	31.2	367	34.8	27.7	343	1.39	1.73	1.50
Canarias	65.5	88.2	1014	56.9	77.7	833	1.90	1.89	2.22
Cantabria	45.9	45.8	581	41.4	41.9	481	1.61	1.60	1.92
Cataluña	40.8	39.2	614	35.5	35.2	534	1.68	1.68	2.08
Castilla-Mancha	29.4	42.4	526	26.7	36.7	450	1.58	1.75	1.83
Castilla-Leon	38.8	41.4	674	29.7	36.2	561	1.86	1.78	2.01
Extremadura	45.3	56.8	692	35.1	45.5	592	1.94	1.93	1.81
Galicia	93.9	68.4	999	72.2	57.3	901	1.96	1.87	1.68
Madrid	47.6	57.7	1113	40.9	50.3	999	1.82	1.85	1.81
Murciana	35.8	25.0	443	34.2	23.4	422	1.37	1.47	1.40
Navarra	33.5	28.6	410	31.1	27.6	392	1.46	1.33	1.35
Pais Valenc.	30.3	30.6	400	27.7	27.4	340	1.59	1.85	1.89
Pais Vasco	47.1	46.5	516	38.7	40.7	371	2.04	1.81	2.68
La Rioja	47.1	58.6	740	46.7	58.4	721	1.20	1.18	1.28
ESPAÑA	39.4	41.4	584	32.3	35.1	484	1.75	1.79	1.90

Table III

COMMUNITY CODE	SURFACE (Km2) POPULATION (MILLIONS) (1985)	G.M. (nGy h-1)	S.D.	Nº of measurements	A.M. (nGy h-1)
1	87267 - 6 680	27,63	2,12	141	3494
2	47682 - 1 210	31,50	1 75	46	3515
3	10565 - 1 140	35,31	1,73	19	40,32
4	6396*- 0 867	33,89	1,22	32	34,57
5	7500**-1 420	52,09	1,42	11	55,10
6	5269 - 0 523	42,05	1,48	66	45 32
7	79225 - 1.660	35,28	2,01	145	43,68
8	94010 - 2.610	38,96	1,77	227	45,16
9	31932 - 6 040	44,71	1,58	42	48,78
10	41602 - 1 060	48,62	1,63	105	54,55
11	29442 - 2 840	59,44	1,72	59	67,96
12	7995 - 4.830	75,95	1,35	62	79,12
13	11317 - 0.990	23,35	1,62	18	26,09
14	10421 - 0 518	29,84	1,35	13	31,16
15	5034 - 0.257	50,35	1,17	9	50,91
16	7250 - 2.180	35,82	1,41	17	37,65
17	23260 - 3 720	22,09	1,76	49	25,49
(*)data only referred to Valencia and Ibiza no. 1984 km2					
(**)data only referred to Tenerife no. 1984 km2					
SPAIN	504750 - 38.40	38,41	1,88	1061	45,76

1.-ANDALUCIA 2.-ARAGON 3.-ASTURIAS 4.-BALEARES 5.-CANARIAS 6.-CANTABRIA 7.-CASTILLA-LA MANCHA 8.-CASTILLA-LEON 9.-CATALUÑA 10.-EXTREMADURA 11.-GALICIA 12.-MADRID 13.-MURCIANA 14.-NAVARRA 15.-LA RIOJA 16.-PAIS VASCO 17.-PAIS VALENCIANO

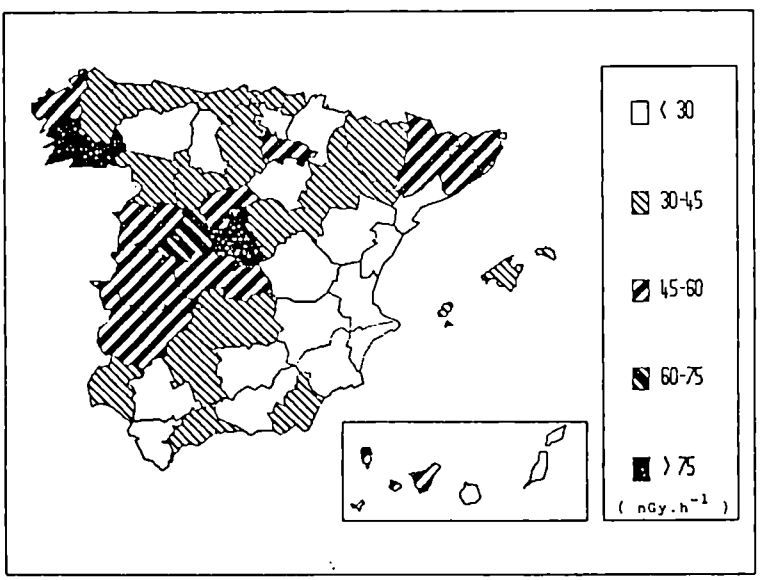

Figure V

With regards to the radioactivity of building materials, Table IV gives us a first evaluation of radioactivity in some building materials for a reduced number of samples that we hope improve in the near future by covering a wider sample.

Finally, few data are available, at the present moment, for the measurement of the equilibrium factor and exhalation rate from soils and building materials. For the first, a sample of only 40 different houses was studied through the continuous measurement of radon gas and working level.

Table IV

Material	No. of samples	Mean activity concentration ($Bq\,kg^{-1}$)			Ra equivalent concentration ($Bq\,kg^{-1}$)	*H* index	*M* index
		^{226}Ra	^{232}Th	^{40}K			
Beach sand	6	5.9	3.7	55.5	15.5	0.04	0.06
Sand I	4	30.3	27.7	30.7	72.1	0.19	0.32
Sand II	7	7.0	2.9	11.5	12.2	0.03	0.06
Clay brick I	3	55.1	43.6	747.4	175.0	0.47	0.69
Clay brick II	8	73.2	59.9	292.3	181.3	0.49	0.78
Cement I	3	25.1	19.6	59.2	57.7	0.15	0.26
Cement II	7	421.8	266.4	599.4	848.8	2.29	3.96
Cement III	5	94.7	66.6	44.7	193.1	0.52	0.98
Cement IV	4	23.3	18.5	85.1	56.2	0.15	0.24
Cement V	5	51.8	40.7	403.3	140.9	0.38	0.58
Cement VI	6	35.5	29.6	203.5	93.2	0.25	0.39
Cement VII	7	53.6	37.7	274.9	126.5	0.34	0.55
Plaster I	3	9.6	4.4	55.5	19.9	0.05	0.09
Plaster II	5	35.9	26.3	155.4	86.5	0.23	0.37
Plaster III	7	50.7	34.0	166.6	112.1	0.30	0.50
Plaster IV	5	11.1	7.4	70.3	27.0	0.07	0.12
Stucco	4	8.1	4.8	74.0	20.7	0.06	0.09
Concrete	24	29.9	31.8	203.5	91.0	0.25	0.36
Soil	12	14.8	11.8	214.6	48.1	0.21	0.32

The range obtained for the equilibrium factor was between 0.2 and 0.8 depending on factors such as ventilation rate, particle size distribution and building material of the houses. Similarly, only 60 different values of the exhalation rate from soil are available and their variability is ranges from 12 $Bq.m^{-2}.h^{-1}$, this time basically depending, not only on the radium content in soils, but also on their physical characterization: permeability, humidity, porosity and diffusion coefficient.

3. Conclusions

As a general conclusion to this Research Project, we can claim that the main objectives have been achieved successfully and the lack of data for natural radioactivity in Spain has been solved. Nevertheless,

further studies are necessary in order to asses both the incidence of the different sources on the concentration of radon in houses, and, of course, the real incidence of radon in the development of lung cancer in the general population. These are the next objectives of our research team.

Publications

Articles published in Spanish journals

- "Radon, principal fuente de radiación natural". L.S. Quindós, J.Soto, P.L. Fernández, G. Newton, J.J. Peña, J. Arteche, E. Villar. REVISTA ESPAÑOLA DE FISICA, Vol. 3, nº 2, pp 22-27 (1989).
- "Medida de la concentración de radón en el interior de viviendas españolas". L.S. Quindós, P.L. Fernández, J. Soto. REVISTA ESPAÑOLA DE FISICA Vol. 5 (1), pp 19-22 (1991).
- "Niveles de 222Rn en el balneario de las Caldas de Besaya (Cantabria)". J.Soto, M.T. Delgado, P.L. Fernández, J. Gómez, L.S. Quindos. REVISTA DE SANIDAD E HIGIENE PUBLICA. Vol 65 (1), pp 61-64 (1991).
- "^{222}Rn en balnearios". J. Soto, P.L. Fernández, L.S. Quindos, M.T. Delgado. BOLETIN SOCIEDAD ESPAÑOLA DE HIDROLOGIA MEDICA. Vol VI, nº 2, pp 102-104 (1991).
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- "National survey on indoor radon in Spain". L.S. Quindos, P.L. Fernandez, J. Soto. ENVIRONMENT INTERNATIONAL. Vol 17, pp 449-453 (1991).

- "A modified Lucas cell for leakage measurement from encapsulated radium sources". L.S. Quindos, P.L. Fernández, J. Soto, G. Newton. APPLIED RADIATION AND ISOTOPES. Vol 42, nº 11, pp 1108-1110 (1991).
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Articles accepted to be published

- "Exposure to natural sources of radiation in Spain". L.S. Quindos, P.L. Fernández, J. Soto. NUCLEAR TRACKS AND RADIATION MEASUREMENTS.
- "Estimate of external gamma exposure outdoors in Spain". L.S. Quindos, P.L. Fernández, C. Ródenas, J.Soto. RADIATION PROTECTION DOSIMETRY.

Articles sent to be published

- "Evolución de la mortalidad por cáncer de pulmón en España (1981-1985)" J. Madrid, L.S. Quindos. REVISTA DE SANIDAD E HIGIENE PUBLICA. 1991.
- "Potabilidad del agua en una región de alto nivel de radiación natural" L.S. Quindos, P.L. Fernández, J. Gómez, C. Ródenas, J.Soto. REVISTA DE SANIDAD E HIGIENE PUBLICA. 1991.

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- "Niveles de radón en casas de la Sierra de Guadarrama, Madrid". L.S. Quindos, P.L. Fernández, J.Soto, E. Villar. XXII Reunión Bienl de la Real Sociedad Española de Física. Mallorca, 1989.
- "Relación entre el tipo de vivienda y la concentración de radón existente en su interior". L.S. Quindos, P.L. Fernández, J.Soto. Congreso de Física Médica. Sevilla. Septiembre, 1991.

- "Medida de niveles de radón con carbono activo". L.S. Quindos. J. Gómez, P.L. Fernández, J.Soto. Congreso de Física Médica. Sevilla. -- Septiembre, 1991.
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- "Measurement of the free exhalation rate of radon from solic samples via an accumulation method2. L.S. Quindos, P.L. Fernández, J.Soto. 32 rd Annual Meeting of the Health Physics Society, Salt Lake City. 1987.
- "Building materials as a source of exposure in houses". L.S. Quindos, J. Soto, P.L. Fernández, G.J. Newton. IV International Conference on Indoor Air Quality and Climate. Berlin, 1987.
- "Survey of radon in Cantabria homes". L.S. Quindos, J.Soto, P.L. Fernández, J. Madrid, J. Arteche. 33 rd Annual Meeting of the Health Physics Society. Albuquerque, 1988.
- "Radon and lung cancer in Spain". L.S. Quindos, P.L. Fernández, J.Madrid, J. Arteche, G. Romero. Workshop on Statistics of human exposure to ionizing radiation. Oxford, 1990.
- "Estimate of external gamma exposure outdoors in Spain". L.S. Quindos, P.L. Fernández, C. Ródenas, J. Soto. V International Symposium on the Natural Radiation Environment. Salzburg. Austria. Septiembre, 1991.

EVALUATION OF THE POPULATION EXPOSURE TO RADON IN THE VICINITY OF URANIUM MINING FACILITIES

Contract Bi6-208 - Sector C12

1) *Galvão*, LNETI

Summary of project global objectives and achievements

The main objectif of this project was to know the different levels of indoor radon in the whole country and to assess the exposure of the portuguese population due to the indoor radon inhalation.

Having the measurement of indoor radon, in Portugal, started by the end of 1986, as a regional survey, in the vicinity of uranium mining facilities and in surroundings of an abandoned radium salts factory, it was proposed to extend these measurements to the whole country.

In zones where high indoor radon levels were found the measurements of indoor radon should be intensified and verified the influence of the outdoor radon in these levels.

In order to evaluate the doses to the portuguese population due to the inhalation of indoor radon, equilibrium factors should be determined.

Objectives for the reporting period

For this last period the aims of this project were:

- to enlarge the indoor radon measurements to whole country (national survey), on a statistical basis.
- to perform a detailed study in areas of higher indoor radon concentrations.
- to perform measurements of radon daughters concentrations and to evaluate the equilibrium factors in some selected dwellings.
- to perform outdoor radon measurements in some selected regions.
- to evaluate the doses to the Portuguese population, due to the inhalation of indoor radon.

Progress achieved including publications

1. Indoor radon

The national survey was carried out in the 276 counties, concerning the 18 districts of Portugal, on a statistical basis of one dosemeter for 2000 inhabitants. Open passive nuclear track detectors were used and exposed for 1-3 month periods.

Whenever possible, measurements were performed twice in each house, in different periods of the year, in order to observe occasional seasonal variations.

The individual indoor radon concentrations corresponding to measurements performed in 4200 dwellings show a large dispersion ranging from 6 Bq m^{-3} (detection limit) to about 4 x 10^{3}Bq m^{-3}. The highest mean values correspond to houses nearby the old radium salts factory (geometric mean of 907 Bq m^{-3}, with a maximum value of 3705 Bq m^{-3}), and the uranium mining facilities (geometric mean of 755 Bq m^{-3}, with a maximum value 2200 Bq m^{-3}).

Nevertheless, some individual values of the same order of magnitute were also found in dwellings from granitic regions.

The geometric mean for each county was calculated and the values ranged from 7 Bq m^{-3} to 200 Bq m^{-3}.

In Table I, the indoor radon means concerning the different districts, can be observed. The geometric mean, per district, range from 16 to 120 Bq m^{-3}.

TABLE I - INDOOR RADON IN PORTUGAL

DISCTRICTS	Indoor radon concentration (Bq m^{-3})		
	Arithmetic Mean	Geometric Mean	Range
Aveiro	39	29	(21 - 141)
Beja	32	21	(7 - 61)
Braga	92	57	(33 - 210)
Bragança	42	24	(17 - 96)
Castelo Branco	175	50	(12 - 223)
Coimbra	50	30	(12 - 165)
Évora	43	26	(13 - 158)
Faro	45	23	(14 - 162)
Guarda	169	120	(28 - 258)
Leiria	31	22	(8 - 88)
Lisboa	22	16	(7 - 66)
Portalegre	70	38	(15 - 207)
Porto	99	41	(13 - 143)
Santarem	34	23	(11 - 65)
Setúbal	24	17	(12 - 37)
Viana do Castelo	79	55	(50 - 160)
Vila Real	84	59	(42 - 154)
Viseu	199	100	(23 - 202)

From the indoor radon individual values, a geometric mean of 37 Bq m^{-3} and an arithmetic mean of 81 Bq m^{-3} were obtained for the whole country.

All the indoor radon results have contributed for the Radiation Atlas-Natural Sources of Ionising Radiation in Europe.

In general higher indoor radon concentrations are observed in ground floor than in upper ones, Table II.

TABLE II - INDOOR RADON LEVELS
(Arithmetic mean)

COUNTY	Indoor radon (Bq m^{-3})	
	Ground floor	Upper floor
Agueda	67 (7)	35 (10)
Amodovar	68 (16)	21 (9)
Arcos de Valdevez	243 (10)	92 (22)
Aveiro	74 (8)	18 (18)
Barcelos	116 (15)	24 (36)
Castelo de Paiva	86 (4)	22 (6)
Espinho	96 (9)	32 (8)
Guarda	507 (19)	177 (55)
Nelas	408 (32)	109 (36)
Ovar	37 (5)	9 (6)

( ) - Number of dwellings

As it can be seen, Fig.1, concentrations until 50 Bq m^{-3} are the most abundant ones (61.3 %) but 8.6 % and 2.6 % of the values are higher than 200 Bq m^{-3} and 400 Bq m^{-3}, respectively, for 4200 surveyed dwellings.

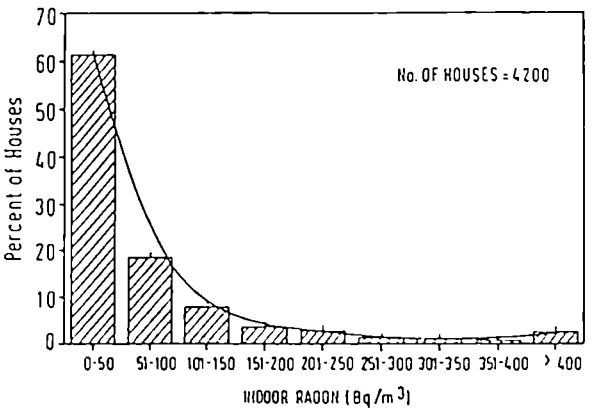

FIG.1 - FREQUENCY DISTRIBUTION OF INDOOR RADON IN PORTUGUESE HOUSES

The smooth curve drew in the histogram represented in Fig.1 shows that the distribution of indoor radon versus percent of houses is approximately a log-normal function.

Significant seasonal variations of indoor radon concentrations were observed either for granitic or non granitic regions with a ratio of about 2 in the winter/summer concentrations in both cases, Figs. 2 and 3.

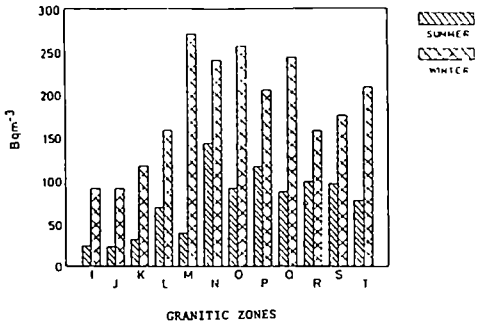

FIG.2 - INDOOR RADON SEASONAL VARIATIONS IN THE GRANITIC ZONES

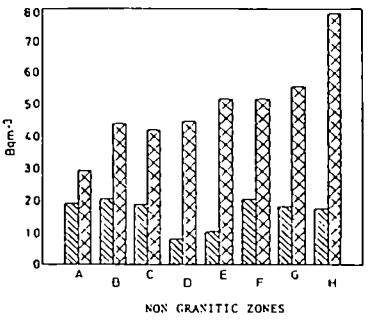

FIG.3 - INDOOR RADON SEASONAL VARIATIONS IN THE NON GRANITIC ZONES

In zones where higher radon concentrations were found monthly measures were performed in some selected houses during a period of 1 - 1.5 years. The obtained results are presented in Table III.

TABLE III - INDOOR RADON IN SOME SELECTED REGIONS

COUNTY		Indoor radon ($Bq\ m^{-3}$) Arithmetic mean	Range
Guarda	dwelling 1	334 (5)	(200-507)
	2	292 (11)	(107-819)
	3	235 (5)	(88-511)
	4	540 (6)	(251-694)
	5	885 (4)	(273-1912)
	6	571 (5)	(491-646)
	7	415 (6)	(255-511)
	8	208 (4)	(137-378)
Barracão	dwelling 1	569 (13)	(256-852)
	2	533 (19)	(301-907)
	3	2795 (27)	(1595-3205)
	4	835 (5)	(365-1870)
	5	124 (11)	(64-236)
	6	207 (4)	(122-347)
Nelas	dwelling 1	372 (14)	(168-427)
	2	363 (20)	(106-774)
	3	397 (10)	(103-907)
	4	761 (5)	(143-821

( ) Number of measurements

2. Radon and radon daughters. Equilibrium factor

Simultaneous measurements of radon and radon daughters concentrations were performed in some selected dwellings from 15 districts.

The average activity concentrations of radon gas and its short-lived decay products were measured under normal living conditions. An integrated system for detection and measurement of short-lived radioactive aerosol alpha emitters, from CEA, was employed.

Samples of air were pumped continuously for 2-3 week periods and the radioactive aerosols containing the short-lived radon daughters were trapped on a filter. A cellulose nitrate film (Kodak LR115) was used as track detector for alpha particles emitted by these daughter products.

By energy differentiation, using moderating screens, it was possible to measure, separatly, the contributions of ^{218}Po, ^{214}Po, ^{212}Bi and ^{222}Rn.

After chemical etching of the film, the traces were counted by optical means.

The results are presented in terms of potential alpha energy due to radon and thoron decay products. The equilibrium factors were also calculated, the observed values ranging from 0.26 to 0.69, Table IV.

TABLE IV - POTENTIAL ALPHA ENERGY CONCENTRATION OF RADON DAUGHTERS EQUILIBRIUM FACTOR

ZONE	COUNTY	$E_{ap}{}_{222}$ (μJm^{-3})	$E_{ap}{}_{220}$ (μJm^{-3})	$E_{a}{}_{total}$	EQUILIBRIUM FACTOR	
Beira	Nelas	0 99	0 10	1 09	0 46	Mean 0 50
	Pinhel	0 03	0 02	0 05	0 53	
Lisboa	Cascais	0 03	0 02	0 05	0 49	Mean 0.53
	Lisboa	0 12	0 06	0 18	0 69	
	Loures	0 05	0 02	0 07	0 61	
	V Vedras	0 06	0 01	0 07	0 46	
	V F.Xira	0 12	0 04	0 16	0 42	
Center	Aveiro	0 06	0 17	0 23	0 40	Mean 0 33
	Coimbra	0 09	0 04	0 13	0 37	
	Fig Foz	0 07	0.02	0 09	0 26	
	Idealhada	0 42	0.04	0 46	0 32	
	Tomar	0 05	0 02	0 07	0 30	
South	Albufeira	0 10	0 04	0 14	0 51	Mean 0 53
	Evora	0 07	0 03	0 10	0 55	
	Loulé	0 02	0 01	0 03	0 53	

As it can be observed the means of the equilibrium factors found from the different zones are similar to the value recommended by UNSCEAR (1982), except in what concerns the mean value from the center zone (0.33).

3. Outdoor radon

Some outdoor radon measurements were performed in selected granitic

areas, close to houses with high indoor radon concentrations. In order to compare these values, measurements were also accomplished in non granitic zones (Albufeira, Loulé).

Grab outdoor air samples, using a Millipore filter AA type 0.8 μm, were performed in some selected regions, mainly in granitic areas.

A portable equipment, RDA-200 from EDA Instruments Inc. (Canada) was employed. Using a filter collection device in series with a flow-through detector, both the gas and the total airborne particulate load which include unattached radon daughters, were simultaneously sampled. A ZnS (Ag) scintillator detector has been employed.

The equipment was calibrated with ^{214}Am and ^{226}Ra sources and the modified Kusnetz method was used. The obtained results are presented in Table V.

TABLE V - OUTDOOR RADON

TOTAL SAMPLE	^{222}Rn Daughters		^{222}Rn
	$\times 10^{-4}$ WL	$\times 10^{-3}$ μJm^{-3}	(Bq m^{-3})
Barracão 1	2.8	5 6	604
	4.2	8 7	639
Barracão 2	1 2	2 6	90
	4 3	8 9	--
Canas de Senhorim	6 1	12 6	119
	9.1	18.9	130
	1.1	2.2	33
	2.4	4 9	73
Covilhã	4 7	9 6	70
Fundão	0 3	0.6	48
	3.8	7 9	58
Guarda	3.1	6 5	61
	5.3	11 0	170
	5.6	11 5	41
	7.3	15.2	75
Mangualde	1.6	3 3	6
	3 6	7 5	-
	1 1	2 2	56
	2.0	4 1	114
Pinhel	1 5	3 1	35
	5.0	10 5	34
Urgeiriça	1.8	3 6	45
	13.5	28 1	171
	3 7	7 7	12
	6.6	13 8	--
Albufeira*	0.3	0 6	< 1
	0.6	1 2	< 1
Loulé*	0.3	0 7	< 1
	0.7	1 5	< 1

* non granitic regions

As it can be seen, the lowest radon concentrations correspond to air samples from the non granitic region and the highest values correspond to samples from Barracão 1. This last sampling point is close to the old abandoned radium salts factory.

Some soil samples were collected in each sampling point and a γ-ray spectrometry was performed. The obtained results are presented in Table VI. It can be observed that the soil sample of Barracão has a high ^{226}Ra concentration, what explains the level found in the outdoor measurement, in the same sampling point (Barracão 1, Table VI).

TABLE VI - ^{226}Ra, ^{232}Th AND ^{40}K CONCENTRATIONS IN SOIL SAMPLES (Bq kg^{-1})

SAMPLING POINT	^{226}Ra	^{232}Th	^{40}K (x 10^2)
Albufeira	16 ± 1.1	14.9 ± 3.1	2.7 ± 0.1
Barracão 1	8034 ± 254	331 ± 10	64 ± 1
Canas de Senhorim	54 ± 4	49 ± 1	13.7 ± 0.3
Covilhã	217 ± 3	12.5 ± 1.5	19.9 ± 1.0
Fundão	55 ± 3	72 ± 10	7.3 ± 0.4
Guarda	89 ± 2	38 ± 1	10.9 ± 0.2
Loulé	14.5 ± 0.5	17.9 ± 1.6	2.9 ± 0.2
Mangualde	150 ± 18	72 ± 11	18.2 ± 0.9
Pinhel	88 ± 9	32.8 ± 1.8	12.3 ± 0.7
Urgeiriça	108 ± 2	88 ± 8	13.7 ± 0.3

4. Dose to the Portuguese population

The dose to the Portuguese population due inhalation of indoor radon was calculated.

From the geometric mean of 37 Bq m^{-3} and applying the equilibrium factor of 0.5 and 0.8 as occupation factor (UNSCEAR,1982) a value of 1.9 mSv/a for the mean effective dose equivalent, concerning the whole country, was found.

5. Conclusions

The global objectives proposed for this project were attained.

Concerning the indoor radon concentrations, the highest values correspond to technologicaly enhanced radioactivity zones. An influence of the geological composition of the soils is also observed.

Considering that 2.6% of the 4200 surveyed dwellings have indoor radon concentrations higher that 400 Bq m^{-3}, some indoor radon mitigation measures, adaptable to the economic conditions of the concerned population, should be studied and proposed.

Concerning the outdoor radon values, these measurements should be intensified in regions where high values were found, in order to calculate the total dose due to radon inhalation.

Publications

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- Faísca, M.C. and Teixeira, M.M.R. (1992) - Determinação da Energia Potencial Alfa dos Descendentes do Radão. To be presented on the 8^{a} Conferência Nacional de Física, Vila Real, September 1992.

RETROSPECTIVE ASSESSMENT OF RADON EXPOSURE FROM LONG-LIVED DECAY PRODUCTS

Contract Bi7-013 - Sector C12

1) *Samuelsson* , Lund University - 2) *Jonassen* , Technical University of Denmark
3) *Falk* , Swedish Radiation Protection Institute - 4) *Poffijn* , Univ. Gent
5) *Vanmarcke* , CEN-SCK - 6) *McLaughlin* , University College Dublin

Summary of project global objectives and achievements

Global objectives

To study long-lived radon decay products in the indoor environment.

To develop detection methods for short- and long-lived radon decay products deposited onto large surfaces.

To investigate the prerequisites for using long-lived radon decay products in dwellings as retrospective risk estimators

Global achievements

Lund University has in all investigated deposited Po-210 and radon concentration levels in 65 single family houses. Swedish Radiation Protection Institute has supported this work with track-etch radon detectors throughout the project period. A pane of glass has been sampled from each dwelling investigated and analysed for implanted Po-210. The age and exposure history of each glass sample has been assessed by interviews and questionnaires. The accumulated radon exposure of each glass sample has been estimated by extrapolating the three-months track-film value. The quotients of implanted Po-210 and radon exposure are scattered around 10^3 [Bq m^{-2}/Bq y m^{-3}] after correcting the Po-210 values for lack of build-up (young samples) or decay (old samples). It is concluded that the fact that the true radon exposure value is not known makes it difficult to "calibrate" the glass-polonium system by *in-situ* sampling of glass panes. In order to be able to tackle the fundamental issue of how implanted activities correlates with absorbed dose to the lung epithelium of the inhabitants, *in-situ* sampling methods must be complemented by well-controlled laboratory studies and room model calculations. Fifthteen household glass panes have been analysed in the laboratory for Po-210 before and after cleaning. The results indicate that trapping of alpha recoils by dirt and dust is a minor problem when utilizing glass sheets from dwellings as a substrate for implanted Po-210 activity. A reference detector for analysing Po-210 on large surfaces by alpha spectrometry has been developed. The detector, an open pulse ionization chamber, accommodates and analyses semi-infinite glass samples undestructively. The latest version, built by the Technical University of Denmark, has a resolution of better than 40 keV (FWHM) for the 5.3 MeV alpha peak of Po-210 implanted into large glass sheets.

The Technical University of Denmark has studied the influence of electric fields on the plateout of short-lived radon daughters on room surfaces and in addition has supported Lund with its workshop facilities, assembling pulse ionization detectors. Plateout rates onto filters or paper disks place on various distances from a support stand at either 0, +7000 or -7000

volt were not significantly influenced by the voltage. The conclusion is that the plateout onto surfaces nearby to an object at a high voltage, e.g. a TV-screen, is only marginally influenced by the electric field. This is in contrast to the situation where the plateout object itself is charged. The experiments with initially charged surfaces show that negatively charged surfaces will attract a considerably larger number of radon daughters than will a neutral or positively charged surface. Surfaces in a home charged by rubbing will be neutralized within, say 15-30 minutes and it is concluded that electric fields such as they may be found in dwellings will not significantly affect the plateout of airborne radon daughters.

Swedish Radiation Protection Institute (SSI) has investigated different autoradiographic techniques for the measurement of Po-210 implanted in glass surfaces. In an effort to improve signal-to-noise ratio both absorbers and track characteristics have been used to discriminate the background alphas. Seven glass panes of known front-surface Po-210 activity have been repeatedly autoradiographed by CR-39 films on the front as well as the back-side. The method if discrimination using elongated tracks seemed to be no better than the absorption method, but it is likely that the track discrimination technique can be substantially improved in the future. Defining the minimum detectable activity (MDA) as three times the standard deviation of the background counts the MDA equals 2.2 kBq y m^{-3} for an autoradiograph extended over 100 days. If the backside of the glass pane can be used as a background the MDA improves to 1.2 kBq y m^{-3}. The conclusion drawn is that measurement of implanted Po-210 in glass panes using autoradiographic alpha-track methods in its present form is feasable, at least in dwellings having enhanced radon levels, and that improvements in the specificivity for Po-210 is to be expected in the future.

University of Gent and SCK/CEN have in a joint project calculated the depth distribution and escape probabilities of radon decay products implanted into glass surfaces by alpha recoils. The range of Pb-214 is less than 55 nm. The mean penetration distance of Pb-210 is slightly greater than that of Pb-214 due to an additional alpha decay. The probability of implanted atoms to reappear at the surface is calculated to be 30%. The relationship between implanted Po-210 activity and radon parameters has been predicted by room model calculations. According to the model the implanted Po-210 activity decreases with increasing aerosol attachment rate. With CR-39 detectors supplied by University College Dublin, *in-situ* alpha autoradiograhpy was tested in four houses of the Ardennes-Eifel epidemiological study. In this first test no clear relation could be established between radon and the Po-210 activity in glass. The detailed information concerning house characteristics and living conditions was utilized in room model predictions of theoretically expected track densities. Although the ratio of calculated to measured number of tracks varied, the performed mitigation in one of the houses was detected quite clearly.

University College Dublin has developed a device (plateometer) to measure the long-term plateout characteristics of short-lived radon decay products. Autoradiographic track-etch technique is used to analyse the plateometer data as well as to determine the surface activity of Po-210 on glass. By means of a specially constructed exposure chamber the alpha energy resolution of CR-39 was investigated. For each exposure the alpha flux and energy were also recorded using a high resolution PIPS detector. Approximately 400 000 tracks were analysed semi-automatically. It was found that track area was the feature that showed the most potential as a means of identifying the energy of the alpha particles in the region of 5.3 MeV (i.e. from Po-210 in glass). As the etching conditions effect the final area of a track, it was necessary to have a high degree of control of the etching procedure and work in order to

optimise these procedures is underway. Also a more empirical approach to track energy resolution has been tried, giving the unexposed CR-39 pieces a small-area "fingerprint" of irradiation from a alpha standard source. Variations in energy resolution response due to variation in etching conditions can by this technique be minimised.

Project 1

Head of project: *Dr. Samuelsson*

Objectives for the reporting period

To develop reference detection methods for long-lived radon decay products deposited on large surfaces

To study the variability of surface Po-210 in dwellings and within dwellings

To identify suitable substrate objects in homes and clarify under which conditions surface Po-210 activity can be used as a radon exposure and lung cancer risk estimator

Progress achieved including publications

The surface activity of long-lived decay products encountered in dwellings is low, typically less than a few becquerels per square metre. Aiming at non-destructive measurements, it was clear from the beginning of the project that only the alpha emitting Po-210 of the long-lived daughters (LRnD) was specific and sensitive enough for the activity levels expected. As solid state alpha spectrometry detectors only come in small areas, it was found necessary to developthe existing concept of pulse ionization chambers towards an open type chamber accommodating plane semi-infinite samples (Figure 1). With technical assistance of the Technical University of Denmark (Dr. N. Jonassen), several slightly different chambers have been built and constructed during the project period. These flow-type pulse ionizing chambers now act as reference detectors for Po-210 implanted in glass surfaces. Though the detectors are mobile, they have been used almost exclusively as laboratory detectors, analysing samples taken from dwellings. The latest version of the detector has a sensitive area of approximately 380 cm^2 and an energy resolution (FWHM) for extended Po-210 sources of better than 40 keV, when high-quality electronics are used. A radon gas exposure of roughly 30 Bq m^{-3} for ten years yields a surface activity of Po-210 that corresponds to the detection limit of the system, assuming a measuring time of 12 hours.

The variability of implanted Po-210 within a house is caused by both dose- and non-dose correlated factors. Exploiting the build-up of implanted Po-210 as a retrospective radon risk monitor it is essential to minimize the influence from the non-dose factors. Exposure geometry is one important non-dose factor and in order to achieve optimum results it is necessary in Po-210 surveys to compare objects of the same type exposed in similar geometries. Openly exposed glass sheets show higher Po-210 values for the same radon exposure than objects in recesses. Future research should try to quantify correction factors for such "restricted view" geometries. Shadowing effects are of great importance as the correction factor can be large. On the other hand, similarly exposed glass objects usually show very consistent Po-210 results provided the radon exposure has been the same. This fact is illustrated in Figure 2, showing Po-210/Rn-exposure ratios for eight windows from a house built from light-weight concrete enhanced in Ra-226. The quotient for windows used for airing ("vent. catch") is low by roughly 40%. Apparently the assumption that the radon concentration close to a window with a ventilation catch is the same as in rest of the room is incorrect.

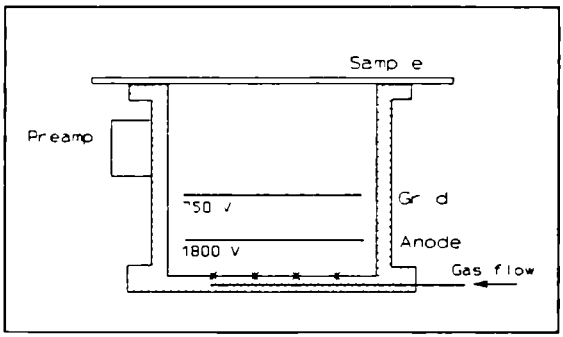

Figure 1. A schematic picture of the open-flow pulse ionization chamber.

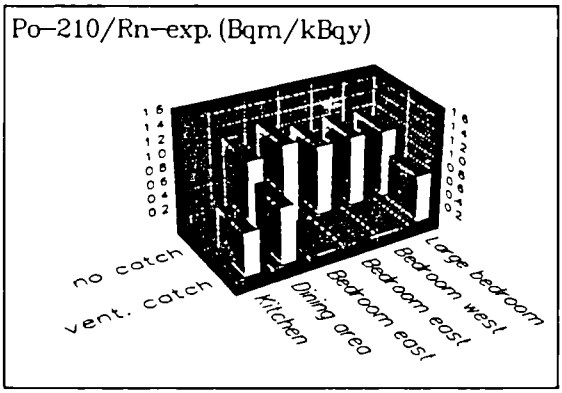

Figure 2. The quotient of the surface activity and the total exposure of different windows in a house.

The variation of the Po-210/Rn ratio for the five "no-catch" windows is surprisingly low (± 10%), considering the difficulties of estimating the relevant radon exposure for this house built in 1967. Another observation is that windows situated above radiators tend to show an enhanced Po-210/Rn-exposure ratio compared with glass sheets openly exposed on walls. The main cause is presumably the increased air turbulence above the radiator, but also cold-surface attraction (i.e. thermophoretic forces) may play a part. An obvious conclusion from the variability study is that only objects with well known exposure history, including position and geometry, are of any value in retrospective radon studies. At present stage of knowledge it is also advisable to analyse more than one such well documented glass sample, in order to improve the precision.

One of the major tasks of the project has been the comparison of implanted Po-210 activities and the contemporary radon-in-air concentration levels. It should be stressed that the quantity "radon exposure" (kBq y m^{-3}) used below, may not be the most adequate quantity for estimating lung cancer incidence, but it was the only quantity that could be estimated with at least some degree of confidence, considering the non-detailed knowledge of house and living conditions and the resources available. The dwellings investigated are mainly single-family houses situated in the southern part of Sweden. A single track-etch film, supplied by the Swedish Radiation Protection Institute, was exposed during a period of 2-3 months, for the assessment of the yearly mean of

radon gas concentration in the room from which the glass sample was taken. The radon exposure of the sample was then assessed as this radon gas concentration times the number of years of exposure, as given by the house-owner. The glass sheets were carefully cleaned in the laboratory and then analysed for Po-210 by alpha spectrometry. The Po-210 values obtained were if necessary corrected for lack of build-up (young samples) and decay (old samples) and plotted against the estimated radon gas exposure (Figure 3). Applying an orthogonal regression technique to the scattered values of Figure 3, the best fit is the line
Y (Bq m^{-2}) = 0.92 X (Bq y m^{-3}) - 0.48. To what degree the scatter in Figure 3 is due to inaccuracy of the exposure estimate and what part is caused by variations in plateout conditions is difficult to say. The spread of values in Figure 3 can be reduced in future exercises by excluding less reliable data, applying plateout geometry corrections etc., but the uncertainty in the exposure estimate can only be eliminated for houses monitored continuously during the whole exposure period.

The range of alpha recoiling nuclei is very short and the probability of recoil implantation into dirt and dust particles residing on a surface must be investigated. Systematic investigations in

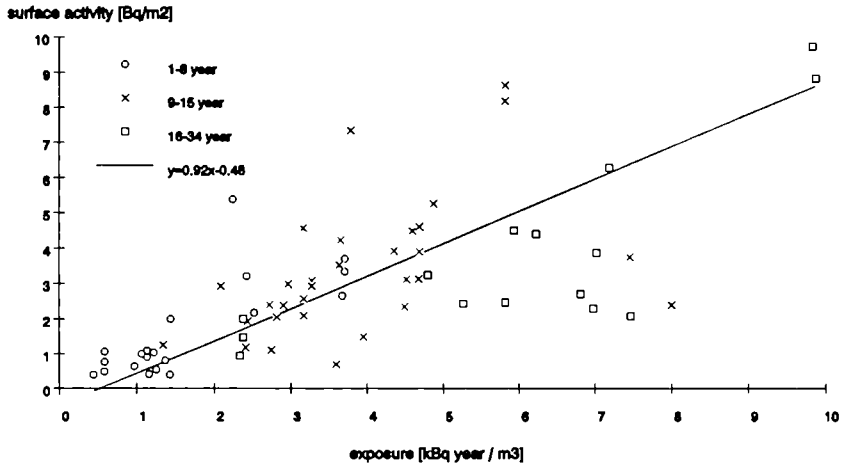

Figure 3. The Po-210 surface activity on glass from different dwellings versus the estimated radon exposure. The radon exposure times are grouped into the three time intervals indicated.

this field are needed. Meanwhile, our pilot study, involving 15 household glass panes, indicates that even for obviously dirty glass samples, most of the Po-210 activity is firmly fixed to the glass surface. This behaviour can be explained by an inhomogeneous distribution of loose contaminants leaving a large fraction of the glass surface open to recoils. For obvious reasons, such objects as mirrors and windows are kept clean during typical living conditions. If a problem of loose contaminations exists, it is in most cases confined to glass sheets covering photos, paintings, etc.

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L. Johansson, B. Roos & C. Samuelsson "Alpha-Particle Spectrometry of Large-Area Samples Using an Open-Flow Pulse Ionization Chamber" Appl. Radiat. Isot. **43** No. 1/2, 119-125, 1992.

C. Samuelsson, L. Johansson & M. Wolff "Po-210 as a Tracer for Radon in Dwellings" Fifth Int. Symp. Natural Rad. Environ., Salzburg, Austria, Sept. 22-28, 1991.

Project 2

Head of project: *Dr. Jonassen*

Objectives for the reporting period

Study of the influence of electric fields on the plateout of short-lived radon daughters on room surfaces.

Progress achieved

It is a well-known fact that radon daughters may be removed from the air by electric fields plating out on room surfaces.
The purpose of the experiments described in the following is to determine whether or not the exposure to an electric field may significantly influence the total plateout, diffusional and field-affected, on a given surface.
The fields may be external fields from charged materials or conductors kept at a voltage in the neighborhood of the surface considered.
Or the fields may originate from a charge on the surface itself.

1. Effect of external fields

In Fig. 1 is shown a metal disk A (diameter 4.7 cm) placed insulated at a height of 23 cm above the table, which can be considered a ground surface.
When the disk is kept at a voltage with respect to ground it will establish a field in its surroundings and thus also at the table surface.
A filter or paper disk B (3.7 cm diameter) can be placed at various distances from the support stand, and thus at a given disk voltage be exposed to various field strengths.
Measurement were performed with A at the voltages 0, + 7000 and - 7000 volt, and B at the distances 15 and 30 cm from the support.
The disk B was exposed to the field from A for a period of 10 minutes and the ^{214}Po-activity counted over a period of 200 s starting 2 minutes after end of exposure.

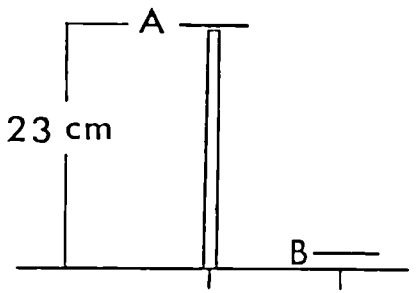


Figure 1
Plateout by external field

Also the activity on a paper disk placed on the metal disk A for the same exposure period was measured.
The results are shown in Table 1.

Table 1. Plateout activity from external fields.

voltage, volt	0	+ 7000	- 7000
activity on B, counts/200 s 15 cm	24	38	24
activity on B counts/200 s 30 cm	25	26	25
activity on A counts/200 s	47	1188	30044

It appears that the field from A has very little, if any, influence at all on the activity plated out on the surface of the table.

The results also show that the activity collected on A increases dramatically when A is kept at a voltage, here $\pm$ 7000 V, indicating the presence of charged airborne radon daughters, positive as well as negative, and also that the field is much stronger at A than at even nearby parts of the table.
The extra activity collected at positive disk voltages is believed to be due to attached radon daughters, while the major part of the extra activity collected at negative voltages is due to unattached, highly mobile, positive ^{218}Po-ions from a much larger volume than is the case with the charged attached radon daughters.

2. Effect of surface charges

If an insulating surface is charged, for instance by being rubbed, the charge will gradually be neutralized by ions of opposite polarity being attracted from the air.
Some of these ions may be airborne radon daughters and the presence of the surface charge may thus affect the natural diffusional plateout of radon daughters on the surface considered.
In order to check if this effect is significant a series of experiments were performed in the following way at a radon concentration of about 2000 - 3000 Bq$\cdot$ m^{-3}.
A sheet of plastic (21x30 cm^2) was placed on the table at a height of 1,5 cm from the table surface. A field meter was mounted 15 cm above the plastic, Fig. 2. The plastic was charged positively og negatively, by a corona discharge, or neutralized, by a bi-polar ion blower.
A paper disk like the ones described above was placed in the middle of the plastic sheet. After a period of 10 minutes the paper disk was transferred to the counting system and the ^{214}Po activity counted for a period of 200 s starting 2 minutes after the end of collection, i.e. the removal of the disk from the plastic.
The electric field was measured continuosly and the collection of radon daughters on the paper disks was repeated with approximately 20 minutes interval until the electric field in practice had been neutralized.
The results of such a series of measurements are also shown in Fig. 2.

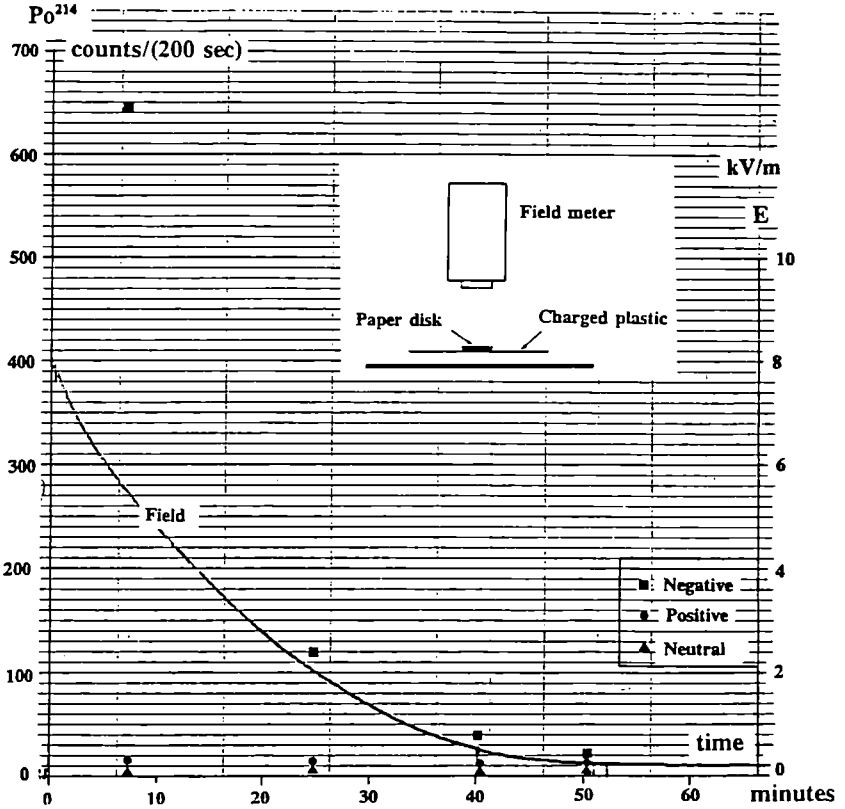


Figure 2
Plateout on charged surface

It appears that the activity collected with a positive charge on the plastic is only marginally, if significantly at all, larger than the activity collected with no charge on the plastic.
With a negative charge on the plastic, on the other hand, it appears that the activity may be several hundred of times larger than with a neutral plastic, and it also appears that the activity collected decays with the field and after about an hour has reached the neutral state value.

If thus an insulated surface is frequently negatively charged to levels comparable with the ones examined above the resultant plateout of radon daughters might be significantly larger than is the case with an uncharged surface.

A likely way of incidental charging of a domestic hard surface like a window pane or the glass in a photo frame is by polishing, and a reasonable guess on the frequency of such an operation is once a week.

Based on these assumptions the following experiments were performed.
Three identical pieces of glass (21x30 cm^2) were placed on insulating supports, 1.5 cm above the surface of the table. One of the glasses was charged negatively, one was charged positively and one was neutralized. On the surface of the glasses was placed CR-39 detectors

for a period of a week, whereafter the films were processed and counted.
The experiments were carried out at a radon level of about 3000 Bq· m^{-3} (5 films on each glass) and 700 Bq· m^{-3} (3 films on each glass).
The results are shown in Table 2.

Table 2. Track density at 1 week exposure of CR-39 films.

radon concentration Bq· m^{-3}	average track density, tracks· cm^{-2}		
	positive	negative	neutral
700	1537	1619	1827
3000	8831	7890	9639

Bearing in mind that the variation in the results for a single group of films varied from 10 - 20 %, the above results indicate that the charging of the glass does not significantly affect the number of radon daughters plating out on the glass surface.

3. Conclusions

Since a fraction of the airborne radon daughters are electrically charged they will move in a electric field.
Such a field may originate from conductors kept at a high voltage. An example of this kind of field is the field in front of a TV-screen or a CRT-tube.
In the present experiments a similar (and stronger) field was established by keeping a small metal disk at a high voltage at a short distance from the surfaces considered.
The results showed that although the disk itself attracted a significant number of extra radon daughters from the air (at positive as well as negative voltages) the plateout at nearby surfaces was only marginally affected.

The field may also originate from the surface itself, if the surface for instance has been charged by rubbing.
It is demonstrated that for a relatively short period after the charging a negatively charged surface will attract a considerably larger number of radon daughters than will a neutral or positively charged surface.

It is, however, believed that a domestic surface is not likely to be heavily charged more often than once a week, and it is shown that with an exposure time of 1 week the initial charging of the surface does not affect the total plateout of radon daughters on the surface.

It can therefore be concluded that electric fields such as they may be found in a normal household will not significantly affect the plateout of airborne radon daughters on surfaces.

Project 3

Head of project: *Dr. Falk*

Objectives for the reporting period

The amount of radon-222 long lived decay products which are embedded by alpha recoil in glass surfaces might be a retrospective measure of radon-222 concentration i dwellings . The objectives were:

- To investigate the feasibility of using autoradiographic alpha-track methods for the measurement of Po-210 embedded in glass surfaces.
- To study different techniques for the discrimination of Polonium-210 alpha tracks from background tracks. Track shape and size as well as absorption layers between the CR-39 detector and the glass surfaces was to be investigated in order to optimize the sensitivity and reproducibility.
- Select a technique on the criteria that it should be a practical method with adequate sensitivity and study the reproducibility and limitations of the method chosen.

Progress achieved including publications

1. Materials and methods

The CR-39 track-etch technique is, at our institute, presently utilized in radon monitoring using plastic holders for the detectors into which the radon gas diffuses. The detectors are chemically etched and analyzed in an image analyzer (Cambridge Instruments Quantimet Q520). The CR-39 detectors used is delivered by TASL in Bristol, UK. The analysis of the detectors has been performed in different ways:

- Standard evaluation at low magnification (4 objective lens) standard selection of "true" tracks using limits on size and shape.
- Special evaluation using a specifically developed reading program which for all detected "features" stores 10 parameters (i.e. size and shape). This has been done using both low and high magnification (4 and 10 objective lens). In the subsequent analysis different acceptance criteria can be tested to optimize analysis.

2. Experiments

The objective of our study is to find a practical method with adequate sensitivity and signal/background ratio to facilitate estimation of long term exposure to radon daughters. The major problem is the background activity of the glass which, when measured using autoradiography, is both significant in magnitude and varying from one glass to the other. The primary task, as we see it, is therefore to minimize the background track density and its variance without lowering the signal from surface activity beyond usefulness. The fact

that the Polonium-210 activity is located at the very surface of the glass has been used in two different ways to discriminate against background activity.

1. An absorber of proper thickness placed between the glass surface and the CR-39 detector will allow most of the alpha-particles emitted from the surface to penetrate the absorber and leave tracks, while alpha particles emitted from activity within the glass (background activity) will due to absorption both in the glass and in the absorber to a less extent be detected. The alpha particles penetrating the absorber will also be the particles emitted mainly in a direction perpendicular to the glass surface, giving round tracks in the Cr-39 detector.
2. The other approach is to expose the CR-39 film in direct contact with the glass surface. As the Polonium-210 is at the very surface of the glass the majority of the tracks will have an elongated shape. The tracks from background alpha-activity will to a less extent be elongated as these alpha particles will to a certain extent be absorbed in the glass before they reach the CR-39 film.

In both these techniques the information on track size and shape was expected to give a gain in the signal/background ratio.

The continued work comprised a series of exposures to glass panes collected from houses in Sweden. Seven different glass panes were used. The Polonium-210 surface activity was determined at Lund University using a large area pulse ionization chamber. The characteristics of the sources used is listed in table 1 below. In all cases it is assumed that the Polonium-210 activity on the back of the panes is insignificant.

Table 1. Characteristic of glass panes used in the study.

ID	Po-210 activity Bq/m²		Age of glass pane (year)
	Front	Back	
A	2.25	no info.	10
B	9.33	-"-	23
C	4.60	0.16	34
D	10.1	0.02	18
E	3.99	no info.	not known
F	3.87	-"-	-"-
G	2.91	-"-	-"-

3. Results

The seven glass panes were repeatedly exposed front side as well as back. Each pane was monitored 2-5 times giving a total of 19 exposures. At each exposure 32 individual detectors were used giving a total of more than 600 detectors. Each detector was analyzed two times:

1. using standard evaluation technique - analyzed area 1.15 cm²

2. using feature store program - objective lens 10 - analyzed area 0.22 cm^2

The analysis using objective lens 10 was suffering from occasional system instability (focusing & light source) problems resulting in deteriorated feature data sets. The method of discrimination using elongated tracks appeared to be no better than the absober method. This we believe is due to varying etching conditions giving different shape characteristics of different etch batches. The results presented in this report are therefore based of standard evaluation technique using absorber.

In future work we expect that further improvement of hardware and software components of the reading system will facilitate the use of larger magnification. It is likely that the discrimination of true tracks from background non-tracks as well as the discrimination of elongated from roundish tracks will improve substantially as a result of such work. We also expect to be able to improve the signal/background ratio by fine adjustment of the mass per area of the absorber.

The results of the analysis is presented in figures 1-2. It is clear from the results that application of an absorber substantially improves the signal to background ratio and lowers the variance of the background within one glass as well as between different glass panes.

The back side of the glass pane can with confidence be used as background only if the surface deposition of Polonium-210 on that side can be assumed to be insignificant in comparison with the front side. An indication on possible surface activity on the back side of the glass can be assessed from track density with and without absorber.

The minimum detectable activity (MDA) is a function of detector exposure time, sensitivity and background variance. If the MDA is defined as three times the standard deviation of the background and the detector exposure time is 100 days it can be concluded from our studies that:

1. When the back side of the glass not can be used as background the MDA will be 2.2 kBq year m^{-3} of radon exposure to the glass pane.
2. When the back side of the glass pane can be used as background the MDA is estimated to 1.2 kBq year m^{-3}.

It is assumed that 1kBq year m^{-3} of radon-222 exposure will result in 1 Bq/m^2 of Polonium-210 glass surface activity. A typical Swedish home has a radon gas level of 60 Bq/m^3. This level will produce above MDA readings if a glass pane were exposed for 36 and 20 years respectively for the two cases.

It can be concluded that the measurement of Polonium-210 activity in glass panes using autoradiographic alpha-track methods is feasible and that retrospective assessment of exposure appear to be possible at least in dwellings with high radon levels.

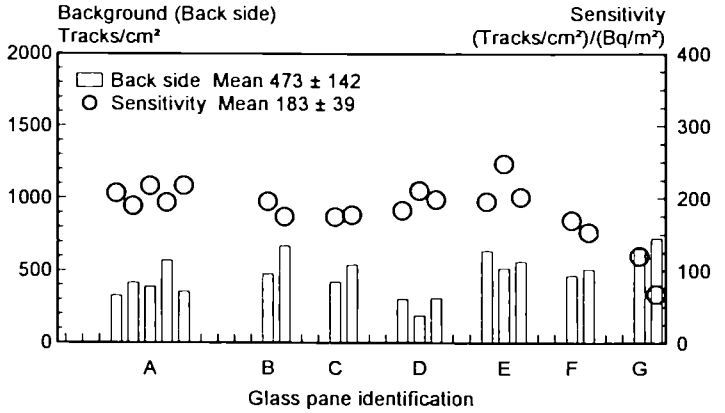


Figure 1 - Standard analyse method 100 days exposure with absorber

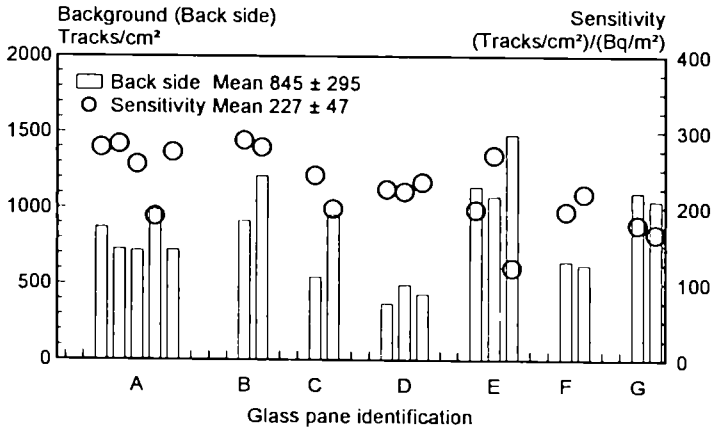


Figure 2 - Standard analyse method 100 days exposure without absorber

Publications

Hans Mellander and Anita Enflo: The alpha track method used in the Swedish radon epidemiological study. Presented at the Fifth International Symposium on the Natural Radiation Environment, Salzburg, Austria Sept. 22-28, 1991.

Projects 4 - 5

Head of project 4: *Dr. Poffijn* - Head of project 5: *Dr. Vanmarcke*

Objectives for the reporting period

Joined project between SCK/CEN (project 5) and RUG (project 4).

The calculation of the depth distribution of implanted ^{210}Po in glass and the determination of the probability of implanted ^{214}Po to escape upon α decay due to the recoil energy.

An experimental and theoretical study of the uncertainties associated with the estimation of the long term radon exposure from the ^{210}Po activity of glass surfaces. In particular it was investigated if household cleaning removes the deposited activity.

The correlation coefficient between the ^{210}Po glass measurements and the past radon exposure was investigated in a number of houses occupied by participants to the Ardennes-Eifel epidemiological study.

Progress achieved including publications

The depth distribution of implanted ^{214}Pb and ^{210}Pb was calculated with the theory of Lindhard (1968) for low energy heavy ions in amorphous media. The details of the calculations are given by Landsheere (1989) and Cornelis (1990a). The layer thickness of ^{214}Pb is not larger than 55 nm. The distribution of implanted ^{210}Pb is composed of the recoil of deposited ^{214}Po and the recoil of implanted ^{214}Po. The average implantation depth is somewhat greater than that of ^{214}Pb. The diffusion of the radon decay products in glass is negligible so that ^{210}Pb and ^{210}Po have the same depth distribution.

Upon α-decay into ^{210}Pb a fraction of the implanted ^{214}Po is capable of reaching the surface. The escape probability is found to be 29.8 %.

The hypothesis that household cleaning wipes away the deposited activity was tested in a number of experiments with cleaning on the short-lived daughters. The cleaning consists of wetting the glass with alcohol and rubbing with a cloth. The details of the experiments are explained in Cornelis et al. (1992). It was found that some of the deposited activity, about 15 %, remains on the surface when cleaned. This may be due to radon decay products forming chemical bonds to the glass or to the fact that glass surfaces are not flat but have hills of several nm.

The implanted decay products are found in a thin layer of less than 100 nm. It should be investigated if decades of household cleaning doesn't remove this layer. Another problem arises in the absence of regular cleaning. A dust and grease layer on the glass may prevent the implantation of a fraction of the recoil nuclei. Occasional cleaning of the glass takes away the activity stuck in the dust layer. Cleaning happens, for instance, before the measurement of ^{210}Po with a pulse ionisation chamber to avoid static electricity problems.

The correlation coefficient between the long term radon concentration and the ^{210}Po surface activity depends on the values of the parameters of the room model. Our model calculations show that the attachment rate to aerosol particles and the plate-out rates of the unattached decay products strongly influence the implanted ^{210}Po activity. Figure 1 illustrates these dependencies. The implanted ^{210}Po activity is given after 10 years of exposure to 1000 Bq/m^3 in a room with a ventilation rate of 0.3 h^{-1} and a surface to volume ratio of 3 m^{-1}. The plate-out rate of unattached ^{214}Bi and ^{214}Pb is assumed to be half of the value of ^{218}Po. The attached plate-out rates are 1/100 of the unattached plate-out rates.

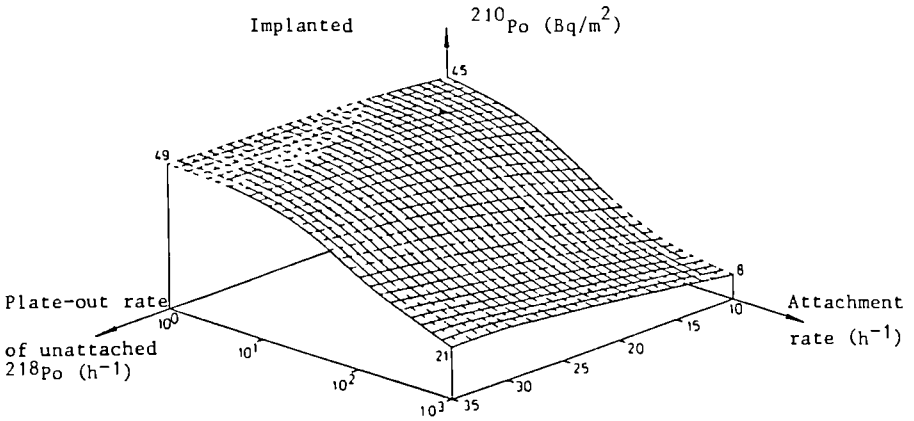


Figure 1

As part of a detailed screening of the problem houses (> 400 Bq/m^3) found in the Ardennes-Eifel epidemiological study some CR-39 detectors were installed together with radon measuring devices. The CR-39 detectors were supplied and analysed by J. McLaughlin of the University College Dublin. In figure 2 the results of these (2 months) measurements are presented. The cumulated radon concentration was derived from the current radon measurements, except for one house where mitigation was performed some year ago. Here the past radon value was taken into consideration. For this first test round no clear relation could be established between radon and the Po-210 activity in glass.

As the study houses were occupied by participants to the epidemiological radon study, a lot of information was available about living conditions and house characteristics. This was used to compare the experimental results with the outcome from model calculations (see table 1). In the house were mitigation was performed model calculations were done for the past high radon concentration of 1500 Bq/m^3 as well as for the current value of 150 Bq/m^3. Although the ratio of calculated to measured number of tracks isn't very constant, the effect of a dramatic change as for

house 4, is detected quite clearly. The observed discrepancies will be studied more systematically, in order to arrive at conclusive results about the possibilities, precision and restrictions of the (passive) ^{210}Po measuring technique.

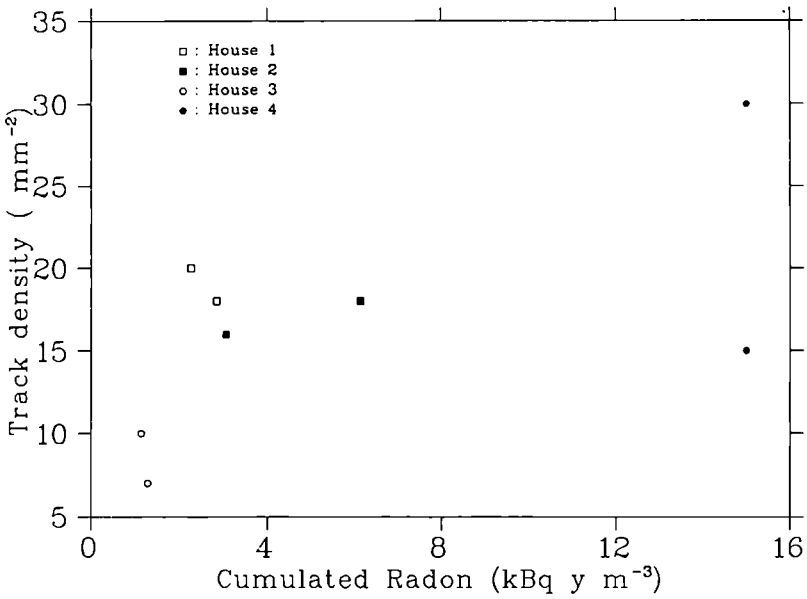


Figure 2

Table 1. Comparison of CR-39 results to model predictions

House	Place	Exposure period (year)	Radon (Bq/m^3)	Track density	Model calculation (arbitrary units)	Ratio
1	Living room	5	567	18	20	1.13
	Bedroom	5	451	20	22	1.1
2	Living room	4	763	16	88	5.5
	Restroom	10 - 15	614	18	40 - 57	2.2-3.2
3	Living room	5	257	7	9	1.3
	Bedroom	5	227	10	11	1.1
4	Kitchen	10 10	1500 150	15	37 3.7	2.5 0.25
	Living room	10 10	1500 150	30	37 3.7	1.2 0.12

Model calculation. The expected number of tracks calculated by means of the room model with appropriate parameters (Plate-out = 18 h^{-1}, Ventilation rate = 0.45 h^{-1}, Attachment rate = 20 h^{-1} for bedroom = 40 h^{-1} for living room and = 500 h^{-1} for house 4).

Ratio. The ratio of the calculated tracks to the counted tracks.

References and publications

Cornelis, J. (1990a). Experimentele studie van de invloed van aerosolen op de in glas geabsorbeerde fractie van de ^{210}Po activiteit. Student thesis, State Univ. Gent, Nucl. Phys. Lab.

Cornelis, J., Landsheere, C., Poffijn, A., and Vanmarcke, H. (1990b). Experimental and theoretical study of the fraction of ^{210}Po absorbed in glass. Proceedings of the 29th Hanford Symposium. Indoor radon and lung cancer : reality or myth. Richland, Washington.

Cornelis, J., Vanmarcke, H., Landsheere, C., and Poffijn, J. (1991). Estimating radon levels from ^{210}Po in glass. Proceedings of the 1991 symposium on radon and radon reduction technology. EPA, Philadelphia.

Cornelis, J., Landsheere, C., Van Trier, A., Vanmarcke, H. and Poffijn, A. (1992). Experiments on glass-absorbed ^{210}Po. Appl. Radiat. Isot. 43 : 127 - 138.

Cornelis, J., Vanmarcke, H., Landsheere, C. and Poffijn, A. (1992). Modelling radon daughters absorbed in glass. Accepted for publication in Health Physics.

Landsheere, C. (1989). Experimentele en theoretische studie van de fraktie van de ^{210}Po aktiviteit geabsorbeerd in glass. Student thesis, State Univ. Gent, Nucl. Phys. Lab.

Lindhard, J., Nielsen, V., and Scharff, M. (1968). Approximation method in classical scattering by screened coulomb fields. Mat. Fys. Medd. Dan. Vid. Selsk. 36 : 10.

Project 6

Head of project: *Dr. McLaughlin*

Objectives for the reporting period

Improvements in (i) a device used to measure the plateout characteristics of short-lived radon decay products and (ii) autoradiographic track-etch methods used to analyse the plateometer data and to determine the surface activity of Po-210 on glass.

Progress achieved including publications

During the first reporting period much effort was devoted to the development and testing of a radon decay product plateometer. This is an instrument which records on a rotating sector of CR-39 (driven by a precision stepping motor) in real time alpha particles (6.00 and 7.68 Mev) emitted by short-lived radon decay products deposited or plated out on surfaces. From an analysis of the time distribution of alpha tracks on the CR-39 the plateout rate of the individual decay products may be derived. A description of this instrument is described in the first Progress Report of this contract and in the proceedings of the NRE V Symposium, Salzburg 1991.

As a working instrument in the physical sense the device has been successful. Improvements in the electronic control unit have been made and the plateometer has been found to operate trouble-free continuously when tested for periods up to a month. Considerable effort during the present reporting period has been devoted to improvements in analysing the alpha track distribution on the CR-39 sector in order to derive the most accurate plateout rates for the individual radon decay products. Software has been written for an image analysis system so that each individual track on the CR-39 can be assigned a set of location and time coordinates. For typical operating rotation speeds of the sector (1 to 2 degree/min) the time resolution of each track is less than 1 second. Surface specific activities of the radon decay products (and hence plateout rates) can be derived from the track location/time data files using gross alpha counting analysis procedures such as those developed by Jonassen, Knutson and others. Radon decay product gross alpha counting methods of analysis are inherently less accurate than those based on alpha spectroscopy. It was therefore decided to investigate methods to achieve energy resolution of the alpha tracks of sufficient precision so that tracks from the two main energies (6.0 and 7.68 Mev) could be resolved. This work also has the added advantage that it can be used for alpha energy resolution of tracks in investigations of Polonium-210 (alpha = 5.3 Mev) on glass surfaces in houses.

1. Alpha energy response of Cr-39

A total of 280 exposures of CR-39 to alpha sources of known energy were carried out in vacuo in a specially constructed exposure chamber. Collimated beams of alpha particles at angles of incidence from normal down to 40 degreees were used. Three types of sources were used:

Americium 241 (with and without absorbers at 5.47 Mev and less), Po-214 (7.68 Mev from electrostatically deposited radon decay products on steel discs) and a non-emanating radium/radon source (4.78, 5.49, 6.0 and 7.68 Mev). This latter source, on loan from Lawrence Berkeley Laboratory (courtesy of L. Ruzer), is of Soviet origin. It consists of a thin Radium-226 deposit sealed to a metal substrate by a layer of titanium oxide of sufficient thickness to prevent the escape of radon gas but sufficiently thin such that the FWHM of each of the four alpha peaks was about 50 kev.

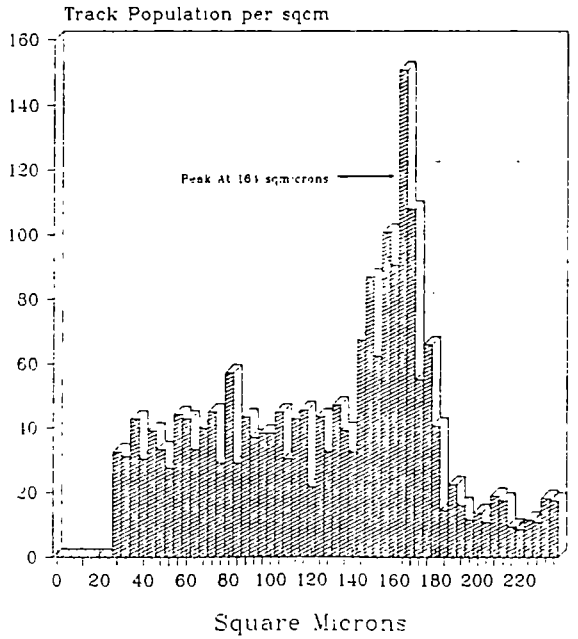
For each source a total of approx. 60 exposures was made covering separate angles of incidence between 40 and 90 degrees. For each exposure the alpha flux and energy were also recorded using a high resolution PIPS detector MCA system. The FWHM energy for the alpha beams ranged from about 20 kev for the Polonium-214 source to about 40 kev for the Americium-241 source (with absorber). Using the information acquired by the MCA system each exposure was of sufficient duration to obtain a minium of 1500 tracks in the CR-39 which ensured an acceptable level of counting statistics and minimal track overlap. Etching conditions were: 6.25 N NaOH at 72^0C ($\pm$ 0.1^0C) for 8 hours. Following etching the tracks were analysed using a Quantimet Image Analysis system. For each individual track the (following features were obtained using the image analysis system: area, perimeter, major axis, minor axis and roundness factor. Approximately 400000 tracks were analysed. In order to minimise error the track analysis was not carried out automatically but took place in a semi-automatic mode in which a human operator previewed on a monitor the digitised images of tracks in each microscopic field of view before image analysis for that field of view was authorised. This procedure while very time consuming and laborious was necessary as due to microwarps in the CR-39 as well as its response characteristics for some energies and angles of incidence slight adjustments to focussing were sometimes necessary to maintain track images at an acceptable degree of sharpness.

The track data files acquired were analysed to determine the relationship between track features (i.e. area, perimeter etc.) and alpha particle energy at different angles of incidence and under different etching conditions. It was found that track area was the feature that showed the most potential as a means of identifying the energy of alpha particles in the region of 5.3 Mev (i.e. from Polonium-210 in glass). The following table gives an example of the alpha energy/track area response of the CR-39 for the standard etching conditions used for collimated alpha particles at an angle of incidence of 70^0:

ALPHA ENERGY (Mev)	4.63	5.47	7.68
TRACK AREA (μm^2)	144 $\pm$ 8.5	110 $\pm$ 10	85 $\pm$ 12

Because the final area of a track is both a function of alpha energy and etching conditions in order to achieve an acceptable and reproducible alpha energy resolution for CR-39 it is necessary to have a high degree of control of etching conditions. Work is therefore continuing to optimise etching conditions to achieve improved track energy resolution. In parallel with this another more empirical approach to track energy resolution is being tried. In this approach a small defined area of each piece of CR-39 received a "fingerprint" or marker of alpha particles of

known energy from standard sources before it is used in field alpha autoradiography of glass or in the plateometer. In this way at the end of a field exposure (for example on a window in a house) the plastic will contain alpha tracks both from the glass and also from the standard sources of known energy. After etching the energy distribution of the non-collimated alphas from the glass can, on the basis of their area (for example), be determined by reference to an internal energy calibration obtained using the areas of the alpha tracks from the standard sources on the same piece of CR-39. Variations in energy resolution response due to variations in etching or even in track registration sensitivity of different batches of CR-39 can thus be empirically minimised. This approach has already been tried with some success on plastics exposed in Belgian houses by the Gent group (see figure below).



This histogram shows the alpha track area density as a function of area on a piece of CR-39 sealed to a glass surface in a Belgian house for some months. A strong track area peak at 164 square microns is apparent.

Based on Americium-241 "fingerprint" alpha tracks on the same piece of CR-39 the peak is estimated to correspond to an energy of about 5.0 ± 0.5 Mev which energy window includes the 5.3 Mev alpha particles from Polonium-210. Work to improve alpha track energy resolution will continue by optimising etching conditions and also by intercomparisons of the alpha autoradiographic technique with pulse ionisation chamber measurements on identical specimens of glass.

2. Assistance to partners

During the contract period assistance was given to other contract partner laboratories at Gent, Lyngby and Lund. This assistance consisted of the supply processing and track analysis of CR-39 detectors which were used to measure, long lived radon decay product activity on glass surfaces in houses (Gent and Lund) or short-lived activity on glass used in studies on the effect of electric fields on plateout (Lyngby). In addition to carrying out normal track analysis (track density, area, perimeter etc.) on these plastics software was written to produce a map of the individual track distribution on the detectors. The purpose of this is to be able to identify and establish the cause of any significant track density inhomogeneities. These can arise either from track registration inhomogeneities present in the CR-39 or (more likely) from uneven deposition or buildup of long lived decay product activity on the glass. Such information will be of value in the interpretation of measurements of house glass activities.

Publications

"A new technique to measure the activities of radon progeny deposited on surfaces", J.P. McLaughlin and B. Fitzgerald, Proceedings of NRE V Symposium, Salzburg, 1991 (in press).

CHARACTERISTICS OF RADON- AND THORON DAUGHTERS AEROSOLS

Contract Bi7-047 - Sector C12

1) *Porstendörfer* , Georg-August-Universität - 2) *Poffijn* , Univ. Gent
3) *Vanmarcke* , CEN-SCK - 4) *Akselsson* , Univ. Lund
5) *Tymen* , Univ. Brest - 6) *Falk* , Nat. Inst. of Rad. Protection
7) *Ortega* , Univ. Politécnica de Catalunya

Summary of project global objectives and achievements

1. Summary

The deposited fraction of the total amount of the inhaled radon daughters and the deposition site in the bronchial tree depend on many parameters such as the physical and chemical characteristics of the airborne particles carrying the radon daughters, the way of breathing, the breathing rate and the size and form of the airways.

Especially the particle size of the aerosol-attached activities and of the "unattached" activities (ultrafine cluster mode) are in all dosimetric models important parameters for the estimation of the natural human radiation exposure.

Some epidemiological studies based on the assessment of retrospective radon exposure where the activity of the long-lived nuclide ^{210}Pb in smooth surfaces (glasses of windows or pictures, mirrors) is determined. The reliability of these studies depends on the knowledge of the variation of plateout processes of the airborne decay products and it is essential to consider the size dependence of these deposition processes.

2. Global objectives

The physical and chemical interaction (particle growth, cluster formation, plate-out rates) of the unattached radon and thoron decay products with trace gases (SO_2, NO_x, humidity) and other aerosol particles have to be studied in radon chambers under controlled conditions. Besides these chamber experiments the exact shape of the unattached and aerosol-attached activity size distributions, the quantity of the unattached activities, f_p, and the equilibrium factor, F, will be measured in the normal domestic environment and the results will be compared with model calculations. These parameters will be determined in different european countries (Spain, France, Belgium, Sweden, Germany) to estimate the real variation and to analyse the influence of different living conditions of the habitants in various geographical regions.

The size dependence of the regional deposition in the human respiratory tract will be measured directly or using screen combinations which simulate the deposition in the nasal cavity and in the tracheabronchial region. These experiments will be completed by theoretical calculations.

For the experimental investigations the sensitivity and efficiency of different experimental techniques for measurements of size distributions (active and inactive) have to be improved and modified techniques will be developed (e.g. diffusion batteries, impactors, electrostatic classifiers). These techniques have to be calibrated with monodisperse aerosol particles. The different methods including different data evaluation methods have to be compared during joint exercises.

3. Global achievements

The radiation protection programmes of the different groups, partly supported by the CEC, dealt mainly during the reporting period (2 years) with the design, construction, and calibration of improved size fractionating instruments, of radon chambers and instruments for the determination of the deposited activity in different parts of the human airways. Some of these measuring techniques were compared during joint exercise. Although the improvement and development of experimental techniques had highest priority, progress was also achieved in the determination of aerosol size

characteristics, activity concentrations of radon, thoron and their short-lived decay products (f_p, F) in the domestic environment, the determination of activity deposition in the human lung and controlled chamber studies concerning the plateout rates of radon progeny:

3.1 Chamber studies

a) The IL group (Göttingen) designed and constructed a radon chamber (0.05 m^3) to study the dynamics of cluster formation processes in the diameter size range 0.5-10 nm. The basic items of this chamber are an electrostatic classifier and a rotating screen diffusion disk in connection with surface barrier detectors for α-spectroscopy. The dimension and the inlet of these instruments were especially designed to minimise diffusion losses of small particles.

b) A walk-in radon room at Lund (20 m^3) was further developed and partially rebuilt. Introductory the interaction of radon daughters with aerosol particles (f_p, F) were studied by varying the aerosol particle concentrations.

c) The Ghent/Mol group measured in a 1 m^3-chamber the plateout rates of unattached radon progeny and found that the diameter of unattached ^{214}Pb is twice as large as the diameter of the ^{218}Po particles.

3.2 Measuring techniques

a) The IL (Göttingen) calibrated a commercial available condensation particle counter (TSI, CPC Model 3025) with monodisperse aerosol particles and found a 50% registration efficiency of about 3 nm.

A low-pressure, high-volume cascade impactor was designed, built and calibrated where the size fractionated activities of the radon and thoron decay products can be measured during air sampling by α-spectroscopy.

b) The Mol/Ghent group built up and calibrated a combination of different screens which simulate the deposition of activity in the nose and bronchi. This "bronchial dosimeter" was checked during the radon and radon progeny intercomparison exercise of the IAEA at Badgastein.

c) The Lund group optimised the design of a multi-orifice impactor and studied the collection efficiency as a function of nozzle-to-plate distance, and of the Reynolds number of the jet. The first stage has been constructed and calibrated.

d) The group of the university of Brest improved the SDI 2001 sampling device; an Andersen impactor in series with 6 channels granular bed diffusion batteries.

e) The technical university of Barcelona established in close collaboration with the german group of Göttingen a radon research group.

A passive detector based on an improved activated charcoal canister has been tested and an α-spectroscopy facility has been developed with a single-screen technique for measurements of the unattached fractions of radon and thoron daughters.

An electrostatic monitor for continuous radon and thoron gas measurements was set up.

3.3 Results of measurements in the domestic environment

a) The group of Göttingen measured size distributions of the thoron decay product ThB (^{212}Pb) in indoor and outdoor environments. More than 80% of the activity is associated to aerosol particles in the accumulation mode with median diameters of 217 nm indoors and 330 nm outdoors, respectively. About 10% of the activity is attached to particles in the nucleation region with median diameters less than 82 nm.

First measurements were performed with the online α-impactor in a low ventilated room with elevated radon concentrations. It was found that the AMAD of the accumulation mode of RaA is about 10% smaller and σ_g is about 10% larger compared to the corresponding values of RaB and RaC.

Side-by-side measurements with different size fractionating devices were performed in Northern Bavaria (Germany) by groups of the EML of the DOE/USA, the ARL, Australia and the IL, Göttingen. Size distributions of the unattached radon progeny show mean median diameters between 0.8-1.2 nm (RaA) with mean geometric standard deviations σ_g between 1.2-1.4 and the tendency of slightly larger RaB particles compared with RaA.

b) The group of the university of Brest carried out measurements in 5 houses of Brittany with elevated radon concentrations (> 400 bq/m^3). An average unattached fraction f_p of 0.09 and median diameters between 110-200 nm of the aerosol-attached activities of the potential alpha energy were found.

c) The group of the university of Barcelona measured by α- and γ- spectroscopy the disequilibrium factor of the thoron decay products ThB(^{212}Pb) and ThC(^{212}Bi). In indoor air an average value C^{ThC}/C^{ThB}=0.63 (range. 0.33-0.83) was found.

3.4 Lung deposition studies

In a pilot study the SSI group (Stockholm) determined in a walk-in radon chamber with elevated radon concentrations and using a low level whole-body counter the amount of radon progeny in different parts of the human airways. Preliminary results show that about 80% of the unattached activity is retrained in the nasal region. This finding support the hollow cast studies of Cheng et al. (1988). Nose and mouth breathing yield that about 20% of the aerosol-attached activities are deposited in the lung region during resting conditions.

References

Cheng, Y.S.; Yamada, Y.; Yeh, H.C.; Swift, D.L. "Diffusional deposition of ultrafine aerosols in a human nasal cast", J. Aerosol Sci. 19(1988)741-751.

Project 1

Head of project: *Dr. Porstendörfer*

Objectives for the reporting period

1) The construction of the radon chamber including classifier and rotating screen disk will be finished and first measurements will be performed.

2) Size distribution measurements of the radon decay products RaA-RaC are planned with the online-alpha-impactor after the end of the calibration procedure. The size distribution measurements of the thoron decay products will be continued.

3) Continuation of size distributions measurement of radon and thoron decay products in indoor and outdoor atmospheres.

4) Other parts of the project deal with the influence of air cleaners on the change of the size distributions and on the amount of the unattached fraction and with the particle growth in atmospheres with high humidity.

Progress achieved including publications

1. Methodology

1.1 Radon chamber A radon chamber of 0.05 m^3 was designed and constructed in the workshop of the IL to study the dynamics of cluster formation processes of radon progeny in controlled atmospheres. The major parts of this chamber are an electrostatic classifier (CL) and a rotating screen diffusion disk (RSDD) for measuring radioactive particles in the diameter size range between 0.5-10 nm. Especially dimensions and the inlet of the classifier were designed to minimize diffusion losses of small particles.

The size fractionated activities on the screens will be measured after air sampling by alpha spectroscopy (with surface barrier detectors), and during and after air sampling using the electrostatic classifier. The check of the performance of the radon chamber and the determination of the efficiencies of the CL and the RSDD (e.g. back/front ratio) is in progress.

It is planned to measure the inactive number size distribution by a commercial available condensation particle counter (TSI, CPC Model 3025) in connection with the screen diffusion technique and the classifier. The capacity of this CPC was tested with monodisperse NaCl and Ag particles. A 50% registration efficiency of 2.9-3.1 nm was found (Fig. 1) and a slight decrease of the efficiency from 1 to 0.96 in the particle concentration region above 60,000 cm^{-3}. The influence of the chemical substance of the aerosol particles on the detection efficiency (hygroscopic or nonhygroscopic) can be neglected.

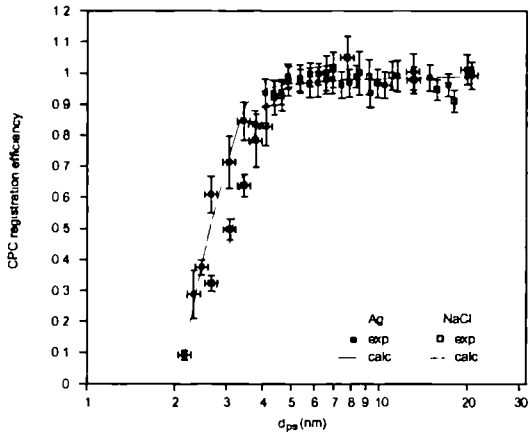


Figure 1: Experimental and calculated registration efficiency of the TSI model 3025 CPC

1.2 Online Alpha Impactor

Activity size distributions of RaB and RaC are usually determined by conventional impactors using gamma-spectroscopic methods after air sampling. However, more detailed investigations require the measurement of the size distributions of the aerosol-attached fraction of all nuclides RaA-RaC. For this purpose a low pressure cascade impactor was designed and constructed where the size fractionated activities can be measured during air sampling by alpha-spectroscopy. This impactor consists of nine stages and a back-up filter and works at a flow rate of 5 m^3/h. The aerosol-attached activities of each stage are deposited on surface barrier detectors with large areas (2000 mm^2) covered with thin foils.

The energy resolution is sufficient to determine all size distributions of RaA-RaC, RaF and ThB from the emitted alpha particles. Rotating detector foils yield sampling times of some weeks for measurements in the human environment at low activity concentrations. The calibration of the most important impactor stages was performed with monodisperse, radioactive marked, liquid aerosol particles in the diameter size range between 80 and 1000 nm (see fig 2).

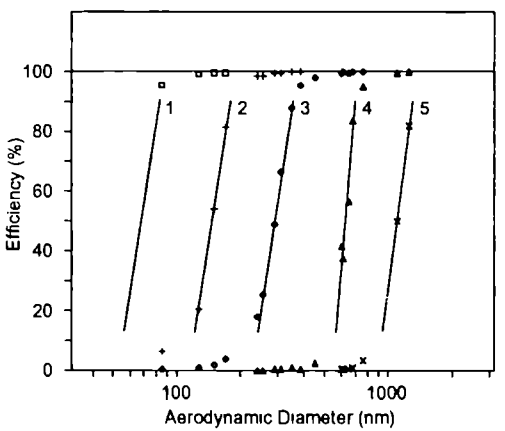


Figure 2: Response function of the last five stages of the online alpha impactor for liquid aerosol particles in the diameter size range 80-1000 nm.

2. Results

2.1 Activity size distribution measurements

Size distribution measurements of the thoron decay product ThB (^{212}Pb) were continued in indoor and outdoor environments using a low pressure impactor (type BERNER). More than 80% of the activity is associated to aerosol particles in the accumulation mode with average diameters of 217 nm indoors and 330 nm outdoors (see table 1). From these measurements it can be estimated that about 10% of the activity is attached to particles in the nucleation region with median diameters less than 82 nm. The ThB size distributions are similar to the size distributions of the short-lived radon progeny.

Table 1: Average ThB size distributions measured in indoor (without additional aerosol sources) and outdoor atmospheres, approximated by a sum of lognormal distributions (AMAD=activity median aerodynamic diameter, σ=geometric standard deviation, f=fraction).

comment/no of meas.	$AMAD_2$ (nm)	σ_2	f_2	$AMAD_3$ (nm)	σ_3	f_3	$AMAD_4$ (nm)	σ_4	f_4
indoor/10	<82	?	0.14	217	1.8	0.86	-	-	-
outdoor/44	<82	?	0.11	330	2.0	0.87	4240	1.6	0.02

First test measurements were performed with the online alpha impactor in a room with elevated radon gas concentration of 500 Bq/m^3. The measured and fitted activity size distributions of all short-lived radon decay products are shown in fig. 3. The AMAD of the accumulation mode of RaA is about 10% smaller and σ_g is about 10% larger compared to the corresponding values of RaB and RaC'. A relative large activity fraction of all nuclides (about 30%) is deposited on the back-up filter. These activities are associated to aerosol particles with diameters smaller than 65 nm (nucleation mode).

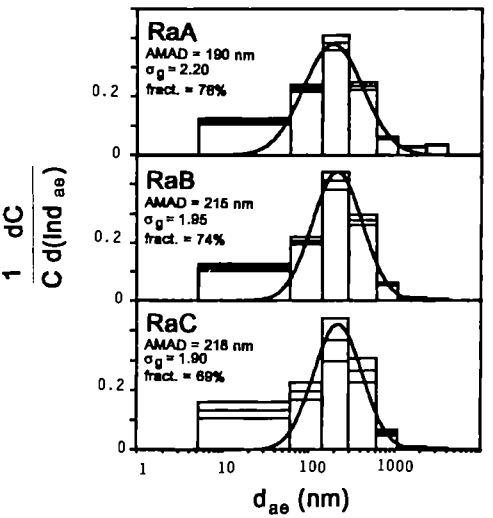


Figure 3: Measured and fitted activity size distributions of the short-lived radon daughters in a low ventilated room. These measurements were performed with the online alpha-impactor.

2.2 Intercomparison measurements

Instrumentations to measure the airborne radon daughters and the unattached fraction has been intercompared with the Swedish Rad. Prot. Institute (R. Falk) and the University of Brest (G. Tymen) during a CEC workshop in Göttingen.

Side-by-side measurements were performed in Northern Bavaria (Germany) in a house with elevated radon gas concentration by the following participants: Environmental Monitoring Laboratory (EML) of the Department of Energy, New York, USA; Australian Radiation Laboratory (ARL) of the Department of Community and Health, Yallambie, Australia and the Isotopenlabor für biologische und medizinische Forschung, University of Göttingen, Germany. These joint measurements dealt with the comparison of different size fractionating instruments (screen diffusion batteries, impactors). Important key results of the evaluated size distributions of the "unattached" radon decay products in a low ventilated room without additional aerosol sources are summarised in table 2. Good agreement was obtained comparing the results of the different groups. The ultrafine radioactive particles can be approximated by a fairly narrow distribution (average σ_1=1.3) with an average median diameter of about 1 nm. The tendency of slightly larger RaB particles (compared with RaA) show the particle growth by cluster formation processes.

A detailed data evaluation of all measurements is in progress.

Table 2: Average size distributions of the "unattached" radon decay products RaA and RaB in a low ventilated room with elevated radon gas concentrations (c_0=200-600 Bq/m^3) and without additional aerosol sources at an average aerosol particle concentration Z=4500 cm^{-3}.

group	AMD$_1$(nm)	σ_1	fraction f_1	nuclide	number of meas.
EML, New York USA	1.19 (1.00-1.30)	1.19 1.02-1.30)	0.34 (0.24-0.48)	RaA	5
	1.80 (1.2-2.6)	1.22 (1.00-1.39)	0.09 (0.02-0.22)	RaB	5
ARL, Yallambie Australia	0.75 (0.50-0.99)	1.21 (1.00-1.39)	0.28 (0.16-0.39)	RaA	8
	0.96 (0.50-1.63)	1.26 (1.03-1.45)	0.09 (0.37-0.64)	RaB	8
IL, Göttingen Germany	1.02 (0.81-1.60)	1.41 (1.01-3.11)	0.50 (0.37-0.64)	RaA	16

Publications

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A. Reineking, J. Porstendörfer, G. Butterweck, J. Kesten "Die kontinuierliche Messung der unangelagerten und aerosolgebundenen Radon- und Thoron- Folgeprodukte in der Luft" Messung von Radon und Radon- Folgeprodukten, Kolloquium des Fachverbands für Strahlenschutz e.V., Berlin, Germany, 6.-7. Mai 1991, Tagungsband (Herausgeber: H. Völkle, D. Borchardt), pp 94-102

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G. Butterweck, J. Porstendörfer, A. Reineking, J. Kesten "Unattached fraction and the aerosol size distribution of the radon progeny in a natural cave and mine atmospheres", to be published in the proceedings of the 5th International Symposium on the Natural Radiation Environment (NRE-V), Salzburg, Austria, September 22-28, 1991

J. Porstendörfer, A. Reineking "Indoor behaviour and characteristics of radon progeny", to be published in the proceedings of the 5th International Symposium on the Natural Radiation Environment (NRE-V), Salzburg, Austria, September 22-28, 1991

A. Reineking, G. Butterweck, J. Porstendörfer, J.C. Strong, H. Vanmarcke, R. Van Dingenen "Intercomparison of methods for investigating the physical characteristics of radon decay products in the indoor environment", to be published in the proceedings of the 5th International Symposium on the Natural Radiation Environment (NRE-V), Salzburg, Austria, September 22-28, 1991

A.Reineking, G. Butterweck, J. Kesten, J. Porstendörfer "Thoron gas concentration and aerosol characteristics of thoron decay products", to be published in the proceedings of the 5th International Symposium on the Natural Radiation Environment (NRE-V), Salzburg, Austria, September 22-28, 1991

J. Porstendörfer, G. Butterweck, A. Reineking, J. Kesten "Activity size distribution of the radon daughters aerosol in mines and tourist caves" Strahlenschutz für Mensch und Umwelt, Jubiläumstagung: 25 Jahre Fachverband für Strahlenschutz, Aachen, Germany, 30. September- 3.Oktober 1991, Tagungsband (Herausgeber: H. Jacobs, H. Bonka) pp 670-676

Projects 2 - 3

Head of project 2: *Dr. Poffijn* - Head of project 3: *Dr. Vanmarcke*

Objectives for the reporting period

Joined project between SCK/CEN (project 3) and RUG (project 2).

To determine the influence of turbulence on the plate-out rates of the unattached decay products of radon. In particular it will be investigated if there is a difference in plate-out rate between the different unattached decay products.

To build a measurement system based on wire screen penetration theory to estimate directly the deposition of the decay products of radon in the nasal cavity and in the bronchial tree. The three measurement channels will be calibrated in laboratory conditions and during a joint exercise.

Progress achieved including publications

The plate-out rates of unattached ^{218}Po and ^{214}Pb were measured in a 1 m^3 chamber of the RUG as a function of the ventilation rate and the generated heat. The details are published in Vanmarcke et al. (1991). The model of Crump and Seinfeld (1981) was fitted to the measured plate-out rates. The expression for k_e thus obtained is proportional to λ_v^3 (ventilation) and $W^{3/2}$ (generated heat). The plate-out rate of ^{218}Po is about three times the plate-out rate of ^{214}Pb. In terms of particle diameter this means that the diameter of the unattached ^{214}Pb particle is twice as large as the diameter of the ^{218}Po particle. This difference is probably due to the chemical properties of the two elements.

A "bronchial dosimeter" has been build at the SCK to measure bronchial and nasal dose directly without deriving a particle spectrum first. The possibility of such a system was described by Hopke et al. (1990). The system is based on wire screen penetration theory to simulate the deposition of the decay products in the nasal cavity and the bronchial tree. A 400-mesh screen operated at a face velocity of 12 cm/s provides an excellent approximation of the nasal deposition curve predicted by Cheng et al. (1988). Four similar screens match the bronchial deposition pattern (James, 1987).

Our measurement system consists of three sampling heads.

1) An open-faced filter which collects the total airborne activity.
2) A 400-mesh screen covering the filter which collects the nasal deposition.
3) Five 400-mesh screens collecting the nasal and bronchial deposition.

After sampling, the back-up filters are counted simultaneously by means of α-spectrometry in vacuum chambers at a pressure of 0.02 atmosphere. The activity deposited in the nasal cavity and the bronchial tree is given by the differences in filter activity. In the indoor environment the differences are expected to be of the order of 10 % so that the

simultaneous measurements must be reproducible within a few percent to give meaningful results. To meet this goal the flow rate of each of the channels is controlled with an identical limiting orifice and the filter remain mounted when transferred to the corresponding vacuum chamber so that the counting geometry is exactly reproducible. The flow rate of each channel at standard pressure and 20°C is 9.1 l/min. The sampling heads have an opening of 4 cm so that the sampler is operated at a face velocity of 12 cm/sec. The 400-mesh screens were obtained from BOPP Switzerland. The wire diameter is 25 μm.

The calibration of the measurement system consists of the determination of the efficiency of one of the channels and the intercomparison of the three channels. The uncertainty and reproducibility of the second step should be less than 1 %, an order of magnitude more precise than the uncertainty on the first step.

The efficiency of one of the sampling channels is determined by measuring the ^{218}Po and ^{214}Po α-activity and the ^{214}Bi γ-activity of the same filter with the "bronchial dosimeter" and with a germanium detector. First, the germanium detector is calibrated in the "filter geometry" with four ^{134}Cs sources prepared by our absolute measurements laboratory. The ^{134}Cs activity was distributed homogeneously over a disk with the same diameter as the active part of the filter. The distance from the source to the detector is 40 mm. The ratio of the photopeak efficiency of the germanium detector at 609.3 keV (^{214}Bi) to 604.7 keV (^{134}Cs) is 0.9927. The cascade summing corrections were derived from Schima et al. (1983) and Griffiths (1971). A value of 0.965 was found for the 604.7 keV peak of ^{134}Cs and 0.977 for the 609.3 keV peak of ^{214}Bi. A photon branching ratio of 0.976 was used for the caesium peak and 0.448 for the bismuth peak. From the ^{134}Cs sources a value of 0.00542 was derived for the efficiency of the germanium detector in the "filter geometry" at 609.3 keV.

Radon concentrations of about 5 kBq/m^3 were generated in a 10 m^3 chamber. Before supplying radon, cigarette smoke was introduced to enhance the aerosol concentration and thus the equilibrium factor. Sampling was performed, after a period of at least 1 hour, with open-faced filters in the three sampling heads. The mounted filters were transferred to the vacuum chambers in less than one and a half minute. They were counted for three periods except for the first filter which was counted for two periods. During the third period the gamma activity of this filter was determined with the germanium detector. The number of ^{214}Po α-counts that would be detected during this decay period was calculated from the data of the previous decay periods. The ^{214}Bi and ^{214}Po activity is equal due to the short halflive of ^{214}Po. From the surface of the 609.3 keV peak and the efficiency of the germanium detector the number of ^{214}Po deintegrations is obtained. The detection efficiency of the channel is the ratio, between the expected number of α-counts and the total number of deintegrations. The average value of three measurements is 0.143. The total uncertainty is of the order of 5 % at 1 standard deviation.

The second step, the ratio between the three channels, is determined from the equilibrium equivalent radon decay concentrations. Seven measurements were performed. The reproducibility of the ratio's was found to be of the order of 0.5 %. The efficiences of the three sampling heads are 0.1430, 0.1530 and 0.1473.

A measurement was performed in a room with a high radon concentration. The sampling period was 10 min. and the two decay periods were 50 sec. to 5 min. 50 sec. and 20 min. to 50 min. The radon progeny activities are :

	^{218}Po Bq/m^3	^{214}Pb Bq/m^3	^{214}Bi Bq/m^3	EEC Bq/m^3
1 : Open-faced filter	2560 ± 60	1560 ± 30	1430 ± 30	1614 ± 9
2 : One screen	1710 ± 50	1520 ± 30	1390 ± 30	1491 ± 8
3 : Five screens	1690 ± 50	1430 ± 30	1340 ± 30	1422 ± 8

The nasal and bronchial depositions as a fraction of the airborne activity are :

Deposition Formula	^{218}Po	^{214}Pb	^{214}Bi	EEC
Nose (1-2)/1	0.330 ± 0.030	0.026 ± 0.026	0.026 ± 0.031	0.076 ± 0.007
Bronchia (2-3)/1	0.008 ± 0.026	0.058 ± 0.025	0.036 ± 0.031	0.043 ± 0.007

The reported values depend on the validity of the model of respiratory tract retention on which the design of the bronchial dosimeter is based.

Measurements with the bronchial dosimeter are planned in more than 20 Belgian dwellings during the next CEC contract. The radon concentration, the aerosol concentration and the inactive size distribution will be measured simultaneously to evaluate, apart from the bronchial and nasal depositions, also the unattached fraction, the equilibrium factor and the AMD of the attached fraction.

The SCK and the RUG both participated to the radon and radon progeny intercomparison exercise of the IAEA at Badgastein. Although the conditions in the mine tunnels were not favourable because of a relative humidity of 100 % and strong variations and gradients in radon concentration, the results of our measurement systems are in line with the results reported by the four reference laboratories. The average nasal and bronchial deposition in the Heilstollen Böckstein gallery as a fraction of the total airborne activity are :

Deposition	^{218}Po	^{214}Pb	^{214}Bi	EEC
Nose	0.56	0.16	0.01	0.23
Bronchia	0.03	0.03	0.06	0.04

The large values for the nasal deposition indicate a high unattached fraction in the Heistollen Böckstein gallery.

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Project 4

Head of project: *Prof. Akselsson*

Objectives for the reporting period

The objectives for the reporting period were to further develop the experimental facility for radon/aerosol studies, to develop a multi-orifice impactor which combines a low cut-off diameter with a high flow rate and to perform introductory controlled studies of the interaction between radon daughters and aerosol particles.

Progress achieved including publications

During the reporting period the experimental facility has been further developed and partially rebuilt. The previously used radon room, which has been described elsewhere (see "resulting publications" #1 and #3) is no longer in use. Instead, a new room has been designed and built at Lund Institute of Technology. The radon room itself is made of stainless steel and has a volume of 20 m^3. It has an air lock with a volume of 3 m^3 (figure 1). All joints of the room are welded for optimum tightness.

In the walls of the chamber there are seven interchangeable hatches. The hatches are either made of stainless steel (with or without outlets) or glass windows (figure 1). This makes it possible to customize the room without destructing the walls themselves (figure 2). The hatches can also be used for plateout measurements, simply by removing them and placing them on a large-area pulse ionization chamber. A schematic view of the facility is shown in figure 2.

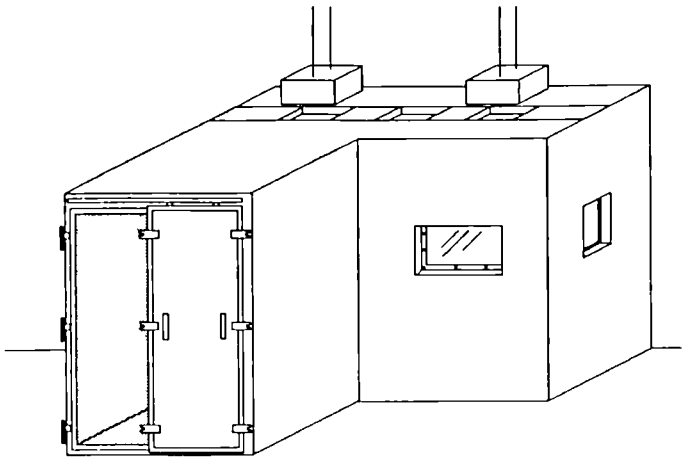

Figure 1. The new radon room at Lund Institute of Technology.

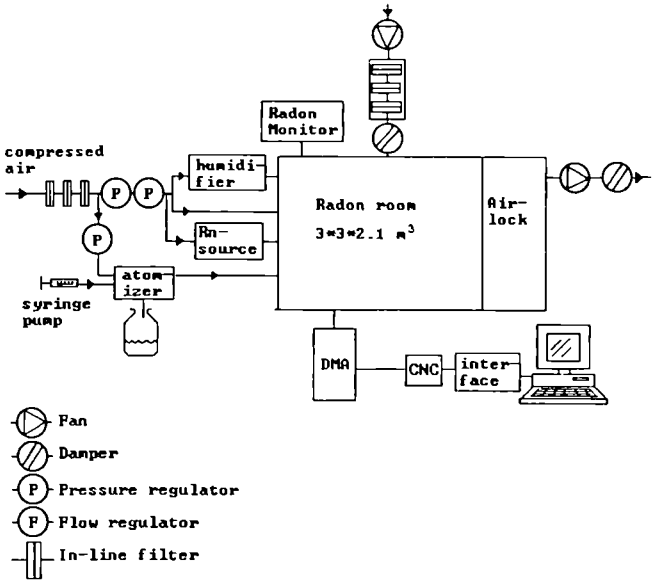

Figure 2. Schematic view of the radon progeny exposure system.

Dry pressurized air is filtered and humidified and then supplied to the room. Whenever there is a need for higher ventilation rates, outdoor air is pushed through a three-stage filter unit and into the room. Various aerosols can be added to the room.

The experimental facility is also used for plate-out studies connected to the "glass method" for retrospective assessment of radon exposure (CEC project B17-CT90-0013).

Multi-jet impactor

The first stage of a multi-orifice impactor has been constructed and calibrated. In order to optimize the impactor design, the collection efficiency characteristics have been studied as a function of nozzle-to-plate distance, and of the Reynolds number of the jet. The nozzle plate of the current stage has 2704 laser-drilled orifices. The diameter of the nozzle plate is 26 mm and the orifice diameters are 50 um. A cut-off diameter down to about 100 nm can be achieved. An example of a cut-off characteristic, as a function of the square root of the Stokes' number, is given in figure 3 (Air flow: 24 l/min., pressure drop over the impaction stage: 13 kPa).

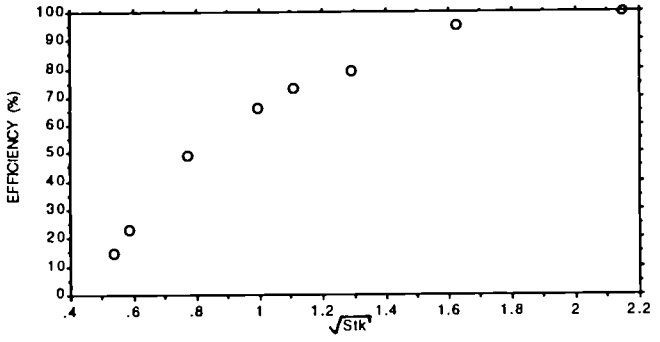

Figure 3. Cut-off characteristic of the impactor stage at a flow rate of 24 l/min.. The 50% cut-off corresponds to a particle diameter of 150 nm. A sharper cut-off can be achieved by increasing the flow rate and decreasing the nozzle-to-plate distance.

Resulting publications

#1 An Experimental Facility to Simulate Radon Progeny Behavior in Dwellings, Proceedings of the 29th Hanford Symposium on Health and the Environment. Richland, USA, October 1990.
(Eklund P., Bohgard M.)

#2 Multi-Jet Impactor with 50 Micrometer Diameter Nozzles for Uniform Deposition of Submicron Particles. Proceedings of the Symposium of the Nordic Society for Aerosol Research, Gothenburg , Sweden, November 1990.
(Gudmundsson A., Bohgard M., Hansson H-C)

#3 A Full-Scale Experimental Set-Up for Determining Relevant Parameters for Radon Daughter Behaviour in Dwellings. Proceedings of the Symposium of the Nordic Society for Aerosol Research, Gothenburg, Sweden, November 1990.
(Eklund P., Bohgard M.)

#4 A Large-Scale Experimental Facility for Studying the Interaction Between Radon Daughters and Airborne Particles in Dwellings. Abstract, European Aerosol Conference, Karlsruhe, September 1991.
(Eklund P., Bohgard M.)

Project 5

Head of project: *Dr. G. Tymen*

Objective for the reporting period

In some Brittany's houses, caracterised by consequent radon levels ,a pilot study was carried out in order to characterize indoor radon daughters. Five of these houses were selected in which sources and transfert ways of ^{222}Rn were in the same time investigated. This work was performed in collaboration with the "Laboratoire d'Etudes et d'Intervention Radon et Polluants" de l'Institut de Protection et de Sureté Nucléaire du Commissariat à l'Energie Atomique (Drs. RANNOU, ROBE).

Instrumentation used in the RnD study is reported in table 1. One of the objective of this first part of the C.E.E. contract was to check the ability of the SDI 2001 to determine size distribution α activity due to radon progeny and particularly the one of individual daughters.

Table 1

Parameters measured	Methodology	Type of measurement
Radon 222	ionization chamber	continuous (response time 1 min)
Unattached fraction	wire-screen + filter (Thomas Method)	15 min sampling time
Attached fraction	CEA-SDI 2001 Samples	30-60 min sampling time
PAEC ($\mu J.m^{-3}$)	Mimil II portable device (Rolle's method)	Spot
Particle size distribution	TSI 3040 + CNC	semi-continuous

The SDI 2001 sampler is a combination of an ANDERSEN MKII Impactor followed by a six channel granular bed diffusion battery. This last diffusionnal system comprises 5 tubes with 1 to 5 mm glass beads under various depths, the 6th being used as open channel. Flowrate through these tubes was controlled by critical orifice, corresponding to an inlet flowrate of 28.3 $l.min^{-1}$ at the level of the impactor. This sampler, previously calibrated in the Commissariat à l'Energie Atomique, was conceived in order to determine particle size distribution of particles in the 0.007-15 µm range. It is based on a suitable adaptation of Freed'hom equation solution using the non-linear iteration method of Twomey.

Progress achieved

Due to irremediable collection of unattached fraction on inlet and on first collection plates of the impactor, this ultrafine fraction of RnD was separately studied by a 250 mesh stainless wire screen calibrated in the 0.5-5 nm size range, with a cutt-off diameter of 4 nm.

Parallely, global Potential Alpha Energy Concentration was episodically measured thanks to a portable device (CEA Mimil II), bought in the frame of this contract. This last equipment was tested at the occasion of comparative experiments carried out in April 1991 at the Isotopen Laboratorium of Gottingen University.

One of the aim of this study was to compare α activity size distribution with natural particle size distribution. This last one was determined through a TSI 3040 DB coupled with a condensation particle counter, and continuously obtained each 12 min. size interval.

One of the major problem of this investigation concerned the method of alpha counting. Because of the long time of transfer of filters and impactor plates to α counters, it was not possible to measure activity not before four minutes after the end of sampling. For that reason we used the Tsivoglou method to determine size distribution of RnD by using a non-linear iteration method from concentration data calculated on each sample. However, the degree of unaccuracy of this procedure was quickly confirmed by unrealistic solutions on individual size distributions of RnD. So only global α activity size distribution was considered as valid.

Experiments were conducted in five houses caracterised by radon activity concentration higher than 400 $Bq.m^{-3}$ and PAEC higher than 1 $\mu J.m^{-3}$. Samples were taken during daytime in living-rooms of these houses, in non smoking and closed room conditions (but ventilation was not measured). The only sources of particles was occasionnaly due to cooking activities.

Table 2 resume results obtained without distinction between investigated houses.

Table 2. Summary of results on unattached fraction and Activity Mean Diameter of attached fraction(28 experiments).

Unattached fraction f_p	Mean : 0.086 Range : 0.008-0.49
Attached fraction	0.11 µm < AMD global < 0.2 µm 0.07 µm < AMD Pb^{214} < 0.13 µm 0.1 µm < AMD Bi^{214} < 0.23 µm

Mean Equilibrium factor measured during this study (F=0.26), was found the same magnitude as in our general survey in Brittany.

Unattached fraction measurements show a large variation of data in the range of 0.01-0.45 with mean value of 0.086 close to the results of Reineking and Porstendorfer.

Concerning size distribution of α activity, it was found that for low aerosol concentrations (no particle source) a simple, rather narrow distribution was generally observed in the 10-500 nm size range, the activity mean diameter being within 100-200 nm. In presence of particles sources-e.g. during cooking activities in the kitchen- the attached activity spectrum appeared to be enlarged and of a bimodal aspect in agrement with Reineking-Porstendorger findings.

Fig. 1 gives three exemples of those situations. However if the presence of the impactor upstream from the granular bed allow to detect the presence of RnD particles of size above 300 nm and to avoid collection of large particles as it might happen in systems based on screnns only, that increases the number of samples to be analysed for determination of complete size distribution. For that reason and because of statistical unaccuracy in α counting procedure at low level of RnD concentration, it was decided at the begining of this year to reconsider the procedure of counting. This project, carried out in collaboration with the electronic laboratory of CEA was slow because of problems of restructuration inside CEA. This should be planed again in some weeks.

At the end of 1991, it was also decided to conceive an integrated measuremnt device of unattached fraction by using a judiciously calibrated diffusion battery having a track detector as collecting support of this ultrafine component. First thinkings yielded to suggest an annular diffusion battery of 30 cm lenght able to collect unattached fraction (mainly formed of Po^{218}) on the internal cylindrical part of the system on which a LR 115

film detector, covered by a mylar film of 13 µm was stretched. First results indicated that this idea might be give interesting results but further research was necessary in order to minimize and quantify the direct effect of radon gas.

We are now engaged on this way

Publications

M.C. ROBE, A. RANNOU, J. LE BRONNEC and G. TYMEN. Le radon dans les habitations : identification des sources et des voies de transfert, et caractérisation des aérosols radioactifs produits". GIGG Colloque International sur la Géochimie des Gaz. Mons 1990. To be published in *Annales Geologiques de Belgiques* (1992).

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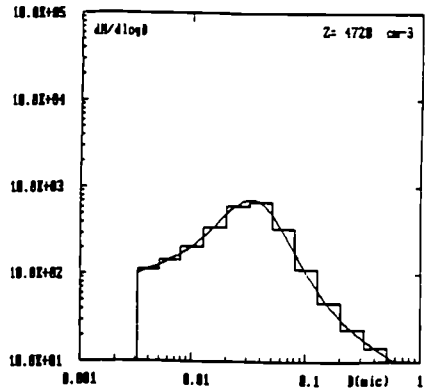
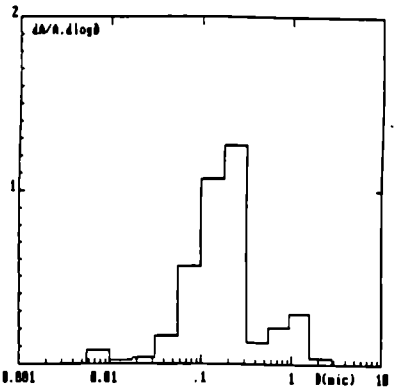
G. TYMEN. Caractérisation des descendants du Radon". Journées IAI-APPA. Paris Octobre 1991. To be published in *Pollution Atmospherique* (1992).

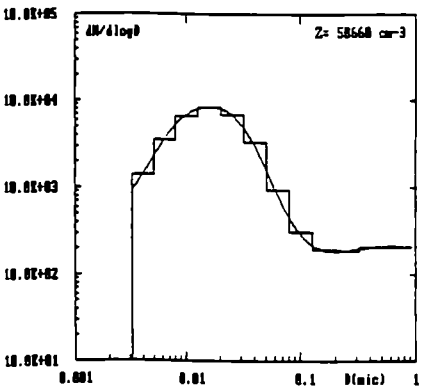
M.C. ROBE, A/ RANNOU, J. LE BRONEC, G. TYMEN. Le radon dans les habitations. Identification des sources et des voies de transfert" *Proceedings of the 8th International Congress of the International Radiation Protection Association*. Volume II. Montréal, 17-22 mai 1992,pp 1363-1366 .



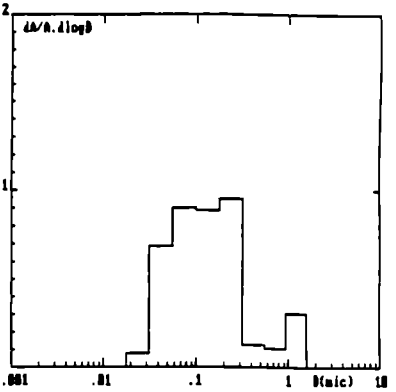
Particle size distribution (living room, house n°4, no aerosol source).



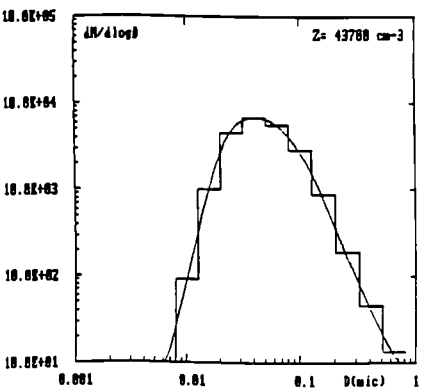
Attached α activity size distribution (unattached fraction f_p = 0.083).



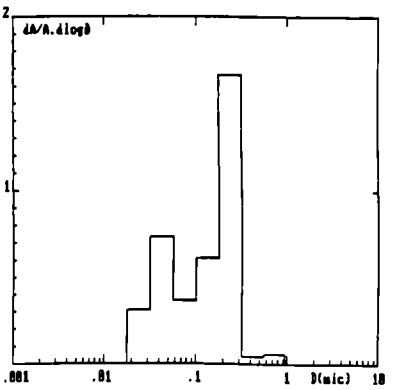
Particle size distribution (Living room, house n° 4, cooking activity in the kitchen).



Attached α-activity size distribution (unattached fraction : f_p = 0.031).



Particle size distribution (Living room of house n°1, cooking in the kitchen).



Attached α activity size distribution (unattached fraction f_p (0.01).

Figure 1

Project 6

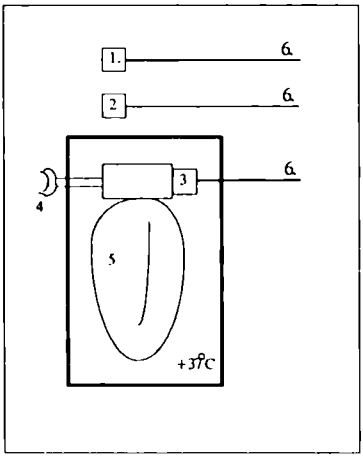
Head of project: *Dr. Falk*

Objectives for the reporting period

The health effect from exposure to atmospheric radon-222 and its short lived decay products is due to the deposition of the airborne decay products in the human respiratory tract and the subsequent radiation doses delivered to the living tissues. The deposition to the bronchial tree is assumed to be of greatest concern for the assessment of the dose received. The deposited fraction of the total amount of radon daughters inhaled and the deposition site is dependent on many parameters such as the physical and chemical characteristics of the airborne particles carrying the radon daughters, the way of breathing, the breathing rate and size and the form of the airways. The objectives are to experimentally study the uptake and the regional deposition of inhaled radon daughters in humans with special attention to the characteristics of the airborne radon decay products such as the unattached fraction and nasal breathing.

Progress achieved including publications

The experimental studies to determine the fraction of inhaled radon daughters deposited in the human air ways has been carried out with a combination of two different techniques. The total amount of radon daughter deposited during the exposure was determined by measurement of the radon daughter concentration in inhaled and exhaled air (Fig. 1). The site of deposited radon daughters were immediately after the end of the exposure assessed by external γ-measurements of the subject in a low level whole-body laboratory (Fig.2).



1. Filter for inhaled air. (Environmental air)
2. Collection of unattached radon-daughters. (Wire screens)
3. Filter for exhaled air.
4. Mouth piece.
5. Rubber bladder.
6. To air pump and volume meter.

Fig. 1 Experimental set-up for measurement of the total deposition of inhaled radon daughters

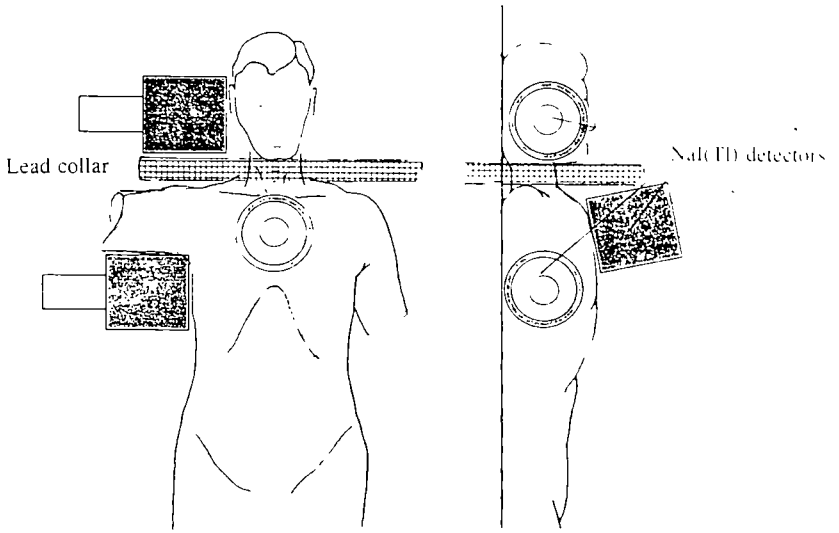


Fig. 2 Experimental set-up for measurement of the regional deposition of inhaled radon daughters

During circumstances when the atmosphere has an aged aerosol, which is the case indoors most of the time, the size distribution of the aerosol carrying the radon daughters is quite well known and the deposition in the human airways can readily be assessed from the known behaviour of aerosols in the size range 0.05 μm to several μm in diameter.

The deposition behaviour in humans of the "unattached" radon daughters is not so well known due partly to the small size of the "unattached" fraction and partly to the incomplete knowledge of the dynamic processes that takes part within the warm and humid atmosphere of the respiratory tract.

The experiments carried out during the reporting period have focused on the different deposition pattern between the "unattached" fraction and the radon daughters carried by an aged aerosol.

1. Exposure conditions

A walk-in radon-chamber having a volume of 30 m^3 was used for the exposure, where the concentration of radon-222 and the radon decay products, temperature, aerosol concentration, ventilation rate and humidity were continuously recorded. Numerous exposures with various aerosol concentrations ere tested. For the attempt to experimentally determine the fate of the "unattached fraction" two different extreme condition were chosen. One condition was when the aerosol concentration was high enough to give no significant "unattached fraction" and another condition was with a low aerosol concentration where the

"unattached fraction" dominated.

The high aerosol concentration was achieved by using an aerosol generator, but before the exposure the aerosol generator was turned off to allow for "aging" of the aerosol for at least one hour giving stable conditions during the exposure period. The low aerosol concentration was achieved by closing the ventilation system of the chamber and running a air-cleaner inside the radon-room. The air-cleaner was turned off more than one hour before the exposure to allow stable conditions during the exposure. An aerosol concentration of less than 300 particles/cm^3 could be maintained in this way, but when the subject entered the room the aerosol concentration increased a little due to aerosols emitted by the subject.

2. Results

The experimental difficulties associated with inhalation studies on humans are numerous. To obtain a exposure situation similar to what is normal indoors the subject had to enter the radon-room to start the exposure. The plate-out of radon daughter onto the surface of the subject during exposure was avoided by covering the entire body with a one-piece suit. Even the skin of the face had to be covered. This was specially important during exposure with low aerosol concentration. Before the external γ-measurement, the subject was obliged to changed to an uncontaminated measuring suit. The exposure time was kept short to minimize the influence of radon-222 gas absorption in the body, disturbing the signal from the internal deposited radon daughters. As the determination of the amount of radon daughters deposited in the respiratory tract were calculated from the concentration of the radon daughters in the exhaled air and in the room air the collection of the radon daughters from the exhaled air had to be done so that the divergence from the normal breathing was as small as possible.

Keeping the above mentioned and other sources of error under control have given results which are illustrated in fig 3 and summarized as

- ~ 20 % of the attached inhaled decay products is retained and deposited in the lung region for mouth-breathing during resting conditions.
- ~ 26 % of the attached inhaled decay products is retained of which about 5 % is deposited in the nasal region (head measurement) and about 21 % in the lung region for nose breathing during resting conditions. The aerosol carrying the radon decay products is an aged aerosol.
- more than 90 % of inhaled activity is retained for nose breathing during resting condition for low aerosol concentration when the unattached fraction is about 80 %. This means that the unattached fraction is found to be retained to 100 % as expected. About 80 % of the unattached fraction is retained in the nasal region (head measurement) and less than 20 % can be deposited in the bronchial region. These findings supports the results from a penetration study of ultrafine particles through a nasal cast (CHENG et al).
- Clearance of deposited radon daughters from the respiratory tract was also studied. No significant clearance could be found compared to the physical decay of the deposited activity.
- The feasibility to obtain knowledge of importance from experimental studies on humans for the dose estimation of inhaled radon daughters is demonstrated.

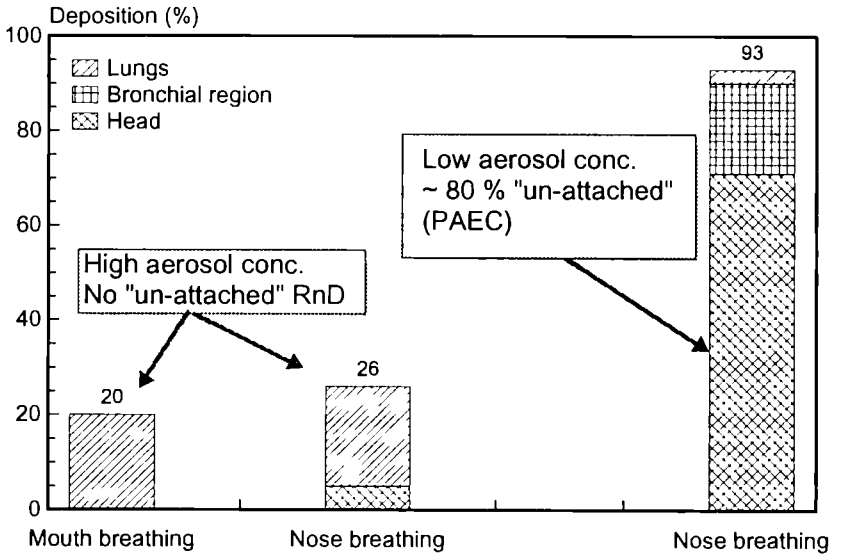


Fig. 3 Deposition of inhaled radon progeny in human air-ways during different exposure conditions.

References

1. R Falk, H Möre, L Nyblom and I Östergren. Regional deposition of radon decay products in human airways. Presented at the fifth International Symposium on the natural radiation environment, NRE-V, Sept. 22-28, 1991, Salzburg.

Project 7

Head of project: *Dr. Ortega*

Objectives for the reporting period

1. Development of a training programme attached to the isotopenlaboratorium of Göttingen.

2. Development of a passive detector devoted to undertake a campaign of measurements linked to the use of other active techniques.

3. Setting up of some facilities in focused do mesurements with active techniques on radon and thoron decay products concentration in the air, the equilibrium factor and unattached fraction under realistic conditions in the Mediterranean coast.

Progress achieved including publications

1. The training programme has been accomplished according to the agreements with the Isotopenlaboratorium of the Georg-August-Universität of Göttingen.
2. A passive detector based on an improved activated charcoal canister with a desiccant layer has been tested satisfactorily.
3. An alpha spectroscopy facilities has been developed with a screen diffusion battery for active measurements of short level radon decay products concentration and unattached fraction.
4. Setting up of an electrostatic monitor equipment for continuous radon and thoron measurements.
5. Checking of alpha and gamma measurements methods for the evaluation of ThC/ThB in the air.

Publications

Contribución de los descendientes del Radon-222 y del Toron a la dosis efectiva individual y colectiva.

Proceedings of the XVIII Meeting of the "Sociedad Nuclear Española". October 1991.

Contribution to the group of the polytechnical university of Catalunya (by X. Ortega, X. Dies, M. Novell)

The training plan began with a visit of Dr. Porstendorfer to Barcelona in July 1990. During this visit it was decided that Dr. X. Dies, belonging to the Spanish group, would stay in the Isotopenlaboratorium in Göttingen in August 1990. After

the stay and a short visit to Göttingen, by Dr. X. Ortega, leader of the Spanish group, it was agreed to implement some experimental facilities in Barcelona, with the aim of doing some measurements on radon and thoron decay products concentration in the air, the equilibrium factor and unattached fraction under realistic natural conditions on the Mediterranean coast, taking into account the fact that measurements on this type have never been carried out in Spain. On the occasion of the contractors meeting in April 1991, it was decided to pursue the training plan by moving Dr. M. Novell to Göttingen in the next month of July 1991.

The activities of the group have been concentrated in the following items:

1. Passive detection

A passive detector has been developed based on the original design by A.C.George. The response of the canister has been tested in an environment with constant radon concentration of 340 Bq/m^3 and 75% relative humidity. The effective sampling rate, was not constant, instead, it decreased during the sampling period. In order to avoid this problem, a modified version of the activated charcoal collector with a dessicant (Silica-gel) has been developed.

In the new configuration for the passive detector the desiccant is a part of the diffusion barrier which reduces the absorption and desorption rate of both ^{222}Rn and water vapor. Nevertheless the effective sampling rate, **calibration factor** measured in l/min, becomes nearly constant during the sampling time.

Fig.1 points out the characteristics of the passive detector with and without desiccant.

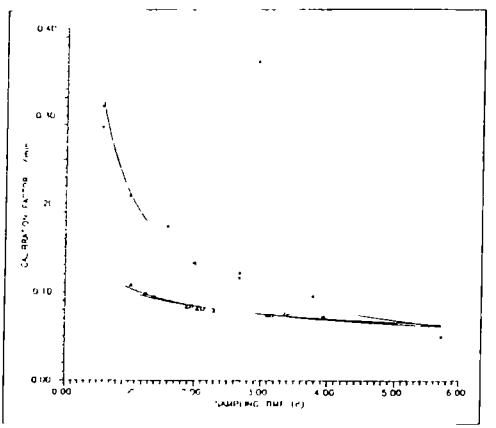


Fig.1 - ^{222}Rn adsorption by activated charcoal collectors as a function of sampling time.

2. Active measurements of radon decay product concentration in the air and the unattached fraction

In relation with this technique the following items have been developed:

1. Setting up an alpha spectroscopy system with screen diffusion battery for active measurements of short lived radon decay products concentration in the air and unattached fraction (C_1, C_2, C_3, C_1^u, C_2^u, C_3^u and f_p). This system has three passivated implanted planar silicon (PIPS) detectors connected to a multichannel buffer. The buffer is controled by a portable computer in order to move easily.
2. Automation of the system: switching on and off the multichannel buffer and the pumping station, measurement of mass flow rate, storage the spectrums, and data evaluation methods.

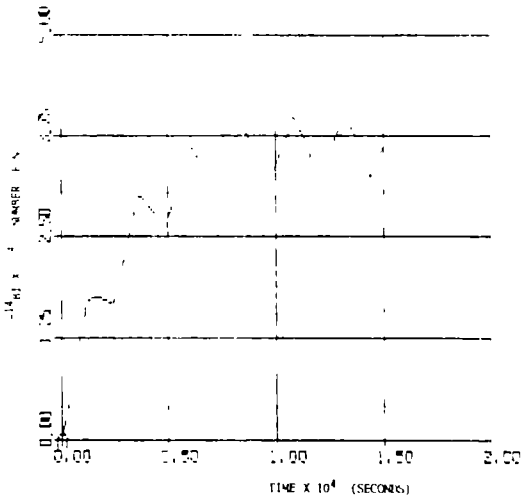


Fig. 2 - Temporal variation of ^{214}Bi concentration in the membrane filter during pumping (20 minutes) and waiting (20 minutes) periods.

3. Optimisation of the measurement conditions in order to get more accuracy. Using a digital simulation language, the temporal variation of radon decay products concentrations in the membrane filter has been evaluated during pumping and waiting periods (Figure 1).
4. Statistical studies have been performed with the aim of calculating the associated error to the radon decay products concentrations measurements. It can be useful in the optimisation studies.

3. Electrostatic monitor for radon and thoron concentration measurements

Since the Isotopenlaboratorium from Universität of Göttingen provided us with an electrostatic chamber, the following items have been tackled related with this technique:

1. Setting up the electrostatic monitor for continuous gas radon and thoron concentration measurements. This monitor is also connected to the multichannel buffer and controled by the portable computer. With the aim of controlling the effect of the humidity, a dryer system has been included.
2. The monitor has been automated in order to evaluate the temporal variation of gas radon concentrations in the air.

4. Measurements of thoron progeny

Attention on has been focused the the evaluation of the concentration of ThB (^{212}Pb) and ThC (^{212}Bi) in the environment and the extent of disequilibrium among them. For the measurement, standard filter techniques used for radon progeny work well for thoron progeny.

When the gamma counting was used it was necessary to work with a high-volume air sampler. The operation flow rate was 40 m^3/h and the air passed through a fibre-glass filter. The progeny concentration is evaluated by means of a single counting time a few minutes after sampling by measuring the gamma activities of ^{212}Pb and ^{208}Tl in a germanium detector.

For the alpha particle counting, the flow rate was lower than for gamma counting (1 m^3/h) and the air passed through a membrane filter. The concentration of ThB and ThC is evaluated by means of two counting periods. One of them is a few minutes after sampling and the second one performed about 4 hours later. Employing alpha espectroscopy, the alpha particle emitted after the decay of ^{212}Bi (8.8 MeV from ^{212}Po) is easily resolvable from the lower-energy alphas that come from the other radon and thoron progeny.

SITE	ThB	ThC	ThC/ThB
CLOSED ROOM	1.51 1.96 1.33	0.86 1.47 1.13	0.57 0.75 0.83
LECTURE ROOM	0.17	0.13	0.73
CELLAR	0.90 0.36	0.54 0.12	0.61 0.33

Average activity concentrations (Bq/m^3) of ^{212}Pb and ^{212}Bi measured in indoor air.

To evaluate those concentrations the grab sampling facility was set up. Accurate results with their associate errors will be obtained after and optimization of measurement protocol.

ASSESSMENT OF THE GEOLOGICAL FACTORS INFLUENCING THE OCCURRENCE OF RADON HAZARD AREAS IN A KARSTIC REGION

Contract Bi7-059 - Sector C12

1) *O'Connor*, Geological Survey of Ireland
2) *Madden* , Radiological Protection Institute of Ireland (formerly Nuclear Energy Board)
3) *McLaughlin* , University College, Dublin - 4) *McAulay* , Trinity College, Dublin
5) *Brock* , University College, Galway
6) *Van den Boom* , Bundesanst. Geowissenschaften

Summary of project global objectives and achievements

1. Rationale

Radon and its decay products in the indoor environment arguably constitute the most significant natural radiological impact on human health. For this reason, it is important that we should attempt to understand the nature of radon generation in bedrock and its derivative soil cover and the migratory routes to surface dwellings. Such an understanding will undoubtedly be of assistance in the formulation of effective radon remedial strategies aimed at limiting the radiological risk to the population at large.

2. Global objectives

The primary aim of the project was to carry out an integrated and multidisciplinary investigation of the geological factors controlling the occurrence of certain high radon exhalation sites in Western Ireland. Specifically, the project set out to:-

(i) Determine the geological controls of radon production and migration in karstic limestone terrain.

(ii) Develop a more efficient and effective field sampling methodology for radon detection and test the use of soil-gas helium mapping as an aid in delineating radon migratory routes.

3. Global achievements

3.1 Selection of study area

A field study area was selected by the project team in Western Ireland, centred on the village of Moycullen (Co. Galway), where elevated indoor ^{222}Rn levels had been reported during monitoring carried out by U.C.D. in 1987. The study area straddles the NW-SE trending boundary or contact zone between the, in part, uraniferous late Caledonian Galway Granite and its unconformable cover of younger Carboniferous karstic limestones. These bedrock lithologies are overlain by varied, and often thick, glacial deposits which include a substantial component of fluvioglacial sands and gravels. The geological and topographic relationships of the study area are shown schematically in a cross-section (Fig. 1a). Surface dwellings in which indoor ^{222}Rn concentrations were measured, are distributed throughout the area and overlie either granite or limestone bedrock.

Technical annexes, which include details of the methodologies employed, tabulations and statistical summaries of the data obtained, and computer-integrated maps of all spatial geodata have been prepared by each of the partners and lodged with the Commission to

supplement the summary of results presented here.

3.2 Results of geological, geophysical and geochemical investigations

Investigations carried out by GSI comprised systematic field mapping of the bedrock geology and glacial deposit geology of the study area, supported by a reconnaissance total-gamma survey and a diamond drilling campaign (11 boreholes) of selected surface and subsurface targets. These geodata, together with other spatial data depicting the geographic distribution of indoor ^{222}Rn concentrations (RPII), soil gas ^{222}Rn and ^{4}He concentrations (BGR), and soil ^{226}Ra activities (TCD) were digitized and computer-integrated to aid interpretation using customized mapping software (Autocad) available at GSI.

Geochemical analysis of 82 samples of rocks and soils recovered from surface or in drillcore was completed by TCD, using high resolution gamma spectrometry. The measured ^{226}Ra, ^{234}Th, ^{228}Ac and ^{40}K activities of samples were used to identify potential ^{222}Rn sources.

Geophysical investigations carried out by UCG (under subcontract to GSI) involved detailed resistivity surveys (EM-VLF-R, VES and dipole-dipole array) in the vicinity of houses with high indoor ^{222}Rn levels in 3 selected sub-areas. The resistivity data were used to aid definition of subsurface bedrock structures which might act as ^{222}Rn migratory routes.

Assessment of the results of geological, geophysical and geochemical investigations identified the likely potential radon sources and migratory routes in the study area, which are summarized in Table 1. Radon availability at a particular house site is controlled by a combination of the proximal existence of a radon source *and* the presence of localized subsurface structures (fractures, faults, shear zones, cavities) in bedrock which act as zones of enhanced permeability.

3.3 Results of indoor ^{222}-Rn surveys

Time-integrated indoor ^{222}Rn measurements ($\geq$90 days exposure) using closed passive CR-39 detectors were completed by RPII in 235 houses almost equally divided between granite and limestone terrains. Concentrations ranged from 8 Bq m^{-3} up to 725 Bq m^{-3} with an arithmetic mean concentration of 82 Bq m^{-3} and a median concentration of 53 Bq m^{-3}. Overall, 10% of houses had ^{222}Rn concentrations in excess of 200 Bq m^{-3} (National Reference Level). When considered in lithological terms, 13% of houses underlain by limestone and 6% of houses underlain by granite had indoor concentrations in excess of 200 Bq m^{-3} (see Fig. 1d). There is no obvious systematic spatial pattern to the indoor ^{222}Rn data, and high and low concentrations occur, often contiguously, over both granite and limestone terrains.

3.4 Site-specific Investigations

A co-ordinated series of site-specific investigations at 18 houses, completed by RPII, UCD and TCD, involved (i) time-intergrated (passive) and instantaneous (active) soil gas ^{222}Rn measurements, (ii) determination of ^{226}Ra, ^{234}Th, ^{228}Ac and ^{40}K in soils, and (iii) terrestrial gamma radiation measurements. UCD successfully developed and tested a new multi-chambered type of CR-39 detector which allowed a much greater range of soil gas ^{222}Rn concentrations to be measured. A soil permeability probe was also developed but adverse ground conditions precluded its use in the study area.

The ranges of soil gas ^{222}Rn concentrations measured at sites using both passive and active detectors are shown in Table 2.

Table 2

	Passive (CR-39)	Active (Lucas Cell)
Granite	340-58760 Bq m^{-3}	330-108370 Bq m^{-3}
Limestone	2600-53010 Bq m^{-3}	4560-165165 Bq m^{-3}

Large within-site and between-site variability was encountered. No apparent correlation was observed between measured soil gas and indoor ^{222}Rn concentrations, although the within-site variability posed a serious problem to proper interpretation.

Measured ^{226}Ra activities in soils at specific house sites ranged from 7 to 89 Bq kg^{-1} (average 48 Bq kg^{-1}) and, again no correlation with indoor ^{222}Rn levels was apparent.

Terrestrial gamma measurements at specific sites indicated average absorbed doses of 58 nGy h^{-1} over granite and 48 nGy h^{-1} over limestone, consistent with the relative radioelement contents of each lithology.

3.5 Results of combined soil gas ^{222}Rn-^{4}He investigations

A total of 367 soil gas ^{222}Rn samples and 447 soil gas ^{4}He samples were collected by BGR using a modified grab sampling technique. Radon concentrations were determined on a Pylon AB-5 monitor and helium concentrations by mass spectrometry. A successful intercomparison test of RPII and BGR grab sampling techniques under field and laboratory conditions was also carried out.

A statistical summary of the soil gas ^{222}Rn and ^{4}He data is shown in Fig. 1c and Table 3.

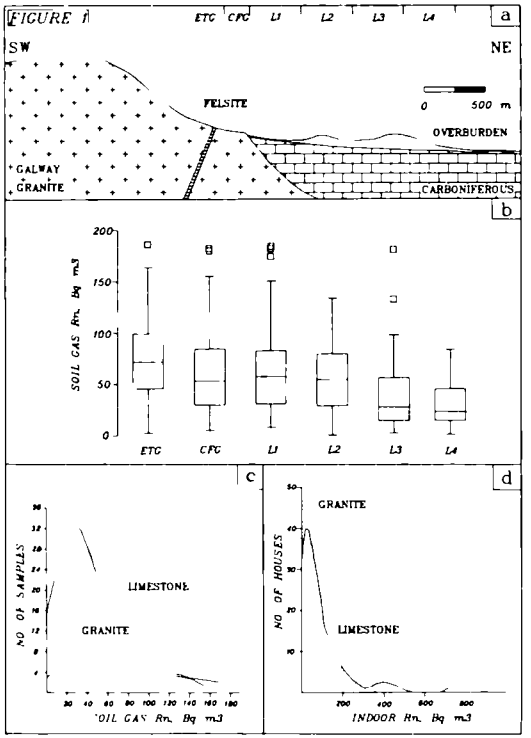
Table 3

	^{222}Rn (Bq m^{-3})	^{4}He (ppb)
Granite	2600-186300 (median 65650)	5013-5685 (median 5283)
Limestone	400-184000 (median 37300)	5092-5759 (median 5267)

Although the median soil gas ^{222}Rn value recorded over limestone is only half that over granite, nearly twice as many houses built on limestone had indoor ^{222}Rn levels in excess of 200 Bq m^{-3}. For the study area, the maxima of the radon distributions are, perhaps, a better guide as to whether or not an indoor problem is likely to exist.

Table 1: Radon Sources and Pathways

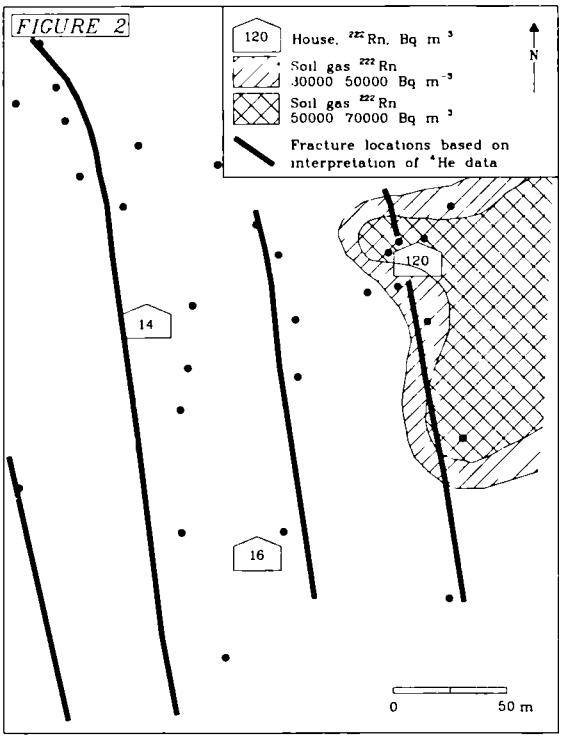
	Source	Radioelement Content	Geographic Distribution	Migratory Pathways
1.	Main Galway Granite	**Moderate** (resistate) accessory minerals)	Widespread	Intergranular; along fractures (all scales); altered shear zones; in solution in groundwater
2.	Felsite Dykes	**High** (U, Ra in labile accessory minerals	Localized linear zones	linear fracture zones occupied by dykes
3.	Murvey Granite	**High** (U, Ra in labile accessory minerals	Not exposed (located in contact zone if present)	Along contact zone (sheared)
4.	Lower Carboniferous Limestone	**Low**	Widespread	Along joints/fractures and through karst cavities/channels; in solution in circulating groundwater
5.	Basal Carboniferous Black Shale	**High**	Probably widespread	Along fractures and shear zone at contact; in solution in circulating groundwater
6.	Upper Carboniferous Shales and Phosphorites	**High-Very High**	Not known (eroded)	Along fractures and in downward circulating groundwater leading to deposition within or beneath the cover limestones
7.	Glacial Deposits	**Low**	Widespread	Through open pore spaces (especially in sand/gravel deposits)



Soil gas ^{222}Rn levels over limestone show a systematic decrease with distance from the granite (Fig. 1b). While such a decrease could reflect a decrease in the permeability of the limestone and/or its glacial overburden, it is thought more likely to reflect the decay of ^{222}Rn during transport (by groundwaters?) from the granite source.

Contouring the soil gas ^{222}Rn data defines a number of high ^{222}Rn anomalous zones, some up to 500m in maximum dimension. At such scales there is an apparent spatial correlation between some of these anomalous zones and the occurrence of high indoor ^{222}Rn levels in houses, although when this correlation is examined in detail (site-specific studies) it is not often found to be upheld.

Spatial analysis of the soil gas ^{4}He data defines a number of linear arrays of high ^{4}He values, thought to represent zones of enhanced permeability. Such He "lineaments" often correlate with known fracture zones and are often centred on soil gas ^{222}Rn anomalies. Where a house is sited on a zone of enhanced permeability defined by anomalous ^{4}He values and within an area underlain by a soil gas ^{222}Rn anomaly, high indoor ^{222}Rn levels many occur (see Fig. 2). The existence of both a radon source and a physical pathway for radon migration appear to be equally critical factors in controlling indoor ^{222}Rn levels. If either is absent, then high indoor levels will not develop.



4. Conclusions and recommendations

(i) The present study shows that geological mapping, when supported by combined Rn-He soil gas surveys, can succeed in defining radon availability over broad geographic areas of varied geology and pedology. Further development of such predictive mapping methodologies could assist in focussing the indoor monitoring campaigns of EC radiological institutes in a more effective way. They may also be used to categorize areas in terms of Rn potential which are designated for urban development and thereby help to reduce or avoid the cost of later remedial actions.

(ii) The mapping methodologies employed suggest that for specific house sites the migratory routes for Rn transport are likely to be very localized physical pathways. Site specific measurements of soil ^{226}Ra activities and soil gas ^{222}Rn concentrations may fail to show a meaningful correlation with indoor ^{222}Rn levels for a variety of reasons.

(iii) Geophysical resistivity-based survey techniques may only achieve partial success in imaging subsurface radon migratory pathways and it is suggested that other geophysical methods (e.g. ground probing radar) might prove more effective in locating physical pathways for radon ingress beneath houses and in their immediate vicinity (particularly in urban environments).

(iv) Carbonate rocks such as limestone contain very low concentrations of U and Ra and dwellings built on carbonate bedrock might be expected to have low indoor ^{222}Rn concentrations. However, such rocks are also highly prone to dissolution (karstification) by

circulating groundwater which thereby greatly enhances their permeability. The present study shows that they can act as very efficient radon conduits where karstification is well advanced or complete and where U or Ra are mobile.

Recent studies in Denmark and the USA have reported enhanced ^{222}Rn levels in dwellings built on limestone sequences and support the view that rock permeability strongly influences ^{222}Rn availability even in otherwise poorly uraniferous lithologies. Indoor monitoring of ^{222}Rn should be extended to populated areas of the EC underlain by karstified limestone sequences in order to assess the true extent of the radiological risk to the population of these areas.

Project 1

Head of project: *Dr. P.J. O'Connor*

Objectives for the reporting period

The objectives of the geological investigations carried out by GSI in the study area were:

(i) To determine the location and geographic extent of radioelement-enriched rock types which might act as potential radon sources.

(ii) To determine the nature and spatial distribution of geological structures which might act as potential radon migratory routes to dwellings at surface.

Progress achieved including publications

1. Methodology

(i) Systematic mapping of bedrock geology (1:10560 scale) and glacial deposit geology (1:25000 scale) of the study area was completed.

(ii) A reconnaissance total-gamma radiometric survey (based on 200 stations) was undertaken in support of the mapping programme.

(iii) Eleven boreholes were drilled in the depth range 20-80m to investigate the nature of surface and subsurface targets delineated in field surveys by the project team in terms of their radon potential.

(iv) Petrographic/mineralogical investigation of recovered geological samples was carried out and samples were analysed (by neutron activation in Canada) to determine their radioelement contents.

(v) A preliminary investigation of ^{222}Rn activities in surface and groundwaters in the study area was completed (with the assistance of the British Geological Survey).

(vi) The compiled geological maps were digitized and integrated with other spatial geodata (provided by the other partners) using computer-based mapping software (Autocad).

2. Results

2.1 Identification of radon sources

The results of the total-count gamma radiometric survey of the study area show that the granite-limestone contact zone is reflected by a transition from higher total-gamma values recorded over granite terrain to lower values over limestone terrain. Within the area underlain by granite, the detected radiometric anomalies correlate spatially with known fracture zones and, in particular, with occurrences of radioactive felsite dykes which frequently occupy these zones.

Radioelement analysis of samples recovered from outcrop has confirmed high abundances of U ($\sim$ 15ppm), Th ($\sim$ 50ppm) and ^{222}Ra activity ($\sim$ 160 Bq kg^{-1}) in the felsite dyke rocks which are in contrast to lower and more typical radioelement levels in the

surrounding main Galway granite. The high radioelement contents of the felsite dykes are similar to those recorded by GSI for the Murvey granite variety of the Galway Granite batholith and to radioelement levels recorded in the granites of Devon and Cornwall in the U.K. (areas which have been designated as "affected" by NRPB). The felsites, therefore, represent localized linear zones of high radon potential within the granitic terrain of the study area and dwellings sited on or close to such zones could develop an indoor radon problem.

The nature of the granite-limestone contact at one locality (Ballycuirke townland) was investigated by GSI in a series of 3 boreholes which were drilled in close proximity to each other to a maximum depth of 80m. The contact was shown to dip at 25°-30° northeastwards beneath the younger limestone cover rocks (Fig. 1a). Intense alteration and deformation of the marginal granite at the contact is evident in drillcore and it is concluded that the contact zone is sheared or faulted along much of its length and that extensive water-rock interaction has occurred in this zone. Petrographic and geochemical analysis of the altered and deformed granitic rocks of the contact zone suggests that ^{222}Ra (and to a lesser extent, ^{234}Th) have been leached and remobilized by circulating groundwaters. This is consistent with the results of other studies (e.g. those recently reported by U.S.G.S.) that shearing of granitic rocks is conducive to the release of their contained radioelements (e.g. U, Ra), mainly as a consequence of the mineralogical changes which occur during the shearing process. There are likely to be a significant number of such (unexposed) linear shear zones in the granitic terrain of the study area which could represent zones of enhanced radon emanation.

The drillcores recovered from the contact zone boreholes also indicate the presence of a previously unknown and severely deformed black shale unit (>5m thick) at the base of the Carboniferous limestone sequence. Analysis of shale samples (by TCD) shows high ^{226}Ra activities (~ 142 Bq kg^{-1}). If the shale unit extends laterally beneath the karstic limestone cover rocks throughout the study area, as is likely, then it would represent a significant and geographically-widespread radon source. The limestones themselves are radioelement-poor.

There is a further potential radon source which, from geological considerations, merits attention. To the south of the study area in Co. Clare, the karstic Carboniferous limestones are overlain by uraniferous shales and phosphorites, of Namurian age. It is likely that these uraniferous lithologies once existed in the study area also, but have since been eroded. They would have contributed substantial amounts of U and Ra to downward-circulating groundwaters during post-Carboniferous times. The radioelements in solution may have been deposited at lower stratigraphic levels in the underlying limestone sequence. Later karstification of the limestones, which greatly enhanced their permeability, would allow them to act as a very efficient transport medium for available ^{222}Rn to migrate upwards to the surface.

A preliminary survey of ^{222}Rn activities in groundwater samples recovered from both wells and springs in both the granite and limestone terrains was carried out (with assistance from personnel of the British Geological Survey who kindly provided the analytical backup). The results indicate that the ^{222}Rn activities of wells on granite bedrock generally exceed 100 Bq l^{-1} and, as might be expected, are approximately twice the activity levels recorded for wells on limestone.

2.2 Identification of radon migratory routes

Following its generation in U-Ra bearing minerals in rocks, radon migrates (by diffusive and convective processes) along crystal defects and grain boundaries, through pore spaces and through macroscopic cracks and fractures of different scale on its upward route to the surface. Below the water-table, radon is in solution and hydrogeological factors are

also important in its migration. Potential radon migratory routes to surface dwellings are, therefore, dependent on the existence of appropriate physical pathways at any given site. The field geological studies have identified a number of physical pathways which, individually or in combination, are likely to have a significant influence on the radon flux measured at surface. These pathways include:-

(1) Fracture Zones: A substantial number of linearly-disposed fracture zones of varying magnitude and intensity were delineated in both the granite and limestone terrains. Movement (faulting, shearing) has taken place on some of these fractures, particularly in the granite-limestone contact zone. Fracture directions in the granite terrain generally trend N-S or NE-SW and many of the fractures are occupied by later radioelement-rich felsite dykes. The felsite dykes thus represent a potential source of high radon emanation situated in linear zones of high permeability. There is a high fracture density in the limestone terrain, with N-S and E-W trends predominant.

(2) Karstified Limestone: Deeply-jointed karstic pavements are exposed at surface in the limestone terrain with measured solution channels up to 2m deep and 0.5m wide. The probable existence of widespread subsurface cavities or channels in the limestone terrain was indicated in a series of 8 GSI boreholes, drilled to depths of 20-50m, in Ballydotia townland. The boreholes were sited in close proximity to two separate houses where elevated indoor ^{222}Rn levels had previously been recorded by RPII and where geophysical and soil-gas ^{4}He surveys by UCG and BGR had indicated the possible presence of subsurface discontinuities. The karstified limestone therefore represents a laterally extensive medium of greatly enhanced permeability through which radon could migrate freely. Spatial variation in the radon flux measured at surface may reflect the degree of karstification attained by the limestone from place to place. If the limestone is underlain by a radioelement-rich black shale, as is thought likely, then a widespread potential Rn source is situated below a highly permeable cover.

(3) Permeable Overburden: The fluvioglacial sand and gravel deposits, which have been delineated and overlie the cover limestones, have low radioelement contents and do not represent potential radon sources, but their high permeability suggests that radon would migrate freely through these deposits to the surface. Most of the other glacial materials (drift, boulder-clay) and the soils derived from them are less permeable and are not enriched in radioelements.

3. Conclusions

The spatial variation observed in the indoor ^{222}Rn data - where high and low values are often recorded in contiguous houses - suggests that localized subsurface structures (e.g. joints, fractures, faults, shear zones), representing zones of greatly enhanced permeability, control radon migration and ingress at specific house sites.

Publications

O'Connor, P.J. Radon hazard in Ireland. (Presented at Colloque International sur la Geochemie des Gaz, Mons, October 1990).

O'Connor, P.J., Gallegher, V., Van den Boom, G., Hagendorf, J., Muller, R., Madden, J.S., Duffy, J.T., McLaughlin, J.P., Grimley, S., Mc Aulay, I.R. and Marsh, D. (in press) Mapping of ^{222}Rn and ^{4}He in soil gas over a karstic limestone-granite boundary: correlation of high indoor ^{222}Rn with zones of enhanced permeability. *Journal of Radiation Protection Dosimetry.* (Presented at NRE-V Conference, Salzburg, September 1991).

O'Connor, P.J. Mapping radon migration in karstic limestone terrain in Western Ireland. (Presented at 2nd Irish Environmental Researcher's Colloquium p. 27, Abstracts, Trinity College, Dublin, January 1992).

Project 2

Head of project: *Dr. J.S. Madden*

Objectives for the reporting period

The specific objectives of the Radiological Protection Institute of Ireland (RPII) in this project were

(i) To approach and obtain on behalf of the Research Group the participation of householders, and to determine the geographical distribution of indoor radon concentrations in selected townlands within the Moycullen postal district.

(ii) To approach and obtain on behalf of the Research Group the further participation of specific householders whose houses were selected for detailed follow-up site investigations, and

(iii) To conduct site investigations incorporating soil gas radon measurements using passive, integrating CR-39 alpha track radon detectors, instantaneous soil gas radon measurements using a grab sampling technique and terrestrial gamma radiation measurements. In addition the RPII supplied passive radon detectors to UCG, a sub-contractor to the GSI, for deployment in several boreholes drilled by GSI in the Moycullen area.

Progress achieved including publications

1. Introduction

The choice of the Moycullen area for this project originates in the discovery by University College Dublin (UCD) in 1985-1989 of elevated indoor radon concentrations in houses on the limestone sequences. Regional follow-up studies by the RPII and UCD in 1989-1991 confirmed these earlier findings and predicted that 14% $\pm$ 5% of houses in Co. Galway would exceed the adopted national Reference Level of 200 Bq m^{-3} (Radon gas). In addition the regional survey identified an anomalous area in Co. Galway, which incorporates Moycullen, in which 24% $\pm$ 9% of the houses were predicted to exceed the Reference Level. Radon concentrations monitored in houses in the Moycullen area during the regional survey ranged from 42 Bq m^{-3} up to 1751 Bq m^{-3}.

2. Geographical distribution of indoor radon concentrations

2.1 Sample selection

A total of 494 householders in selected townlands within the Moycullen postal district were contacted by the RPII regarding participation in this project, and indoor radon measurements were completed in 235 houses. All houses were plotted on 1:10560 O.S. maps, and their locations subsequently digitised by GSI.

2.2 Indoor radon gas measurement technique

Time integrated radon gas concentrations were measured using the standard RPII domestic radon dosemeter. This dosemeter is a passive, closed, alpha track radon detector which is left undisturbed in a ground floor living area or bedroom for a minimum exposure period of 90 days. It consists of a cylindrical plastic bottle with a screw-on lid. The alpha particle detecting medium i.e. polyallyl-diglycol carbonate or CR-39 is held in position inside the lid by a small plastic insert placed inside the bottle.

On return the detectors were chemically etched and counted by manual microscopy. The etching conditions used were 10N Sodium Hydroxide (NaOH) at 70^0C for 8 hours. The dosemeters were calibrated by participation in the recent series of intercomparisons carried out by the CEC.

3. Site specific investigations

3.1 Site selection

After consultation with our contract partners 20 houses were selected for detailed site investigations. The selected sites contained houses with both high and low indoor radon concentrations on both sides of the granite/country rock geological contact. Investigations were completed at 18 sites and all site locations were plotted on 1:2500 O.S. maps.

3.2 Measurement techniques

3.2.1 Passive integrated soil gas radon measurements

Time integrated soil gas radon concentrations were measured using the standard RPII domestic radon dosemeter. Site conditions permitting a portable Cobra drill with a 4.5 cm diameter soil sampling head was used to penetrate the overburden to a depth of 1m. The hole was then cased with tight fitting plastic tubing to preserve, it and sealed at the surface with an air-tight rubber cap. All detectors were suspended in the pipe so as to hopefully remain above the water table.

Difficult and unfavourable ground conditions at most sites dictated that practically all passive radon detectors were deployed and retrieved by manual excavation of the soil. Holes were dug by pick and shovel to practical attainable depths, and the radon detectors positioned on top of a stable base, usually a stone, and then covered with a plastic cup of protection. The holes were then backfilled and marked. After an exposure period of 190 hours the detectors were retrieved for processing. Where possible the measurements were taken in original soil as opposed to imported top soil.

3.2.2 Instantaneous soil gas radon measurements

Soil gas was extracted from the ground by sucking through a 4 mm internal diameter hydraulic pipe into Lucas cells. To ensure a representative sample of soil gas was obtained a flow-through method was adopted whereby at least 1 l of soil gas was flushed through the Lucas cells.

After a minimum delay period of at least 3 hours the Lucas cells were counted on a Pylon AB-5 Radiation Monitoring System. Radon concentrations were determined using appropriate calibration factors and sample decay corrections. All measurements were taken in original soil where possible.

3.2.3 Terrestrial gamma radiation measurements

Terrestrial gamma radiation measurements were taken at 2 locations at each site, at least 10 m away from the nearest building or outcrop. A Mini Instruments Environmental Meter (Type 6-80) was used for this purpose. The energy compensated GM tube was placed in a vertical position with its centre approximately 1m above ground level. The counting period was 1000 seconds and the results displayed in μGy h^{-1}. An average cosmic ray contribution of 0.04 μGy h^{-1} was subtracted from each reading to give the terrestrial component.

4. Intercomparison of instantaneous soil gas radon measurement techniques

An intercomparison of the radon grab sampling techniques employed in the field by RPII and BGR was undertaken at the RPII Calibration Facility in Dublin. The intercomparison was performed under laboratory conditions in the walk-in Radon Chamber, and also under typical field conditions in the grounds of UCD.

5. Results

5.1 Geographical distribution of indoor radon concentrations

In the survey area indoor radon concentrations ranged from 8 Bq m^{-3} up to 725 Bq m^{-3} with an arithmetic mean concentration of 82 Bq m^{-3} and a median concentration of 53 Bq m^{-3}. There is no obvious systematic spatial pattern in the data, and high and low concentrations occur, often contiguously, over both granite and limestone. Overall, 10% of the houses had concentrations in excess of 200 Bq m^{-3}.

From a purely lithological basis the indoor radon concentrations in general tended to be higher in houses underlain by limestone. Thirteen percent of such houses had radon concentrations in excess of 200 Bq m^{-3} as against 6% of houses on the granite.

5.2 Site investigations

Instantaneous soil gas radon concentrations ranged from 330 Bq m^{-3} up to 108,000 Bq m^{-3} on the granite side of the geological contact and from 4500 Bq m^{-3} up to 165,000 Bq m^{-3} on the limestone side. On both sides of the geological contact some of the highest recorded instantaneous soil gas radon concentrations on site are normally associated with the lowest indoor radon concentrations.

Terrestrial gamma radiation measurements indicated absorbed doses ranging from 38 nGy h^{-1} up to 60 nGy h^{-1} with an average value of 48 nGy h^{-1} over the limestone. Over the granite absorbed doses ranged from 44 nGy h^{-1} up to 70 nGy h^{-1} with an average value of 58 nGy h^{-1}. The higher values over the granite are to be expected because of the uraniferous nature of the Galway Granite Batholith.

5.3 Intercomparison exercise

The results of the intercomparison of RPII and BGR grab sampling techniques are presented in Table 1. Good agreement between both techniques under laboratory and field conditions is evident.

TABLE 1

	Volume	Counts/10 min	Radon Concentration Bq m^{-3}
Field Test	RPII BGR	161 ml 10 ml	23320 24630
Lab. Test	RPII BGR	161 ml 10 ml	54260 55500

Passive Radon Detectors Deployed in Deep Boreholes

Soil gas radon concentrations ranged from 657 Bq m^{-3} up to 12974 Bq m^{-3}. The degree of atmospheric mixing in the boreholes is unknown as is the degree of air mixing from the various open cavities encountered in the boreholes.

6. Conclusions

No apparent correlation between indoor radon concentrations and site specific soil gas radon concentrations is evident. The occurrence of high and low indoor radon concentrations, often contiguously, over both granite and limestone suggests that other parameters such as house characteristics and site specific geotechnical, geophysical and hydrogeological features must be important influences on radon ingress into domestic dwellings in this area.

Publications

Madden, J.S. 1991. Radon in Buildings. What is it? Where does it come from? Why are we concerned? Proceedings of the Institution of Engineers of Ireland Seminar on the Investigation and Cure of Sick Buildings, May 1991.

O'Connor, P.J., Gallagher, V., Van den Boom, G., Hagendorf, J., Muller, R., Madden, J.S., Duffy, J.T., McLaughlin, J.P., Grimley, S., McAulay, I.R. and Marsh, D. (in press). Mapping of ^{222}Rn and ^{4}He in soil gas over a karstic limestone-granite boundary: correlation of high indoor ^{222}Rn with zones of enhanced permeability. *Journal of Radiation Protection Dosimetry*. (Presented at NRE-V Conference, Salzburg, September 1991).

Madden, J.S. 1992. The Radon Problem in the West/South of Ireland. Proceedings of the Institution of Engineers of Ireland Seminar on Radon in Buildings, May 1992.

Duffy, J.T. 1992. Dealing with Radon in Ireland. *Construction 1992*, Vol. 4, p. 7. Published by Environmental Research Unit ISSN 0791-2099.

Project 3

Head of project: *Dr. McLaughlin*

Objectives for the reporting period

To determine soil gas radon concentrations in the granitic/karstic limestone contact region of Moycullen, Co. Galway using standard techniques and a new type of passive detector being developed for this purpose.

To integrate, compare and interprete these measurements with those of other collaborating contractors.

Progress achieved

1. Development and calibration of a passive alpha track detector for use in soil gas radon measurements

The objective was to produce miniature multichamber passive radon detectors which could be implanted in the ground in a region where little or no previous knowledge of soil gas radon levels was available. The novel aspect of this approach was to make the chambers of such small dimensions that their response to the alpha particles from radon and its progeny was sufficiently low to considerably reduce track saturation. In this way the detectors would be used in very high radon concentrations for prolonged periods.

A theoretical model was developed to predict the sensitivity of small cylindrical detector chambers as a function of chamber radius and length (see Figure 1). On the basis of this model a three chamber detector made from solid perspex was designed which was capable of covering the radon range from 10000 to 150000 Bq/m^3 for exposure periods from about 1 to 3 weeks without track saturation effects becoming unmanageable (see Figure 2). This is ideal for soil gas radon measurements. A Kitamura CNC high precision computerised Machine Tool Centre was used to manufacture 150 of these multichamber detectors for the project field work. CR-39 was the detecting medium used. The detectors were intercalibrated against regular radon detectors calibrated at the NRPB (UK) as part of the ongoing CEC radon detection intercalibration programme.

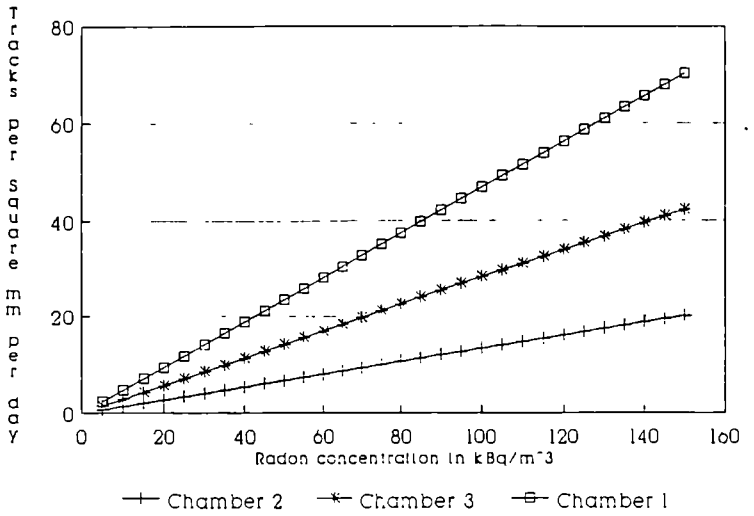


Figure 1 - Track production vs radon concentration

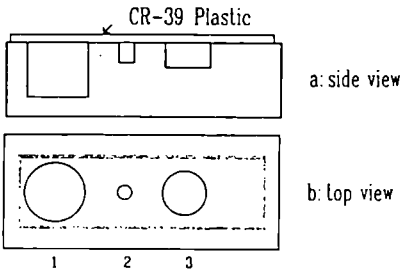


Figure 2 - New multichamber passive detector
Chamber 1-R_c = 0.0060m/D = 0.011m
Chamber 2-R_c = 0.0015m/D = 0.004m
Chamber 3-R_c = 0.0045m/D = 0.005m

2. Field measurements

Field work in the Moycullen area of Co. Galway took place mainly in July 1991. Due to the close proximity of the bedrock to the surface and the stony ground, it was very difficult to make radon measurement at depth. In places the soil cover was as shallow as 2 or 3 cm. Therefore the depths of the integrated measurements ranged from about 0.3 to 1.25 m and the depths of the soil gas grab measurements from 0.3 m to 0.7 m. Where possible, the measurements were taken close to each house and in original soil as opposed to imported top soil which the owner had brought into the garden to overcome the general soil deficiency.

Instantaneous measurements of radon levels in soil gas were made using a grab sampling technique. Soil gas was pumped from the ground through a hydraulic pipe with a 4 mm internal diameter into 100 ml Lucas scintillation cell. Integrated measurements of soil gas radon of duration 10 days were made using both standard and the new multichamber alpha track passive radon detectors.

A soil gas permeability probe was designed and constructed based on a design by Anders Damkjaer at the Technical University of Denmark (contract B16 - 347f - 114), to make relative measurements of the soil permeability. Unfortunately, the soil and ground conditions encountered at almost all the sites proved unsuitable for the reliable operation of the permeability probe.

Wide variations were obtained in radon soil gas levels in the field area. The time integrated soil gas radon measurements gave concentrations ranging from a few hundred Bq/m^3 up to 58000 Bq/m^3. Most of the higher concentrations occurred on the granitic side of the Moycullen area. The grab samples gave radon concentrations ranging from 330 Bq/m^3 up to 165000 Bq/m^3.

It should be noted that at individual house sites considerable variations of soil gas radon levels were found to exist. Radon soil gas level ratios of ten to one between the soil at the front and back of a house were not unusual. Ratios as high as sixth eight to one were detected. These wide variations of soil gas radon levels over a distance of a small number of metres indicates the complexity of the radon migration and availability in the field area. This considerably reduces the possibility that area mapping based on soil gas surveys as carried out in this work in such a karstic area can give rise to a radon prediction capability of sufficient accuracy and power to predict the existance of a high radon risk down to the scale of an individual house site.

3. Conclusion

The general elevation of indoor radon levels in the Moycullen area appears to be due to the underlying uraniferous granite (see reports of other partners for a fuller discussion). No direct correlation was found between the indoor radon concentrations and those in the ground; houses built side by side may have indoor concentrations differing by several hundred Becquerels. This would suggest that there are other important parameters governing indoor radon concentrations apart from the existance of the granite and the karstic limestone such as:-

1) House structure, (in particular the foundations),

2) House heating and ventilation,

3) Soil permeability,

4) Localised faults and fractures in the underlying bedrock.

From a measurement perspective, it was found that the newly designed multi-chamber radon detector which was designed specifically for this work proved to be very suitable for field work in the unfavourable conditions found in the Moycullen area.

Publications

There were no publications on the project work during the contract period.

Project 4

Head of project: *Dr. I.R. McAulay*

Objectives for the reporting period

(i) To determine by gamma ray spectrometry the radioactivity content of samples of soil and rock collected in the region selected for study.

(ii) To investigate the importance of radium content in the soil and rock samples in assessing the potential for high radon levels in dwellings in the region.

(iii) To study the uranium series disequilibrium in the samples and attempt to determine the significance of this factor in predicting domestic radon concentrations.

Progress achieved

1. Correlation of Soil ^{226}Ra and ^{234}Th with indoor radon

From the results of the initial indoor radon survey (Project 2), 17 houses were selected for further study, including houses with low and elevated radon levels on each of granite and limestone bedrock. The objective of the soil measurements was to investigate the concentrations of ^{226}Ra (the precursor of ^{222}Rn) in the soil surrounding these selected houses. At the location of each house, a soil sample was collected from a depth of 30-40cm. Care was taken to ensure that the collected sample was of natural soil, and not imported topsoil. When samples were returned to the laboratory they were dried and powdered to be suitable for gamma activity measurement. This powder was then placed in standard Marinelli beakers which have a sample volume of 450ml. Typical sample masses were in the range 300-600 grams. Samples were measured for gamma activity using a high resolution HpGe solid state detector. The naturally occurring radionuclides of interest are ^{234}Th (93 KeV) and ^{226}Ra (186 KeV) from the uranium-238 series, ^{228}Ac (911 KeV) from the thorium-232 series and ^{40}K (1461 KeV). The figures in parathesis indicate the energies in the spectrum at which the nuclide activity is measured. Sample measurement time varied but most were counted for approximately 24 hours which yields a lower detection limit of about 11 Bq kg^{-1} for ^{226}Ra.

No significant degree of correlation was found for indoor radon levels when tested against any of the other quantities measured for soils. However, the ^{226}Ra values found in the Moycullen soils were considerably less than those found in other parts of Ireland. Values up to 430 Bq kg^{-1} had previously been found within 60km of Moycullen and over 500 Bq kg^{-1} in the Kerry area further to the south. The highest values for ^{234}Th in this survey were 149 Bq kg^{-1} as compared with a maximum value of 543 Bq kg^{-1} found in an earlier national survey consisting of 651 samples taken on the basis of the 10km grid. The disequilibrium found in the Moycullen soils was also much lower than found elsewhere in the country with the highest measured value for the ^{226}Ra/^{234}Th ratio in this series of measurements being 1.91 compared with values up to 10 in some samples from Co. Clare. The average values of radium in soil found in the national survey was 46 Bq kg^{-1} which compares with the Moycullen soils mean of 48 Bq kg^{-1}; the corresponding values for ^{234}Th were 39 Bq kg^{-1} nationally and 49 Bq kg^{-1} in the Moycullen samples.

2. Rock ^{226}Ra and ^{234}Th results

No significant correlations were found for relationships between the different activity concentrations as measured in rock outcrop and drillcore samples supplied by GSI. The radium concentrations appear in general to be rather lower in the core samples than in the soils and there is even less evidence for disequilibrium in the $^{226}Ra/^{234}Th$ ratio.

A series of surface or near-surface rock samples had also been referred for analysis by GSI for Galway granites in general and for specific rock types in the Moycullen area investigated in this project. In the case of the Galway granites, some degree of correlation was found ($R2=0.615$) between ^{234}Th and ^{226}Ra values and also between $^{226}Ra/^{234}Th$ ratio and ^{226}Ra values ($R2=0.798$). This indicates a slight increase in degree of disequilibrium with increasing activity concentrations of ^{226}Ra, though it must be stressed that the degree of disequilibrium was never large and in most cases was not detectably different to unity.

In the case of the Moycullen rock samples, the radium values were lower than for the granites, but a reasonable degree of correlation ($R2=0.759$) was found between ^{226}Ra and ^{234}Th activity concentrations. For most of these samples the degree of disequilibrium appeared to be less than one, but it should again be noted that for individual samples it would be difficult to interpret this as having any relevance to the geological factors influencing the nature of the rocks. The geological significance of ^{226}Ra activities measured on rock samples are further discussed in the report of Project 1.

3. Terrestrial gamma measurements

A number of measurements were made of gamma radiation dose rates above the ground in the Moycullen area. The dose rate obtained over exposed limestone slabs was 13 nGy h^{-1}, which is extremely low but consistent with values measured elsewhere in the country over similar limestone terrain. Dose rates measured over soil in and around Moycullen and over granitic terrain averaged 70 nGy h^{-1}, which is in the range recognised as the highest found in a series of measurements made over the whole country.

4. ^{40}K results

Potassium-40 was measured in all samples and the activity concentrations were high for all rock samples whether core or surface, with similar values being obtained for the means within each classification. In the case of the soil samples, generally lower values of ^{40}K were found, with the mean for this grouping being about 2/3 that of the means for the rock samples.

5. Conclusions

It may therefore be concluded that the ^{226}Ra activities present in the soils do not in this survey provide a reliable indicator to the radon levels found in houses built on such soils. The degree of disequilibrium between ^{226}Ra and ^{234}Th found in the measurements was not large and it would therefore not be justified to draw any general conclusions between this ratio and the potential for high radon levels in houses. The mean values for ^{226}Ra in the soil and in the rock core measurements were close to and below the national average respectively, which again does not provide any justification for drawing general conclusions.

Project 5

Head of project: *Prof. A. Brock*

Objectives for the reporting period

(i) To assess and report on the available regional gravity data in the Moycullen area in order to identify any structural geological trends which may influence radon migration.

(ii) To carry out and report on detailed geophysical surveys to aid the geological appraisal of three follow-up locations in the Moycullen area as specified by a sub-contract with the Geological Survey of Ireland. These locations are designated: (a) Ballydotia; (b) Moycullen Village and (c) Uggool.

Progress achieved

1. Appraisal of regional gravity data

Gravity data were gridded and contoured to produce a regional map for the Moycullen area. The available data were of limited geographical extent and the station density was poor in the follow-up locations. The data provided no evidence of hidden, major deep geological structures but confirmed the gentle NE dip of the granite/limestone contact in the Moycullen region.

2. Results of field geophysical surveys

A detailed ElectroMagnetic-Very Low Frequency-Resistivity (EM-VLF-R) survey was carried out in the Ballydotia area which lies on limestone bedrock. An apparent resistivity high, abutted by a low, was found to coincide with a house having high indoor-radon values. A second house which had high, but variable, indoor-radon values was found to lie close to an apparent resistivity gradient. In the first case, the anomalous apparent resistivity values encountered are thought to be caused by current channeling associated with a zone, or zones, of cavities in the limestone bedrock. In the second case, the resistivity gradient is thought to represent a jointing pattern in otherwise massive limestone.

A colinear, dipole-dipole array resistivity survey was carried out in the vicinity of each house in order to further define features found from the EM-VLF-R survey. The results, plotted on resistivity pseudosections, are interpreted as indicating a zone of low resistivity, weathered limestone, with possible cavities, to the north of the first house and probably a joint in limestone lying to the west of the second house. The resistivity data indicate the zone of weathering to be approximately 25m deep to the north of the first house and the limestone in the area of survey near the second house to be largely unweathered.

Two resistivity, Vertical Electrical Soundings (VES) were carried out in the vicinity of the first house in order to quantify the extent, depth and nature of the overburden and limestone strata to the north and south of the weathered zone. The first sounding, to the north, showed overburden to be less than 2 metres thick and underlain in turn by a 5.5m thick layer of weathered limestone and then competent limestone. The second sounding, in

the south, showed a thin overburden of 0.6m lying on competent limestone.

Subsequent drilling by the Geological Survey of Ireland in the vicinity of, and under, the first house found a number of small cavities associated with the weathered zone. Competent limestone was encountered to the south of the house and the weathered zone. Drillholes near the second house proved massive limestone with a very small cavity at depth to the west of the house. This cavity was not imaged by the geophysical surveys.

The EM-VLF-R survey carried out over limestone bedrock near Moycullen Village, was limited in its extent by powerlines and access difficulties due to the high density of housing in the area. The result showed a simple apparent resistivity gradient increasing in a NE direction. This pattern may be related to either a thinning overburden or more massive limestone occuring in a NE direction. No further geophysical surveys were carried out in this area.

In the Uggool area, the EM-VLF-R survey was carried out over granite bedrock. The survey, around a high indoor-radon house, was hindered by powerlines, roads and steep topography. As a consequence, the results could not easily be interepreted, but lower apparent resistivities are thought to be influenced by the more clayey nature of the overburden. No distinct pattern, which might relate to geological structure, could easily be discerned from the limited data collected. No further geophysical surveys were carried out in this area.

3. Conclusions

Geophysical surveys proved the most successful in the Ballydotia area where a zone of weathered limestone containing cavities was identified in the vicinity of a house having high indoor-radon. Geophysical surveys in the vicinity of high density housing were hampered by cultural noise. Further work is necessary to investigate the possible radon migration pathways from cavities in the limestone bedrock, through the foundations, and into selected high indoor-radon houses in the Ballydotia area. The foundations of these houses should be assessed using ground probing radar and active indoor-radon measurements to map possible migration pathways.

Publications

There are at present no publications arising from this work.

Project 6

Head of project: *Dr. G. van den Boom*

Objectives for the reporting period

The objectives of the research project carried out in 1991/92 by the BGR in the Galway area (Western Ireland) were:

(i) Tests and applications of new methodologies in defining potential areas with high radon concentrations and migration paths for mobile terrestrial gases (helium and radon).

(ii) Correlation of outdoor radon anomalies with radon-polluted buildings and attempt to predict radon contamination of populated areas based on a combined helium-radon mapping method.

Progress achieved including publications

1. Results of combined Rn-He soil gas surveys

In summer 1992 soil gas investigations were carried out in the study area near Galway (Western Ireland). A newly developed methodology using a combination of the noble gases radon and helium was applied in the field to allow the detection and identification of gas migration paths and the documentation of accompanying radon anomalies especially in populated areas. This new methodology has opened up new possibilities to delimit the boundaries of radon contaminated regions. The co-operation with the Irish group of physicists that carried out indoor measurements was very productive and successful.

The investigation included outdoor measurements of radon concentration in soil air in populated areas and detailed sampling around individual houses. The number of radon samples collected was 367. For determination of migration paths for radon a total of 447 soil air samples were collected from 90cm depth and analysed for their helium concentration. It was assumed that helium as a very mobile and inert noble gas would prove advantageous in detecting migration channels used by other terrestrial gases (in this case radon) and their dispersion pattern in the overlying soil cover. Specially designed stainless steel gas probes were used for sampling both radon and helium. The sampling procedure guarantees that no ambient air contaminates the soil gas sample. A detailed description of the sampling method is given in the technical annex to the final report.

The results of the statistical data evaluation in brief are the following:

Radon soil gas values measured show a wide range between 400 and 186000 Bqm^{-3}. The ranges measured for both limestone and granite sample groups are similar. The distribution histogram of all collected radon samples shows two clearly separated populations. The lower one includes radon concentration values <50000 Bqm^{-3}. The upper population covers samples with values >50000 Bqm^{-3}. If one considers the two lithologies separately, it is obvious that the granite population is skewed towards higher radon values as expected, but has no major influence on the distribution shape in the histogram of all collected samples. The very distinct division of the limestone-radon population is approximately the same as the total population. This means that the majority of the granite values are gathered in the upper population. The statistical parameteres of the measured radon values in soil air above both

lithological units are as follows:

Granite Area
N total: 110 samples; Minimum value: 2600 Bqm^{-3};
Maximum value: 186300 Bqm^{-3};
Median: 65650 Bqm^{-3};

Limestone Area
N total: 256 samples; Minimum value: 400 Bqm^{-3};
Maximum value: 184000 Bqm^{-3};
Median: 37300 Bqm^{-3};

Surprisingly, the maximum values of the granite and limestone soil gas radon populations are approximately the same, but the median values of the granite population are nearly double that recorded for the limestone population.

However the radon hazard has almost the same impact on the populated areas in the limestone region as in the granite region (as is evident from the results obtained from the indoor radon surveys in houses carried out by RPII).

The statistical parameters of the helium distribution for the two areas of different lithology are:

Granite Area
N total: 151 samples; Minimum value: 5013 ppb(v);
Maximum value: 5685 ppb(v);
Median: 5283 ppb(v);

Limestone Area
N total: 295 samples; Minimum value: 5092 ppb(v);
Maximum value: 5759 ppb(v);
Median: 5267 ppb(v);

Taking into account that the worldwide helium concentration in atmospheric air is 5240 ppb(v), the median of the limestone area is in accordance with the theoretical value. As expected, the corresponding granite value is slightly higher.

2. Regional helium-radon distribution

Three separate sub-areas were surveyed to determine the spatial distribution of soil gas radon and helium. Two of the sub-areas are situated in the limestone region: Ballydotia and Moycullen. In the granite region, the sub-area of Uggool was studied.

The Ballydotia and Moycullen sub-areas are contiguous and are situated east of the Galway-Oughterard highway. The geological contact between the granite and the limestone has been mapped by the GSI and runs parallel to this road. It is inferred from borehole investigations that this contact is marked by a NW-SE striking major fault or shear zone. Samples were collected exclusively in the limestone area where radon contaminated houses were known to occur. The application of the combined helium-radon mapping method necessitated sampling traverses close to the populated areas. The distribution patterns of both noble gases indicate the location and direction of migration paths with high radon haloes in their vicinity. Houses which have high indoor radon levels are very often located in a zone

of high permeability, most probably a fracture zone, which coincides with both high helium and/or radon concentrations in soil air, whereas an adjacent house less than 50m distant, with low indoor radon levels may not be influenced by the radon emanation from the migration channel. This suggests that houses located a short distance away from the fracture zone may not develop an indoor radon problem. The migration paths deduced from the helium-radon data correlate spatially with different fracture systems e.g. N-S, the main joint direction in the limestone and NW-SE, the direction of major faulting (for example the granite/limestone contact). The highest soil gas radon values were observed near the intersections of the two systems.

The sub-area of Uggool is situated within the granite terrain. Here, also, the helium-radon soil gas data suggest the same similar directions of migration channels. The spatial correlation between radon concentrations in soil gas and indoor radon data is also evident in this sub-area but not to the extent observed in the limestone area.

3. Conclusions

The radon contamination of buildings and dwellings is often (especially in areas overlain by sedimentary rocks) not controlled by the lithology or pedology but mainly by highly permeable fracture zones which serve as migration paths for the terrestrial radon gas.

The combined helium-radon mapping method applied in the present study has been successful in the detection of such permeable migration zones.

Publications

O'Connor, P.J. et al. (in press). Mapping of ^{222}Rn and ^{4}He in soil gas over a karstic limestone-granite boundary: correlation of high indoor ^{222}Rn with zones of enhanced permeability. *Journal of Radiation Protection Dosimetry.* (Presented at Fifth International Symposium on the Natural Radiation Environment, Salzburg, September, 1991).

Boom, G. van den & Muller, R. (1991). Bericht uber die Durchfuhrung von Helium-Radon Messungen in funt Testgebieten in der CSFR. Unweltradioaktivitat, Interdisziplinare Umweltforschung, Marianska (CSFR), Vortrag und Bericht BGR, Archiv Nr. 108 990.

Enmotec (1992). Mogliche Auswirkungen der Grubenflutungen auf die Radonemanation in oberflachennahe Sedimente und potentielle Gefahrdung fur angrenzende Siedlungsbereiche. Workshop der Wismut G.m.b.H. in Chemnitz, Vortrag und Bericht.

CONSEQUENCES OF IRRADIATION OF POPULATION AND WORKERS (CEA ASSOCIATION)

Contract Bi6-122 - Sector C13

1) *A. Després*, CEA-FAR - 2) *J. Brenot*, CEA-FAR
3) *H. Maubert*, CEA-Cadarache

Summary of project global objectives and achievements

The Association Contract between CEC and CEA has been existing for a long time. During the last 20 years, the objectives of the work carried out in the framework of this contract have considerably evolved in relation with the evolution of the problems, knowledges and radiation protection concepts in the field of nuclear and radiological activities.

1. Objectives: evolution and current status

Initially, the studies carried out intended to cover all the general problems associated with the protection of individuals, workers or persons of the public, in any situation involving radiation exposure.

In course of time, it appeared that some of them were of minor importance compared with others, especially accidents, waste management and public reactions.

Gradually, the work carried out was focused on these aspects. The period covered by the present report is characterized by such a transition.

During this period, three main projects were developed : they correspond to successive steps in the process of assessment and management of an accidental situation.

The purpose of **Project 1** (***European data base and decision aiding***) is first to gather and organize in an appropriate structure the data that would be necessary, in the case of an accident, to assess its consequences at the European scale : they concern the environment, the population and the interface between them. A sub project aims to develop an expert system (named DACFOOD) in order to help the decision makers in choosing the most appropriate protective measures concerning foodstuffs for the mitigation of the consequences of an accident.

The purpose of **Project 2** (***subjective dimension of the radiological detriment***) is to analyze the subjective dimension of risk perception for nuclear and non nuclear activities in order to achieve a better understanding of public attitudes and facilitate communication between experts and the population.

Project 3 (***Soils and surfaces rehabilitation after an accident***) is based on experimental studies and aim at providing information on the transfer of radionuclides in the environment to man (migration in the soil, soil to plant and plant to animal transfer) and on possibilities to reduce it. Another part of the work is to develop techniques allowing the decontamination of soils and surfaces after a large nuclear accident.

2. Summary of the results

2.1 Project 1

The data base "Eurogrid" is operational but needs to be updated and enlarged. During the period covered by the present contract the population distribution and other environmental parameters were updated. The data base now includes Switzerland and contacts have been taken with Austria.

In addition different feasability studies have been carried out with the aim of introducing new parameters in the grid, especially :

- --> parameters concerning water resources and their different uses ;

- --> protection factor due to housing characteristics against external exposure and internal contamination due to inhalation ;

- --> exchanges of agricultural products between the different meshes of the grid.

Concerning the decision aiding system "DACFOOD", the cost-effectivness part of the software has been achieved and the system has been tested during two emergency exercises. The interest expressed by decision makers is an encouragement for the improvement of the system, especially by taking experts judgements into account. A close cooperation has been maintained with T.N.O. (Netherland) where a similar study has been conducted.

A preliminary study has also been carried out in order to identify those situations where decisions concerning agricultural productions need to be taken urgently during the early phase after an accident. Several cases have been selected where a delay in the decision process could result in very important economical or social consequences.

2.2 Project 2

The main tasks achieved during the 1990-1992 period are the following.

A review of public attitudes concerning risk perception has been carried out and presented at the 39th UNSCEAR session.

An enquiry on risk perception for major hazards has been conducted among safety specialists from various activities and lay people.

Concerning radioactive waste perception, a national representative survey was performed in 1990 and some of the results were presented at the 3th Conference of the Society for Risk Analysis in December 1991.

Two papers respectively on perception of hazardous situations by workers and with social and economical consequences of major accidents have been prepared. The first one was presented at the IRPA 8 Conference in Montreal in May 1992 and the second one at a CEC Seminar held in Athens in May 1990.

A restricted workshop on the different situation of risk perception in Member States was organized in November 1990.

2.3 Project 3

The selection of soils to be studied and the choice of sampling sites in France and in other countries (Belgium, Germany, Spain and United Kingdom) have been realized and a demonstration of sampling made in a French site.

A furnace, the "Polyr" furnace, was used for the production of aerosols in order to contaminate soils an plants. Their solubility was studied in different conditions. Experiments on selected soils to study the behaviour of radionuclides produced by the "Polyr" furnace and their transfer to plants and animals were conducted at the Universities of Gembloux (Belgium) and Piacenza (Italy).

Different techniques which could be implemented for environmental decontamination environment (mainly soil) after a nuclear accident have been developed.

Two approaches were followed : analytical experiments (for instance the technique of saving turfing plants by hydro-seeding and removing the vegetal carpet after growth) and *in situ* experiments (defoliation tests conducted on forest trees).

2.4 Other studies

In addition to these main projects, three specific studies were carried out within the framework of the present contract.

- A synthesis of the evaluation of radioactive body burdens by *in vivo* measurements carried out in several European populations after the Chernobyl accident. The results show that ingested activities calculated from measurements performed in the food chain overestimate the actual body burden by a factor up to one order of magnitude.
  The report was published (Report EUR 13054).

- A study on "Comparative genotoxicity for environmental factors" have been carried out with the genetic system of the Tobacco Xanthi Variety, which allows to assess the mutagenic potential of various environments. Genetic effects have been observed in urban and industrial environments. In addition, laboratory experiments have been conducted for different contaminants such as SO_2 and ^{222}Rn and for gamma irradiation at relatively low doses.

- An attempt to establish a comparison between carcinogenic risk to man due to chemicals and radioactivity. Two reports were prepared. The first one aimed at making to state of know ledge about one of the well documented group of chemical substances (nickel and its organic compounds). The second one was a review of the experimental studies carried out on the carcinogenic risk of plutonium compounds.

  However, due to the difficulty of such a programme and to the limited means available, this programme was given up.

Project 1

Head of project: *A. Després*

Objectives for the reporting period

Project 1.a : The European Data Base EUROGRID

works were to be carried out according to three axis :

1 - updating of the data base

2 - methodological research to introduce further parameters (data on resources and use of water, protection factors due to housing and living habits, exchanges coefficients for agricultural productions between meshes)

3 - softwares developments to facilitate the consultation of the data base

Project 1.b : The decision aiding system DACFOOD

Objectives of the reported period were to test the DACFOOD system during simulated emergency crisis, to collect the experts judgements and to develop a method allowing to take into account these judgements.

Progress achieved including publications

Project 1.a: The European Data Base EUROGRID

1 - updating of the data base

Updating of the population files is achieved (UK excepted) on the basis of census performed between 1986 and 1990. Switzerland has also been included in and contacts are established with Austrian statistics services. Collect of other parameters is in progress

2 - methodological research to introduce further parameters

2 - 1 parameters allowing the assessment of exposure by the water pathway

A feasibility study has been conducted in the Adour bassin (S-W of France) to estimate water resources and uses (domestic, agriculture, industry) and to define a methodology allowing the evaluation of these parameters in the meshes of the european grid. Modelisation works are achieved. The feasibility to integrate water parameters in a meshed network is demonstrated for France, but the availability of data at the European scale is not proved. In all the cases, generalisation of this work at the European scale should need an extensive amount of work.

2 - 2 protection factors due to housing caracteristics

A distinction is made between protection against external exposure due to the plume or to inhalation, for which housing characterization is sufficient, and protection against external

exposure due to deposition for which the knowledge of the environment (trees, gardens, streets,...) is required. Protection factors against external exposure due to the plume have been calculated for four types of housing (individual or collective, recent or ancient), in 31 french departments. Globally, the weighted mean for this protection factor varies within a factor four from a department to another. Concerning the protection factor against external exposure due to the deposition, the study conducted with the habitations of Bourg en bresse (France) shows a variation within a factor 8 according to the environment. For the inhalation protection factor, the main parameter is the duration of sheltering : for a 24 hours sheltering, the protection factor varies within a factor 8 accordiing to the air-tightness of doors and windows.

2 - 3 exchange of agricultural products between meshes
A faisability study has been conducted for one agricultural product (cereals) and a country (France). Three methods have been employed, respectively based on :

. optimization of transport costs (transport method) ;

. the assumption that exchanges between a mesh with deficit (excedent) is proportional to the excedent (deficit) of the other meshes (compensation method). This method can be used at regional or national level ;

. exchanges between meshes are assumed to be proportional to the exchanges between regions in which they are included (independence method).

These three methods give significantly different results. Moreover, all these methods only give mean annual exchange coefficients. For these reasons, it seems to be difficult to envisage the extension of this work at the European scale and at the totality of the agricultural productions.

3 - softwares developments to facilitate the consultation of the data base
Numerical softwares have been developed, providing tools allowing an easy consultation of the data base. A graphical software is also available, but its application is limited to the vizualisation of large meshes and its use need first the acquisition of a graphical software.

Project 1.b: The decision aiding system DACFOOD

A first attempt of the cost-effectiveness part of the software being achieved, works have been mainly devoted to the theorical reflexion on a Truth Maintenance System in which the cost-effectiveness study will be integrated as a module. Such an expert system is devoted to deal with rules formulated by experts, and to try to find a solution acceptable by all the experts by relaxing some rules and by studying the consequences of such relaxations.
In its current form, the system have been tested during two crisis exercices, during which the interest of decision makers have been proved. These simulations have also show the way to improve the system.
In parallel, a report have been produced with the objective to

identify actions to be immediately taken : The classical approach concerning foodstuffs considers that decision can be delayed for some days or more. In the reality economical consequences can be modified in a large extend by decisions that, if immediately taken, allows to avoid situations difficult to manage.

Publications

S. BONNEFOUS, A. DESPRES
Evolution of the European Data Base
in : Proceedings of the seminar on methods and codes for assessing the off-site consequences of nuclear accidents, Athens, 7-11 May 1990
S. BONNEFOUS, A. DESPRES
La base de données européennes EUROGRID : Problèmes méthodologiques et développements récents
8th International Congress of the International Radiation Protection Association, Montréal, 17-22 May 1992
A. DIAZ, A. DESPRES, D. SOULATGES
DACFOOD : A knowledge-based system for decision support in case of radiological contamination of foodstuffs
in : Proceedings of the seminar on methods and codes for assessing the off-site consequences of nuclear accidents, Athens, 7-11 May 1990
A. DESPRES, A. DIAZ, D. SOULATGES
DACFOOD : Un système d'aide à la décision en cas de contamination de la chaîne alimentaire
8th International Congress of the International Radiation Protection Association, Montréal, 17-22 May 1992
D. SOULATGES, A. DESPRES, A.DIAZ
DACFOOD : A Decision Support System in case of Foodstuff Contamination
Joint International Conference. Operational Research - Management Science, Helsinki, June 29th -July 1st 1992

Project 2

Head of project: *J. Brenot*

Objectives for the reporting period

Analysis of public attitudes toward nuclear energy shows the considerable importance of subjective components. As far as risk is concerned, fear and anxiety are not the only explicative factors, and both ideology and culture must be taken into account. Within a comparative approach, are analyzed :

- the subjective dimensions of risk perception for activities, the nuclear one obviously but also others which are common in the everyday life,
- the difference between risk perceptions of specialists and of lay people which can explain the difficulty to communicate.

The final goal is to propose methods or at least recommendations for integrating this subjectivity in risk management and more precisely in risk communication.

Progress achieved including publications

1. Concepts and approaches used in risk perception studies

A review on risk perception and attitudes [1] was prepared in 1989 and presented at the 39th UNSCEAR Session 1990. The text has been discussed during this Session and the two following ones. It was modified to put a larger focus on radiation. One part of it, devoted to the risk perception phenomenon, has been exposed at the International Conference on Radiation Effects and Protection, in Mito Japan, March 18-20, 1992 [2].

2. Risk perception of specialists and lay people

This study has been made by interviewing individuals and using pre-defined questions. The questionnaire addressed the following issues : the opinion on major hazards, the level of risk and its acceptability (as a willingness to do more for risk reduction) for various activities, and elicitation of criterias used by people when they manage the risk. 150 safety experts from various technical domains and a representative sample of lay people in the Bordeaux area (705 individuals) answered. Results of the in-depth analysis are given in a technical report [3]. Results are summarized in a paper published in the French review Préventique [4]. Firstly, experts and lay people rank almost similarly the 19 hazardous activities that were proposed. Large differences appear only for ozone depletion emphasized by the public and for domestic accidents and transport of dangerous materials emphasized by the experts. Secondly for experts as for lay people, perceptions of risk between pairs of hazards tend to be positively correlated. That is, persons concerned about one hazard are more likely to be concerned about other hazards as well; those unconcerned about one hazard are more likely to be unconcerned about others. Thirdly, the demand for more safety measures by the public is very high; all activities are concerned; and higher the perceived risk, higher the demand.

3. Radioactive waste perception

This topic, studied some years ago, has been re-analysed with French data issued from a national representative survey performed in June 1990; 1000 persons answered in face to face interviews. Two sections in the questionnaire were devoted to beliefs about the various types of wastes, and to psychological and social indicators respectively. Relations between the two sections have been studied. Some of the results were shown at the 3th Conference of the

Society for Risk Analysis, Paris, December 1991 [5]. There is a very large majority (more than 80 %) to consider radioactive wastes and chemical wastes as worrying problems regarding to the environment, and to ask for more safety. Wastes from other industries and household are far less considered. It is difficult to dissociate the perception of the wastes from the perception of the industry at the source. Household wastes are perceived differently from the other wastes, even if there is no difference in acceptability. Psychological factors show no relation with the perceived risk of wastes, a result which was not expected a priori. Trends since 1977 in the perception of wastes in France have been compiled [6].

4. Perception of hazardous situations by workers

A paper presenting some conclusions of the studies developed in Saclay with nuclear workers during the 1980s has been exposed at the IRPA 8 Conference in Montreal, 17-22 May 1992 [7]. It is expected to extend it for submission in Health Physics.

5. Social and economical consequences of major accidents.

At the CEC Seminar on Methods and Codes for Assessing the Off-Site Consequences of Nuclear Accidents, held in Athens, on May 7-11, 1990, a paper has been presented which deals with social and economical consequences [8]. More details are given in a report [9].

In the paper, methods for estimating the economic consequences of major technological accidents, and their corresponding computer codes, are briefly presented with emphasis on the basic choices. When applied to hypothetic scenarios, those methods give results that are of interest for risk managers with a decision aiding perspective. Simultaneously the various costs, and the procedures for their estimation are reviewed for some actual accidents (Three Mile Island, Chernobyl,..). These actual costs are used in a perspective of litigation and compensation. From the comparative analysis, some points may be emphasized.

- For large accidents the unit for cost is the billion.
- Costs from scenarios and those observed for actual accidents are of the same order of magnitude, when side effects are not accounted for.
- Side effects cannot be avoided when there are long term consequences.
- Cost estimates obtained from codes are of good value for emergency planning, and for short term countermeasures associated with rapid recovery.
- On-site costs are not dominating, as it was often supported.
- Environment recovery is a costly action which does not reduce to decontamination.
- Social activities disruption is more or less compensated in actual accidents.

The last two points that always involve costs and compensations in actual situations are neglected in codes; even if the task is difficult, it should be useful to introduce them in the codes in order to achieve better cost assessments.

6. Workshop on risk perception of technological hazards

A restricted workshop on the present situation of risk perception in the Community with respect to technological activities was organized in Paris, November 8-9, 1990. Participants presented their subjects of interest that were, for some people, the social representations of hazards, and for others, the improvement of risk communication. The project of an extended workshop in 1992 on "Risk perception for energy cycles and lessons for communication" has been proposed.

Publications

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Project 3

Head of project: *H. Maubert*

Objectives for the reporting period

The main topics to be studied were:

1. Global experiments

A choice of soils for lysimeter sampling had to be done. A demonstration sampling had to be performed in Tricastin in June 1991.

The aerosol generator Polyr had to be used for the contamination of plants and animal feed in collaboration with teams of Piacenza and Mol. The solubility of particles had to be determined.

2. Analytical experiments

The technique called "Decontaminating Vegetal Network" had to be tested in the laboratory and in the fields.

The possibility of using organic polymers for radionuclides adsorbtion and further decontamination had to be investigated.

Experimentations of methods to treat large amounts of organic wastes were to be started.

The soil to plant transfer factors of ruthenium and tellurium had to be measured.

3. In situ experiments

Non lethal defoliation had to be experimented on trees.

Methods to study wet deposition had to be set up.

Progress achieved including publications

1. Global experiments

The sampling sites have been chosen in France (near the NPPs of Tricastin, Belleville, Cattenom and Flamanville [1]), and in other countries:(Belgium: Mol, Germany: Kfa Jülich, Spain: Barcelona Univ. , United Kingdom: Harwell). The demonstration sampling was done in Tricastin in June 1991 in presence of EEC partners and representatives of the Commission [2],[3]. Sampling of Belleville lysimeter was done in May 1992. The lysimeters of other countries will be sampled during 1992 summer. The collection of data (hydrous potential and temperature of soils [4]) is going on normally in Tricastin and Belleville. In other countries some difficulties appeared, although the equipment is the same. Corrective steps have been taken and it should not impair the creation of the data bank. The lysimeters should enter the new building [5] in September 1992.

The POLYR [6] furnace was used in order to contaminate plants and soils for the teams of Piacenza, University of Gembloux and CEN/Mol.

The solubility of the particles produced by POLYR was studied [7]. It was found that caesium is almost always soluble, but strontium is not. That may explain the discrepancies between Sr transfer factors found with commercial sources and Polyr aerosols. Ruthenium is

not soluble. It may be therefore assumed that Ru transfer factors are negligible, which is in good accordance with post-Chernobyl observations.

2. Analytical experiments

The technique of sowing turfing plants by hydro-seeding and removing the vegetal carpet [8],[9],[10], after growth in order to decontaminate the soils was tested in field experiments at a scale of 100 m2 [11]. It was shown that it may be done on irregular surfaces such as agricultural land. The overall efficiency of the method could nor be accurately assessed because it is impossible to use radioactive tracers outdoors. Nethertheless a demonstration experiment of soil scrapping was done during an international seminar in Cadarache; CEI representatives expressed interest for the method. The machine used is now being tested in Chernobyl, and that should give soon reliable results.

When sprayed on the ground in aqueous solution, (dilution: 0,7%; equivalent to 13 g/m2) the gel film formed by some organic polymers was found efficient to stop resuspension and prevent runoff [12]. Decontamination may be achieved by brushing off the gel. According to laboratory tests, for Sr and Cs, decontamination efficiencies vary between 50 and 85% according to the type of soil.

A bibliographic study was done on the subject of organic waste treatment by processes of microbial digestion. It showed that it seemed possible to obtain reduction of mass and volume of solid wastes and to extract the radioactivity under liquid form. Tests have been done in the laboratory [13], at first with a few hundreds of grams of contaminated organic matter then, at a few kilograms. As an example, for fresh cress, composting reduces the mass of solid wastes by a a factor of 10, and the volume by a factor of 50. The leaching of radioactivity varies from 15 to 60 %. Work was also done on the physico-chemical treatment of leachates [14].

The soil to plant transfer factors of 103Ru under dioxide form were measured. As expected, the values were very low. Even the notion of a transfer factor of such a radionuclide had to be revised. [15].

The transfer factor from soil to bean leaves for 123mTe were measured. They range from 1E-2 to 1,43E-1 (dw/dw) according to the type of soil [16].

3. *In situ* experiments

Defoliation tests were conducted on forest trees (Oaks, Pine trees, Poplars). Some products were found very efficient in burning up rapidly the leaves, but they happened to kill the trees [17]. More tests are under way. The doses have been changed, and new products are being tested.

Experiments about wet deposition should have been done, but unfortunately it was not possible to build a satisfactory aerosol generator. We tried to use micronic particles of silver, but they tend to agglomerate and they could not be dispersed in the atmosphere.

Publications and documents

The letter althe end of a reference indicates:

(p): publication
(t): technical paper or internal note
(s): student's report

[1] H. MAUBERT, Ph. FACHE, .JOUVE., P. RONGIER, E. SCHULTE; Le programme RESSAC; bilan et perspectives. Congrès IRPA 8, Montréal, Québec, Mai 1992. (p)

[2] P. RONGIER; Les lysimètres RESSAC. Bilan des études au 01/01/91. Note RESSAC 01/91. (Français et Anglais).(t)

[3] Video about the sampling of lysimeters in Tricastin. In English.

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[5] P. RONGIER; Brève description du bâtiment RESSAC et de ses fonctions. Note RESSAC 03/91. (Français et Anglais). (t)

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[7] M. PIOCH, Y. CARTIER, J.M. QUINAULT, Ph. PICAT, Solubilité des aérosols émis en cas d'accident nucléaire; conséquences sur les contre-mesures. Séminaire de Cadarache "Intervention levels and countermeasures for nuclear accidents". Oct 1991; Cadarache. (p)

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[13] A. JOUVE, E. SCHULTE, Waste Management of Contaminated Crops After a LWR Accident, Symposium on Waste Management, Tucson, Arizona, Feb. 1991. (p)

[14] F. MORETTO, P. D'HUGUES; Etude de la décontamination des déchets végétaux résultant de la simulation des conséquences d'un accident nucléaire. Maîtrise des Sciences et Techniques de Microbiologie Industrielle et Appliquée. Université de Provence, Juin 1991. (s)

[15] P. CAROL, A. JOUVE; Etude du transfert racinaire du ruthénium 103 sous forme dioxyde au haricot. Juin 1990. (t)

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[17] A. JOUVE, E. SCHULTE, H. MAUBERT, P. BON; Non-lethal defoliation to impair the foliar uptake of fall-out radionuclides by forest trees. Seminar on the Dynamic Behaviour of Radionuclides in Forest, Stockholm, May 1992. (p)

COMPARATIVE ASSESSMENT AND MANAGEMENT OF THE HEALTH AND ENVIRONMENTAL IMPACT OF ENERGY SYSTEMS AND STUDIES RELATED TO THE EXPRESSION OF THE DETRIMENT ASSOCIATED WITH RADIATION EXPOSURE

Contract Bi7-004 - Sector C13

1) *Lochard*, CEPN - 2) *Wrixon*, NRPB - 3) *Kemp*, Univ. East Anglia
4) *Friedrich*, Univ. Stuttgart - 5) *Anguenot*, CEA-FAR

Summary of project global objectives and achievements

With the rising demand for energy and the increased awareness of the importance of environmental protection, it becomes increasingly necessary to focus not only on the health impacts of energy systems but also on the link between energy production and the environment. The initial aim of energy comparison studies was to rank the various electricity production systems. It is now recognized that this was merely an academic exercise, with a limited impact in decision-making. If comparisons, and choices, are to be made, it is essential that a consistent approach is taken. This project has developed in two parts, one dealing with radiological detriment, and the other comparing the coal system in the German region of Baden-Württemberg with the French nuclear cycle in the South-East of France.

A PC-based system for the expression and quantification of radiolocal risk and detriment is being designed with the possibility of using the new detriment indicators investigated during this contract, i.e. the YOLL (years of life lost), YOLI (years of life impaired), and the QALY (quality adjusted life years) so that measures of both fatal and non-fatal cancers as well as genetic effects can be incorporated. This system is still under development and will help define the radiological risks of nuclear electricity production, and put them into perspective witht the risks of other systems.

The second part of the project was concerned with the development of a general framework to incorporate health and environmental impacts into the decision-making process. This framework is currently being utilized for a comparative risk assessment between the coal and nuclear fuel cycles. The methodology was developed after an overview of past comparative studies so that this work could benefit from previous experience, and outstanding limitations such as the lack of environmental indicators, could be identified. It is important that this work is not just a repetition of that performed in the late 1970's, and so the definition of a framework ensures that in future results can be updated without redoing all the work, and additional aspects previously ignored or presumed irrelevant, can be treated.

Project 1: Comparative assessment and management of radiological and non-radiological risks associated with energy systems

Head of project: *Dr. Lochard*

Objectives for the reporting period

During the 1990-1991 Radiation Protection Programme, the project "Expression of Radiological and Non-radiological Detriments in the Comparative Assessment and Management of Risks Associated with Energy Systems" was initiated to collect the available information, and develop a coherent methodological framework, to assess and manage the health and environmental impacts of the nuclear PWR cycle compared with those of the coal cycle. The team led by Dr. Friedrich, IER, was responsible for the coal fuel cycle and CEPN and Dr. Anguenot, CEA-IPSN were to conduct the assessment for the nuclear fuel cycle.

Progress achieved including publications

The methodological framework has been developed to allow for direct comparisons between the coal and nuclear fuel cycles, and allow for the incorporation of the results into decision-making processes related to risk control. This comparative approach has been finalized based on the critical review of the studies performed during the 1980's.

The framework includes the classical dimensions used in the past comparative studies of health impacts on the public and workers under normal and accidental operations. Direct impacts on the environment are also considered for normal and accidental operations. The impacts are assessed in the framework of time and space dimensions. For each step of a fuel cycle a matrix of time and space is constructed. The assessment of the risks applicable for each cell of the matrix is conducted. The transfer of the releases through the environment and ultimately to the public is accomplished by impact pathway analysis specific to the reference environment and the composition and type of release.

Environmental indicators will be the resulting environmental (including agricultural and recreational use) damage from air and water pollution, as well as an increase in contamination levels (especially for nuclear). The different pathways between nuclear and coal have been harmonized in terms of the start-point and end-point of the pathway, common indicators describing detriment, and consistent timescales .

The health impacts for the public and workers will be reported using indicators of : mortality,

morbidity, genetic effects, years of life lost, working days lost and occupational injuries. At this time, direct comparisons between the two fuel cycles can be made using the indicators of deaths or worker-days-lost. New indicators have also been proposed to describe permanent disabilities.

In addition to the survey of past studies and development of general framework, CEPN conducted the risk assessment for the construction and decommissioning of a nuclear power plant, transportation between different steps in the cycle, waste disposal and major reactor accidents.

The methodology developed will also be transfered to DGXII EC/US External costs of Fuel Cycles Project. The results of the assessment conducted under the External Costs Project will be integrated into this comparative assessment.

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Projects 1-2: Expression of the detriment associated with radiation exposure

Heads of project: *Dr. Lochard, Dr. Wrixon*

Objectives for the reporting period

The quantification of attributes of radiation detriment for the purposes of dose limitation has been a subject of increasing focus in radiological protection. However, the topic is complex, and therefore as an aid to decision-making NRPB and CEPN are jointly developing a global computer tool, ASQRAD, that allows rationalization of the health effects and detriment data. In particular, NRPB is charged with the interpretation, quantification, and application of individual and aggregated measures of detriment for inclusion in the code. CEPN is charged with the review of health effects models and the problem associated with the transportation of data across the population. As the first part of a programme of work of at least four years, the main aim during this contract period was to fully plan the structure of ASQRAD, in order that there then be a framework within which the other projects can be developed.

Progress achieved including publications

During the reporting period, ICRP produced a revised set of recommendations in publication 60. This saw the Commission make more extensive use of quantitative measures of detriment to support their advice than had hitherto been seen. In particular, ICRP defined 'effective dose' as an aggregated measure of detriment; and various attributes were calculated, and judgements made on their importance, to assess the consequences of continued or cumulative exposure in order to recommend dose limits.

In spite of this, it is clear that there is no widely agreed methodology for determining how radiation detriment should be assessed with respect to the development of protection standards: it is a subject that remains in its infancy. It is equally clear that similar calculations of detriment sometimes not easily distinguished, they being a function of (for examples) the risk projection model used, the manner in which risk coefficients are transferred across populations, demographic assumptions about the exposed population, as well as the actual attribute of detriment under consideration.

A key step and the primary focus of this contract, was to develop a comprehensive tool -ASQRAD (Assessment System for the Quantification of RAdiation Detriment)- that allows a rationalisation of all these data, which will provide a common framework for developing the application of radiation detriment, and will act as a structure for analysing those aspects of

detriment that require social judgements.

Experience has shown that unless systems such as ASQRAD are fully planned prior to the commencement of coding, the program may be generated in a piecemeal fashion, becoming both inefficient and incomplete. For this reason, the development of ASQRAD has followed three distinct phases:

(i) **Planning paper.** This was prepared to give an overview of the range of models, calculations, end-points, and output required for the code; as well as the features that the various users would expect in the system. In particular, this noted all the data requirements, and the connections between these, highlighting those areas where work would be necessary in order to establish full data sets. This planning paper was completed in early 1991, and has formed the basis of all the subsequent work.

(ii) **Development and application of the database.** The development of the database is part of the ongoing programme of work, and has contributed towards the detailed planning of the software, particularly in relation to the health effects models. There are two components to the development of a rationalised set of health effects models. The first of these requires a clear elucidation of the individual sets of data and assumptions used: for example, for a given organ, the derivation of the risk coefficients, the form of the projection model, and the demographic details employed, are all important.

The second relates to the calculations themselves - the application of the risk projection models. A comparison study was performed using the present limited NRPB and CEPN codes (SPIDER and CORADE) to identify any differences in the assumptions and methods employed. The differences that arose were then traced back to the source, and a decision was made on whether to discard one of the approaches, or develop an alternative course of action specific to ASQRAD. For instance, the way in which survival probability of the over-85 age group is modelled differed, but is very important.

In conjunction with this, the basic calculations were being coded using the APL language. These calculations were designed to draw on a range of models and population details, and at present the database contains five models, and seven populations. These will be expanded.

(iii) **Detailed planning and preliminary coding.** During July 1991, a member of NRPB staff was seconded to CEPN to collaborate on this phase of the work. This was fruitful with a clearly defined structure for the remainder (the bulk) of the code, in the form of detailed flow-charts, being prepared during this time.

The basic calculations mentioned above under point (ii), were linked by an initial set of menus,

thus providing a framework around which the rest of the code, the graphics, and the library and help facilities can be built. This was designated ASQRAD 0.1; subsequently replaced by ASQRAD 0.2 towards the end of 1991.

ASQRAD 0.2 is a preliminary code linked by an elementary set of menus. Using the flow-charts, the rest of the system needs to be constructed around this, and work has commenced on this. It will, however, be the most exacting phase of the work for full help and library facilities directly accessible from within the software are required to be developed in concert with the code. The work in the next two years of the contract relates to the completion of this phase. During this time guidance on the quantification of detriment will also be developed.

Publications

1. **ASQRAD, a PC-based System for the Quantification of Radiological Detriment.** Planning paper - May 1991.

2. SCHNEIDER T. and ROBB JD., **ASQRAD: a tool for the evaluation of radiation detriment.** IN: Occupational Radiation Protection Proceedings of the BNES International Conference, Guernsey, May 1991. BNES, London (1991) pp 57-62.

3. STOKELL PJ, SCHNEIDER T, ROBB JD and BACHELOT R. **Evaluation of Radiation Detriment: ASQRAD.** Progress report, November 1991.

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Project 3

Head of project: *Dr. Ray Kemp*

Objectives for the reporting period

The UEA Environmental Risk Assessment Unit's contribution to the radiological part of the project has been related to investigations of the application of the Quality Adjusted Life-Year (QALY) measure for radiological protection. This has involved four related areas of work:

a) an extensive review of the QALY literature in order to advise on the advantages and disadvantages of QALY measures for this field;

b) an investigation of weighting procedures to adjust the QALY value according to (i) the source, and (ii) the consequences of effects of exposure to radiation;

c) calculating the cost of a QALY.

In all of these areas, the UEA team has liaised with the NRPB and other project members throughout, thereby contributing to the direction and progress of the overall research programme.

Progress achieved including publications

The results can be summarised as follows:

1. Review of the usefulness of the QALY approach

In general, the concept of the QALY is a good one for radiation protection.

However, QALY methods attempt to be too precise in assigning values to health states and a broader classification system may be beneficial for the radiation protection field than is more generally found in the literature.

Problems arise particularly with respect to discounting. We recommend the employment of a 0% discount rate. Viewing the problem from a social time preference perspective, evidence from our pre-pilot study of individual preferences appears to show that subjects agree with the proposition that all generations should be valued equally. On the other hand, taking a theoretical position that human health and human value are distinct from capital and goods in the market place, we would also argue that discounting procedures should not be employed. While there is some irony in that this is in essence what the QALY approach attempts to do, i.e. to enable market values to be placed on health care, we recognise that strong ethical objections do exist and so favour a 0% discount rate for the purposes of calculation.

2. Weigthing procedures according to source and to effects of exposure

2.1 Weighting according to source

There are undeniably strong arguments both for and against differentiating between the sources of radiation in such studies. Nevertheless, we have examined available procedures for determining public weights which might be assigned to different sources of radiation. We recommend that should further work be required, a Robens Institute, University of Surrey, would be appropriate. That study examined public weighting of preferences for alternative radioactive waste disposal routes; discussions have been held with one of the authors and with the NRPB, and it does appear to be a viable methodology. Project resources do not allow this work to be taken forward at this stage.

2.2 Weighting according to effects

A methodology has been developed and a pre-pilot study of individual preferences has been undertaken at UEA. The methodology is complex and initial results seem to show that it may prove to be impossible to draw meaningful conclusions from a wider study other than with respect to one important variable: namely, that subjects appear to prefer to weight all generations equally. If this is assumed to be the case, then the problem of the appropriate discount rate to be applied to the QALY is resolved (see above), but outstanding difficulties arise with respect to: balancing probabilities of detriment against the Years of Life Lost (YOLL), the Years of Life Impaired (YOLI), and the level (%) of impairment.

3. Cost of a QALY

Two approaches to costing a QALY are available. The first is to take the cost of treatment of radiation induced illnesses. These will vary widely; they will change with technological developments and advances in medical treatment; they are difficult to both quantify and to predict.

The second approach is to take a consensus estimate for the Value of Life (VOL), and then calculate the Value of a Life-Year (VOLY). Then, if we assume that one year spent in perfect health is one QALY, substitute with an estimate for a VOLY in perfect health.

An extensive literature review of relevant VOL estimates has been undertaken and the figures re-calculated from base values to £ 1990.

The median value for VOL is £1,590,498 (£ 1990).

The VOLY is £1.59m/39 = £40,782 (£ 1990).

This, assuming a risk factor of 5% per Sv, and an average YOLL value for all cancers of 16 years, results in a revised value for a manSv of £32,626 (£ 1990).

Publication

IVES D., THIEME M. and KEMP R.
The value of the quality adjusted life year.
Proceedings of the Third SRA Conference - Risk Analysis: underlying rationales, Dec. 1991 (to be published).

Project 4

Head of project: *Dr. Fiedrich*

Objectives for the reporting period

As the work of the first phase of the project was mainly focused on the comparison of occupational health risks from the nuclear and the coal fuel cycle, the objective of the current reporting period was to establish a methodological framework for the risk assessment from air pollution that could be applied on both fuel cycles in a consistent way. While there exist well established guidelines for risk assessment in the field of radiation protection, appropriate air transport models and human health models had to be identified to analyze potential health effects from air pollutants emitted from a coal fired power plant. The selected models should be applied to the real conditions of the German reference environment to quantify health effects from power plant operation.

Based on the economic valuation methods worked out during the first reporting period, a first monetization of impacts had to be carried out to demonstrate the integration of the economical dimension of external effects into the risk assessment analysis.

Progress achieved including publications

The analysis of occupational health risks from the coal fuel cycle was revised and harmonized with the work of the French team. The main source of occupational health risks is underground mining. Based on occupational health statistics, occupational health impacts are estimated with a relative high degree of reliability.

In contrast to radiation protection, there do not exist established guidelines for the quantification of health and environmental risks resulting from the electricity production from fossil energy sources. The present study tried to establish a producer related approach in which the pathway of a burden/pollutant is described in a detailed way from the origin to the impact on a receptor, in order to assign all resulting impacts to the respective activities. Such a chain of causal relationships is called an impact pathway. An impact pathway describes all processes and mechanisms from the origin of a pollutant or a burden to the resulting physical impacts on a receptor. Based on the quantification of physical impacts, the resulting socio-economic impacts should be quantified and described as monetary values.

Analysis of the "Air pollution - human health" impact pathway

The risk assessment analysis was carried out according to the levels of the impact pathway. First, a reference power plant was characterized. As it was not possible to use technical data of an existing power plant because of data protection reasons, it was decided to select a site that was identified in a power plant - site planning for Baden-Württemberg from 1976. Technical parameters of a modern German power plant with coal dust firing are used.

Health effects within the general public due to electricity production from coal are mainly caused by the air pollutants sulphur dioxide, nitrogen dioxide, ozone and particulates, which affect the respiratory system of human beings. A description of possible effects is provided in the main report.

The Industrial Source Complex Model (ISC) of the US-EPA was identified as an appropriate model to calculate air transport of SO_2, NO_x and particulates. The ISC Model is a strait line Gaussian plume model that produces a two dimensional field of ambient air concentration and dry deposition. The ISC Model was implemented on a PC and transport calculations were carried out for SO_2, NO_x and particulate emissions of the reference power plant.

The Urban Airshed Model (UAM), a three dimensional Eulerian numerical grid model of the US-EPA, is an appropriate model for the calculation of air transport and chemical conversion of secondary pollutants like ozone. The implementation of the rather complex UAM was not possible within the time scope of the project.

A literature review led to the compilation of human health models describing possible health effects resulting from the exposure to air pollutants. As there are no commonly accepted dose-response functions available for any of the pollutants of concern, threshold values published as air quality guidelines by national and international organizations were used to identify regions were possible health effects might appear. A quantification of effects is not possible without an explicit dose-response function.

Comparing the background concentration of air pollutants within the reference region and the increment of SO_2, NO_x and particulates, threshold values are not exceeded neither for long term exposure (annual mean values) nor for short term exposure (24 hours mean value), so that no adverse effects are expected to occur. However, there are some dose-response relationships published that suggest a linear function without threshold values. Such functions do not represent a scientific consent. Because of time reasons it was not possible to integrate them in the present analysis, but such functions should absolutely be considered in a future analysis.

In a first attempt to integrate the concept of external costs into a risk assessment study, monetary values for occupational risks were calculated based on the Value of a Statistical Life (VSL).

In order to give a more general view on health and environmental risks associated with the electricity production from coal, the most important environmental impacts of the coal fuel cycle were described.

Publications

As the current work is co-financed by the JOULE I Programme of the EC, DG XII (EC/US Project "External Costs of Fuel Cycles"), results will also be used and published within the external costs project.

R. Friedrich, W. Krewitt, B. Staiger: *Die Quantifizierung externer Effekte und deren Grenzen am Beispiel der Stromerzeugung aus Kohle*, VDI Berichte 927, Düsseldorf 1991

W. Krewitt, R. Friedrich: *Human health effects of coal energy technology*, in:Format and structure of a database on health and environmental impacts of different energy systems for electricity generation, IAEA-TECDOC-645, Vienna, April 1992

W. Krewitt, R. Friedrich: *A Methodology for Quantification of Human Health Effects due to Electricity Production from Coal*, in: Methods for comparative risk assessment of different energy sources, Proceedings of a specialists meeting organized by IAEA in Studsvik, Sweden, August 1991, Vienna 1992

Project 5

Head of project: *Dr. Anguenot*

Objectives for the reporting period

Inventory of French nuclear units: description and releases data of the PWR system (mining and milling, transformation of uranium concentrates, uranium enrichment, production of nuclear fuel and assemblies, electricity production and reprocessing of spent fuel). Study of the risks for the public by assessment of atmospheric and food chain transfers and of the risks for the workers.

Progress achieved including publications

For the risk assessment of the nuclear fuel cycle, a system representative for the south-eastern region of France was chosen. The following reference technologies have been chosen for each stage in the fuel cycle.

STAGE	REFERENCE TECHNOLOGY
1) mining and milling	French mines (Vendée, La Crouzille, Hérault)
2) transformation (yellowcake--> UF4)	Comurhex at Malvési
3) conversion (UF4 --> UF6)	Comurhex at Pierrelatte
4) enrichment	Eurodif at Pierrelatte
5) fuel fabrication	Romans and Pierrelatte
6) electricity production	Tricastin PWR
7) reprocessing	Cogema at La Hague
8) conditionning and storage	Cogema at La Hague
9) waste disposal	Aube surface disposal, Auriat hypothetical granite deep disposal site
10) transportation	Road and rail

1. Risks for the public

Exposure of the general public is calculated from the concentrations of the various pollutants in the environment. Atmospheric concentrations are obtained by using a model for atmospheric dispersion and applying it to various source-terms, taking weather conditions into account. Concentrations in other sectors of the environment are also evaluated using models and transfer parameters, appropriately chosen according to the medium involved. Other quantities are needed too, such as the activity of the pollutant inhaled or ingested, or the quality factors indicating the relative biological effectiveness of a substance.

In order to compare the different steps of the uranium cycle, we must be free from the "site effect" such as: weather conditions, distribution of population around the site... For that reason, we have chosen a single site where we have located the different plants with their own characteristics. In this study we selected the site of Pierrelatte locaed in the Rhone Valley, because a certain number of nuclear industries are really running on this site.

For the evaluation of the radiological risk, we consider the case of an imaginary group of the population subjected to the sum of all the maximum levels of exposure around the site of Pierrelatte, evaluated for each of the pollutants. Although imaginary, it has the advantage of indicating an upper limit for the harm that may be done, but does not yield as realistic a comparison as desirable.

The exposures to which the general public are subjected have been assessed at two distances from the emission points: 17 km (100,000 people) and 85 km (about 1 million). The excess mortality and the percentage of nonfatal cancers have been calculated according to the relationship proposed by the new ICRP 60.

2. Risks for the working population

The effects on the health for workers have been estimated by theoretical calculations based on the exposures experienced. They have also been obtained by examining the declarations of occupational diseases recognized by Social Security, although such a recognition is based on the assumption of an occupational origin and not on the certainty of it. Accidents at work have also been added as another form of health hazard for workers.

Publication

AIGUEPERSE J., ANGUENOT F., HARDY S.: French Uranium Fuel Cycle - Assessment of Public and Occupational Risks during Normal Operation, May 1992, IPSN/DPHD.

QUANTIFICATION OF RADIATION RISKS, OPTIMISATION OF PROCEDURES AND ANALYSIS OF OCCUPATIONAL EXPOSURE

Contract Bi6-111 - Sector C14

1) *Jacobi* , GSF Neuherberg

Summary of project global objectives and achievements

Objectives of the report have been a detailed analysis of the of the S-cohort of Czech uranium miners for the improvement of the risk estimates following radon inhalation.

Progress achieved including publications

A detailed analysis of the S-cohort of Czekoslovak uranium miners has been performed in collaboration with the Institute for Hygiene and Epidemiology in Prag.

First step in the analysis has been a comprehensive description of the data with a graphical representation of their various aspects. This has indicated a marked non-linearity of the excess rates with cumulated exposure as well as a decrease of the excess relative rate with age attained.

Second step has been the analysis of the data in terms of the isotomic regression. The rates for lung cancer have been estimated non parametrically under the assumption of monotonicity in cumulated exposure (lagged by 5 years) and age attained (up to 80 years). The isotonic rates are used to indicate the general character of the dependencies, i.e. they are used as a basis to select relationships in the last, parametric step of the analysis.

The parametric analysis is performed with a relative risk model which follows the model recommended by the BEIR IV Committee in its joint analysis of the major Western cohorts of uranium miners.

The results of the analysis are not in complete agreement with the conclusions of the BEIR IV Committee. An important characteristic of the Czekoslovak dfata is the non-linearity of the rates in their dependency on cumulated exposures. The non-linearity is particularly marked at low exposures. The reason is uncertain. It would be related to confounding factors for which information is missing such as individual smoking habits or indoor additional exposures.

To account for the influence of time since exposure, the age at median exposure, i.e. the age at which a miner reaches 50 % of his total cumulated exposure has been used as reference. This is used as an alternative to the BEIR IV Committee's method which is not practicable under the non-linearity in cumulated exposure.

A comparison of the influence of age attained and time since median exposure led to the result that both variables have a significant influence on the excess rate of lung cancer, i.e. the relative excess rate decreases with increasing age attained or with increasing median exposure. In spite of the correlation between the two variables their influence can be detected.

The following expression for the rate of lung cancer was found to fit the data best in the sense of maxi,i, likelihood (with C the cumulated exposure in Working Level Month (WLM) and age attained or age at median exposure in years)

$$r(a,C,e_m) = r_o(a)\left(1 + 4.1C^{0.6}e^{-0.05a-0.06t}\right) \qquad (1)$$

$t = o$ if $a - e_m - 10 \leq 0$

$t = a - e_m - 10$ if $a - e_m - 10 > 0$

r_o (a) are the age specific spontaneous rates, which are here those of the male Czekoslovak population during the years 1960 - 1985. In this expression the decrease in time since median exposure becomes effective only if more than 10 years have passed since half of the exposure was received.

Another peculiarity of the data is the apparent increase of the risk with prolonged exposures, i.e. for the same cumulated exposure longer period of cumulation increase the risk. The inclusion of the duration of exposure, τ,again with an exponential term in the rates leads to the following modification if Eq(1)

$$r(a,C,e_m\tau) = r_o(a)\left(1 + 4.4C^{1.5}e^{-0.05a-0.05t-0.06\tau}\right) \qquad (2)$$

τ is in years.
Again it can not be excluded that this observation may be due to unravelled confounding factors.

Publications relevant to this field of work:

Sevc J., Tomasek L., Kunz E., Placek V., Chmelevsky D., Barclay D., Kellerer A.M.:
A survey of the Czechoslovak follow-up of lung cancer mortality in uranium miners.
Accept. for publication to Health Physics (1992).

STATISTICAL METHODS FOR THE ANALYSIS OF GEOGRAPHICAL CORRELATIONS, APPLICATION TO THE ANALYSIS OF THE CORRELATION BETWEEN POPULATION RADIATION EXPOSURE AND CANCER MORTALITY

Contract Bi6-126 - Sector C14

1) *Hémon* , INSERM

Summary of project global objectives and achievements

The research that was carried out during 1990-1991-1992 in this project is the last part of a comprehensive project which started in 1985.

This research project had a double purpose : first to investigate statistical methods suited to the analysis of models of association between spatially defined variables, then to apply these methods to the study in France of the joint variations of risks factors such as low dose radiation or industrial pollution together with some health indicators such as mortality for cancer of specific sites.

In the first part of the contract, emphasis was placed on the development of parametric tests of association between geographically defined variables. In particular, modified tests of simple and partial correlations for spatially autocorrelated variables were designed and their performance was investigated. Moreover multiple regressions, involving a spatial parmetrisation of the errors, were implemented.

All the tests developed in the first part of the contract were based on an underlying assumption of normality of the variables. This assumption can be quite restrictive in many contexts. In the last part of the contract (1990-1992) which is the object of our report ,attention was turned towards non parametric tests. Modifications of tests of association based on ranks were studied for spatially autocorrelated variables, as well as the designs of tests based on permutations.

During the course of the project, a geographical data file containing mortality rates for different cancer site, same socio-economic indicators, and some indicators of population exposure to low dose radiation, was compiled. Based on this file, we report the results from an analysis of the geographical association between the cancer mortality rates for some radio-sensitive sites in relation to background radiation and consumption of radiodiagnostic examinations.

Project 1

Head of project: *Dr. Hémon*

Objectives for the reporting period

• study the robustness of the modified tests of association previously developed to departure from normality assumptions

• define non parametric tests of association between spatially distributed variables

• analyse the geographical association in France between the mortality rates for some radio- sensitive sites (lung, breast, thyroïd, leukemia) and indicators of population exposure to low doses radiations (background radiations, consumption of radiodiagnostic examinations), taking into account appropriate geographical confounders.

Progress achieved including publications

We first summarize the progress achieved in statistical methodology.
The development of parametric tests of association between spatially distributed variables was complemented by a study of non parametric methods.

1. Non parametric tests of association

As a preliminary step, the robustness of the modified tests of the correlation coefficient to some patterns of departure from normality was investigated.

1.1 Performance of the modified $t_{\hat{M}-2}$ test for non gaussian variables

The development of modified $t_{\hat{M}-2}$ tests for simple or partial correlation between spatially distributed variables has been previously reported (1,2). The construction of these tests as well as the study of their performance was done under Gaussian hypotheses. The performance of the modified $t_{\hat{M}-2}$ test was subsequently investigated when the normality of the underlying variables was perturbed. Three types of perturbations were considered : (a) truncated Gaussian variables, (b) lognormal variables, (c) mixture of Gaussian variables. The $t_{\hat{M}-2}$ test was shown to be quite robust for these patterns of departure from normality in terms of its significance level, with a tendency to be over-conservative in cases of high autocorrelations (3). Alternative non parametric tests would therefore be of interest.

1.2 Modification of Spearman's rank correlation test for large samples

A classical non-parametric measure of association between two variables is Spearman's rank correlation r_S which evaluates a correlation coefficient between the ranks of the two variables. When N is reasonably large ($N \geq 30$), r_S is tested using the transformed variables, $(N-2)^{1/2}\, r_S/(1-r_S^2)^{1/2}$, which follows approximately t-distribution with N-2 d.f. When X and Y are measured at N sites of a spatial domain and are positively spatially autocorrelated, this procedure is no longer correct as it leads to inflated significance levels. Similarly to the case of the empirical correlation coefficient, a modified rank correlation test can be defined, based on an effective sample size $\hat{M}$ (instead of N) which takes into account the spatial autocorrelation of each variables. $\hat{M}$ is estimated as for the modified $t_{\hat{M}-2}$ statistic defined in (1). A simulation study showed that the observed type I errors of the modified r_S test are very close to their nominal level.

1.3 Tests of association based on permutations

Monte Carlo tests can be defined which rank an observed statistic t among a set of statistics simulated under the null hypothesis, defining in this way a Monte Carlo significance level for the statistic t. In the case of spatially autocorrelated variables X and Y, using all the permutations of the values of X or Y without restrictions to simulate the set of statistics, lead to over significant Monte Carlo tests, as could be expected since the spatial structure of X and Y is destroyed.

To overcome this problem, only those permutations leading to realisations of X or Y which preserve in some way the internal autocorrelation structure should be retained.

We chose to define this restricted subset of permutations on the basis of a distance criteria between the autocorrelations of the permuted realisation of X and that of the original realisation. We found that permutation tests constructed in this way had correct significance levels except in the more strongly autocorrelated cases.

Hence our study showed that permutation tests for spatial association can be defined for irregular spatial networks. This class of method needs to be studied further with other spatial networks and autocorrelation structures.

2. Geographical analysis of mortality rates for radio-sensitive sites

2.1 Data file

• The data file contains informations recorded at the geographical level of the French "départements".

• The cancer sites chosen were those known to be radio-sensitive. They include lung, thyroid, breast cancer and leukemia. Age standardised mortality rates were computed for 3 periods : 1968-1969, 1974-75-76 and 1984-85-86, which are close to census dates.

• Mean gamma radiation was measured indoors and outdoors in 50 French départements (Tirmarche et al, Radiation Protection Dosimetry, 24 : 479-482, 1988). For a smaller group of départements (42) mean radon level, an exposure which could be linked to lung cancer is also available.

• The total number of radiological examinations per inhabitant which are reimbursed by the "Securité Sociale" or used by hospitals was available at the level of the départements only in 1989. This variable will be used as an indicator of differential geographical distribution of radiodiagnostic examinations before 1989 since this consumption has been shown to increase somewhat in parallel in the different French regions since 1975.

• In view of important known risk factors for some cancer sites, adjustment variables will be taken into account. Specifically male lung cancer mortality rates will be adjusted on cigarettes sales per inhabitant and percentage of blue collar workers, female lung cancer mortality rates will only be adjusted on cigarette sales per inhabitant and finally breast cancer rates will be adjusted on the proportion of urban communes per départements as an indicator of socio-economic level of the département.

2.2 Method

• *Association with consumption of radiodiagnostic examinations.* Modified $t_{\hat{M}-2}$, tests of simple or partial correlation between cancer mortality rates in 90 departments for the period 1984-85-86 and consumption of radiodiagnostic examinations in 1989 were calculated, using a 15 distance strata.

• *Association with background exposure* : Modified $t_{\hat{M}-2}$ test of simple or partial correlation between cancer mortality rates and background radiation exposure were calculated for the 3 periods. In view of the moderate number of areas only four strata (<150, 150-300, 300-450, >450 kms) were chosen for calculation of the effective sample size $\hat{M}$. It was checked that this particular choice of strata had little influence on the results.

• Finally significant associations with background radiations were also adjusted by consumption of radiodiagnostic examinations.

2.3 Results

2.3.1 Radiodiagnostic examinations

• Before any adjustment on possible confounders, there is some evidence of association between lung cancer rates (male and female) and consumptions of radiodiagnostic examinations (Table 1). There is a high correlation between the geographical distribution of cigarette consumption and that of radiodiagnostic examinations, ($r = 0.56$), making it difficult to separate out their respective effects. As a result, male lung cancer rates are no more significantly associated with radiodiagnostic examinations, once confounding factors (including in particular cigarette sales) have been taken into account. Some degree of association between radiodiagnostic examinations and female lung cancer remains after adjustment on confounding factors. No direct association was found with either leukemia or thyroid cancer (male or female). The significant simple correlation with breast cancer is entirely explained by the adjustment on socio-demographic factors.

2.3.2 Background radiations

• There is weak evidence of a link between lung cancer mortality and gamma radiation exposure for the period 1968-1969 (Table 2) with similar correlations coefficients for men and women, indoor or outdoor exposure. For the other 2 time periods, there is no evidence of any pattern and the correlations are non significant contrary to what would be expected if the 1968 correlations reflected a direct link. No geographical association was found between lung cancer rates and radon exposure.

• No positive association was found between gamma radiation exposure and either breast cancer or leukemia for any of the 3 periods analysed.

• There is some evidence of geographical association between female thyroïd cancer rates and gamma radiation (Table 3). Simple correlation coefficients are broadly similar for the 3 periods even though the modified $t_{\hat{M}-2}$ statistic is only statistically significant for the first and third period. Some evidence of positive association is maintained after adjustment on a gradient of distance to sea, a covariate which is significantly linked to female thyroïd cancer for the periods 1968 and in 1984. In 1984-86, adjustment on consumption of radiodiagnostic examinations further weakens the link. No geographical association was found for male thyroïd cancer.

2.4 Discussion

Some evidence of positive geographical association between female lung cancer and consumption of radiodiagnostic examinations have emerged. For female lung cancer, in contrast with male lung cancer, this link is not explained by a geographical indicator of cigarette consumption. It is interesting to note that in a previous geographical analysis concerning the regional level and only mortality up to 1975 (Euratom contract B10 F 515 82 F) the same correlation between radiodiagnostic consumption and female lung cancer had been found. Thus this geographical link is stable in time.

Concerning background radiations,the only positive result to have emerged from our geographical analysis is that of a possible link of gamma radiation with thyroïd cancer in females, link which is weakened in 1984 by the adjustment on consumption of radiodiagnostic examinations. For this site, mortality represents only a small fraction of the incident cases and hence the analysis would have been considerably more powerful if geographical incidence data were available. Thyroïd cancer mortality is approximately twice as high in women than in men which could explain the negative finding for men. Further analyses at a more detailed geographical level would be interesting as the averaging of the exposure over a whole département produces certainly some ecological bias (4) which could explain the negative findings for the other mortality sites. For rare cancer sites such as thyroïd cancer or leukemia, an analysis which takes into account the fluctuations of the observed mortality counts around their mean is also warranted.

Table 1

Modified tests of correlation between lung and breast cancer consumption of radiodiagnostic examinations.

lung cancer									
male	r	$t_{\hat{M}-2}$	$\hat{M}-2$	p	female	r	$t_{\hat{M}-2}$	$\hat{M}-2$	p
(a)	0.25	2.06	65	0.04	(a)	0.41	3.25	53	0.002
(b)	-0.13	-1.24	87	NS	(b)	0.18	1.82	99	0.07
(c)	0.02	0.22	91	NS					
breast cancer									
(a)	0.24	1.99	64	0.05					
(d)	-0.12	-1.15	85	NS					

(a) simple correlation coefficient.
(b) partial correlation coefficient after adjustment on cigarette sales per inhabitant.
(c) partial correlation coefficient after adjustment on cigarette sales per inhabitant and proportion of blue collar workers.
(d) partial correlation coefficient after adjustment on the proportion of urban communes.

Table 2

Modified tests of correlations between lung cancer mortality and mean gamma radiation exposure.

lung cancer	Indoor				Outdoor			
(male)+	r	$t_{\hat{M}-2}$	$\hat{M}-2$	p	r	$t_{\hat{M}-2}$	$\hat{M}-2$	p
1968-69	0.29	2.37	62	0.02	0.22	1.75	60	0.09
1974-75-76	0.02	0.17	49	NS	-0.06	-0.46	49	NS
1984-85-86	-0.16	-1.14	48	NS	-0.19	-1.33	48	NS

+ after adjustment on cigarette sales per inhabitant and proportion of blue collar workers.

lung cancer	Indoor				Outdoor			
(female)++	r	$t_{\hat{M}-2}$	$\hat{M}-2$	p	r	$t_{\hat{M}-2}$	$\hat{M}-2$	p
1968-69	0.24	1.56	39	0.13	0.25	1.60	40	0.12
1974-75-76	0.07	0.51	59	NS	0.11	0.87	58	NS
1984-85-86	0.00	0.00	47	NS	0.02	0.14	47	NS

++ after adjustment on cigarette sales per inhabitant

Table 3

Modified tests of correlation between thyroïd cancer mortality (female) and mean gamma radiation exposure

thyroïd cancer		indoor				Outdoor			
female		r	$t_{\hat{M}-2}$	$\hat{M}-2$	p	r	$t_{\hat{M}-2}$	$\hat{M}-2$	p
1968-69	(a)	0.26	1.74	42	0.09	0.32	2.20	42	0.03
	(b)	0.22	1.53	45	0.13	0.28	1.94	44	0.06
1974-75-76	(a)	0.22	1.59	48	0.12	0.22	1.53	47	0.13
	(b)	0.21	1.48	49	0.15	0.20	1.41	49	0.16
1984-85-86	(a)	0.18	1.73	85	0.09	0.20	1.93	85	0.06
	(b)	0.14	1.55	111	0.12	0.16	1.66	107	0.1
	(c)	0.12	1.18	96	NS	0.13	1.32	94	NS

(a) simple correlation coefficient
(b) partial correlation coefficient after adjustment on distance to sea
(c) partial correlation coefficient after adjustment on distance to sea and consumption of radiodiagnostic examinations.

Publications

(1) P. Clifford, S. Richardson, D. Hémon. Assessing the significance of the correlation between two spatial processes. Biometrics, 45 (1) 123-134 (1989).

(2) S. Richardson. A method for testing the signifiance of geographical correlations with application to industrial lung cancer in France. Statistics in Medicine, 9, 515-528, (1990).

(3) S.T. Richardson. Some remarks on the testing of association between spatial processesSyracuse Symposium on Spatial Statistics, April 1989,to be published in the Institute of Mathematical Geography monograph series, under he title of Spatial Statistics : Past, Present, and Future.

(4) S. Richardson .Statistical methods for geographical correlation studies to be publishes (chapter 16) in : "Geographical and Environmental Epidemiology : Methods for Small Area Studies", Eds P. Elliot, J. Cuzick, D. English, R. Stern, Oxford University Press (1992).

(5) S. Richardson, C. Guihenneuc, V. Lasserre. Spatial linear models with autocorrelated error structure. A paraître dans The Statistician, (1991).

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EPIDEMIOLOGICAL STUDIES OF RADIATION CARCINOGENESIS AND ITS BIOPHYSICAL BASIS

Contract Bi6-221 - Sector C14

1) *Gössner*, GSF Neuherberg - 2) *Spiess*, Universität München - 3) *Kellerer*, GSF

Summary of project global objectives and achievements

Project 1: Late effects in ^{224}Radium treated ankylosing spondylitis patients
Prof. Gössner, GSF

Project 2: Late effects in ^{224}Radium treated juvenile and adult patients
Prof. Spiess, Universität München

Project 3: Epidemiology of radiation carcinogenesis
Prof. Kellerer, GSF (früher Universität Würzburg)

The three projects of the research programme are aimed at the epidemiological study of long-term radiation effects in patients injected with ^{224}Radium.

Project 1 is concerned with more than 1500 ankylosing spondylitis patients treated between 1948 and 1975 with repeated intravenous injections of ^{224}Radium. The α-doses to the skeleton, on average 0.67 Gy, are considerably lower than the doses in the earlier patients that are being studied in Project 2. An unexpected increase of chronic myeloid leukaemias (4 cases observed vs. 0.8 expected, $p < 0.009$) has been observed in this low dose group.

Project 2 continues the study of patients that were treated in a German hospital shortly after World War II as juveniles for bone tuberculosis and as adults for ankylosing spondylitis. The data, particularly for bone sarcomas, are largely complete, but statistical and radiobiological evidence suggests that additionally breast, liver, and kidney cancers may be induced. In a continued follow-up, the possibility in increased rates of other types of cancer, such as of the prostate and bladder will need to be monitored.

Project 3 continues and extends the mathematical and statistical studies for the evaluation of the data from Project 1 and Project 2 and for the comparison of these data with the broader experience from other epidemiological studies and other experimental work on radiation carcinogenesis. It was also concerned with the biophysical basis of the effectiveness of different types of ionising radiation, and generally the risk evaluation at low doses. Continued attention has been given to the development of algorithms and to the definition of data sets for general use in radiation carcinogenesis studies.

Project 1

Head of project: *Prof. Dr. Gössner*

Objectives for the reporting period

Contact and follow-up of patients of the exposure group and the control group. Registration of causes of death. Comparison of the results from the exposure and control groups with respect to the risk of late effects in bone, haematopoietic tissue, and other organs known or supposed from Project 2 to be related to the ^{224}Radium treatment.

Progress achieved including publications

In collaboration with a number of Orthopaedic clinics we have been following the health of more than 1500 patients who have been treated for ankylosing spondylitis with the short-lived bone-seeking ^{224}Ra (half-life 3.66 d). The majority of the patients included in this Project 1 has been treated in the years 1948 - 1975 and most of them received one series of 10 weekly injections of about 1 Mbq of ^{224}Ra each. This was the usual dosage in the recent decades for the treatment of ankylosing spondylitis and leads to a cumulative α-dose of about 0.56 Gy to the marrow-free skeleton of a 70 kg man. In addition we also follow a control group of ankylosing spondylitis patients not treated with radioactive drugs or X-rays in order to provide comparative information on causes of death and lesions possibly related to the basic disease itself or to chemotherapy.
Patient data relating to ^{224}Ra exposure and/or treatment with other pharmaceuticals, for both collectives, were drawn from hospital records. Information on the current status is mainly gained from questionnaires send periodically to the patients. Causes of death were determined from hospital records, reports from family physicians or death certificates. In addition for several patients autopsy protocols were available.
Until end of this contract, 560 patients in the exposure group and 711 patients in the control group had died (Table 1). We observed 3 cases of malignant primary bone tumours (according to the Histological Typing of Bone Tumors of the WHO) in the exposure group: one fibrosarcoma of bone, one reticulum cell sarcoma (malignant lymphoma) of bone and one medullary plasmocytoma (multiple myeloma). In the control group we observed only one case, a medullary plasmocytoma (Table 2). The range of expected cases for these tumours is exceptionally broad (3 cases observed vs. 0.7 - 2.4 expected, $p = 0.43$), and this leads to the conclusion that, in contrary to earlier assumptions, for malignant bone tumours there is no longer any significancy of elevated risk in the exposure group. The types of bone tumours in our exposure group, however, were different from those observed in Project 2: two of the three cases observed in this Project 1 were tumours of the bone marrow whereas in Project 2 mostly osteosarcomas were found.
We moreover observed 10 cases of leukaemia in the exposure group (vs. 2.7 - 2.8 expected, $p < 0.001$) and 6 cases in the control group (vs. 3.3 - 3.5 expected, $p = 0.14$). Subclassification of the leukaemias (Table 3) shows that in the exposure group only the chronic myeloid leukaemias (4 cases observed vs. 0.8 expected, $p < 0.009$) are significantly elevated whereas in the control group the observed

cases are within the range of expected values. Similar findings have not been observed in the earlier group of patients of Project 2 treated with higher doses of ^{224}Ra.

The increased rate of myeloid leukaemias in the collective of Project 1 is in agreement with observations from experiments with mice injected with bone seeking α-emitters at very low dose rates, lower than those found to cause bone tumours. The induction of myeloid leukaemias has also been demonstrated in mice treated with $^{239}Plutonium$, a bone surface seeker like ^{224}Ra, down to dose rates of a few mGy/day.

Table 1: Follow-up status of ankylosing spondylitis patients in the exposure and control groups

	Exposure Group	Control Group
Total number of patients	1577	1462
- Treated with X-rays additionally	106	126
Remaining patients	1471	1336
Deceased patients	560	711
- Cause of death certified	542	650
- Cause auf death not yet known, still in work	18	61

Table 2: Skeletal diseases

	Exposure Group		Control Group	
Observed patients	1471		1336	
- Deceased, cause of death certified	542		650	
Total cancers	118	(22L*)	146	(13L)
Bone marrow failure	12	(8L)	9	(3L)
Bone tumours	4	(1L)	2	
- Exostosis (osteochondroma)	1	(1L)	1	
- Malignant primary bone tumours	3		1	
- Fibrosarcoma	1		0	
- Malignant lymphoma	1		0	
- Medullary plasmocytoma	1		1	

* living

Table 3: Diseases of haematopoietic and lymphatic system

	Exposure Group	Control Group
- Myeloproliferative diseases	7 (1L*)	3
- Myeloid leukaemia	6	3
- Chronic myeloid leukaemia	4	1
- Acute myeloid leukaemia	2	2
- Osteomyelosclerosis	1 (1L)	0
- Lymphatic leukaemia	3	2
- Leukaemia of unknown type	1	1
- Non-Hodgkin-Lymphoma	2 (1L)	1
- Hodgkin's disease	1	0
- Extramedullary plasmocytoma	0	1

* living

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Project 2

Head of project : *Dr. H. Spiess*

Objectives for the reporting period

- Review of existing data using personal computers.

- Standard questionnaires have been sent out to the women treated as juveniles to examen their status of health and to control the appearence of mamma cancers.

- Standard questionnaires have been sent out to all living patients during 1990 and 1991 to complete the case history.

- Patient visits have been made for patients living in Northern Germany.

- Cooperation with Prof. F. Stefani to examine patients eyes with a Scheimpflug-camera at Eye Hospital of the University of Munich. The camera was purchased in summer 1991.

- Cooperation with Prof. Breipohl / Prof. Hockwin Eye Hospital of the University of Bonn to specialize in the field of Scheimpflugcamera in autumn 1991.

Progress achieved including publications

At 3 year intervals we are following the health of 900 patients (509 men, 173 women, 111 boys, and 107 girls) who received repeated injections of ^{224}Ra after World War II, for treatment of ankylosing spondylitis or bone tuberculosis, but also for other non-cancerous diseases.
On the average, the dosage in kBq/kg was about twice as high to the children as to the adults, and because of the growing skeleton, the average skeletal dose was much higher in the children than in the adults. Usually the patients received 1 or 2 injections per week. The time spans were averaging 6 months for the adults and 11 months for the juveniles. At the time of last contact 575 of 900 patients were deceased. 54 patients developed bone sarcomas, 2 patients developed a second bone sarcoma. The last bone tumour appeared four years ago, but the risk appears to be nearly exhausted now. There were 127 observed soft tissue malignancies, this number presents a little excess to the expectation based on the distribution in age, the length of the follow-up of the cohort, and the age specific population rates for the different malignancies. The age specific rates were taken from the Saarland and the former GDR tumour registry.
For a few cancer types, however, the observed numbers are in excess of the expectation values.
The breast cancer excess came as a surprise, with 18 cases observed versus approximately 4.1 - 6.1 cases expected. All but one case occurred more than 10 years after irradiation and all but one occurred after the age of 35. In patients given ^{224}Ra as adults the 9 cases observed are approximately a twofold increase to the 3.5 - 5.2 cases expected. More than that, for those given ^{224}Ra as juveniles, a thirteenfold increase occurred (9 cases observed vs. 0.6 - 0.9 expected, $p < 0.000005$).

Liver cancers occurred in seven ^{224}Ra patients, i.e. in a significantly larger number than the 1.1 - 1.2 expected cases ($p < 0.001$). One "probable" liver cancer might possibly have been a metastasis, but the clinical and pathology reports clearly indicate that the other six were primary liver cancers. Even for the five confirmed cases versus 1.1 - 1.2 expected, the difference is still significant ($p < 0.008$).
Kidney cancers have occurred in seven patients versus 2.4 - 2.6 expected cases ($p < 0.02$). With the exception of one all of these cancers were "hypernephromas", the most common form of kidney cancer. The tumour appearence times ranged from 12 to 35 years after the start of ^{224}Ra injections.
Leukaemia occurred in six patients. The elevated leukaemia rates observed in the control group of ankylosing spondylitis patients of Project 1 would correspond to five leukaemia cases among the ^{224}Ra treated spondylitis patients of this project, whereas from data from the German cancer registries 2.2 cases would be expected.
Of the six leukaemias among the ^{224}Ra patients in our study, four occurred among the 396 spondylitis patients; only two occurred among the 504 other patients who mostly had tuberculosis for which few drugs were available at that time in Germany. Only one of the juvenile patients has developed leukaemia; she, a tuberculosis patient, had chronic lymphatic leukaemia, a type not assumed to be associated with radiation exposure.
Statistical and radiobiological evidence suggests that ^{224}Ra and its decay products can induce bone sarcomas and may induce breast, liver, and kidney cancers in humans. In the continued follow-up, the possibility of increased rates of additional types of cancers, such as prostate and bladder will need to be monitored.

Table: Summary of diseases of the ^{224}Radium patients (June 1992)

	age at first injection		
	0-19 yr	adult	total
Skeletal diseases			
Bone sarcoma	38	18	56
Exostosis	29	0	29
Growth retardation	28	0	28
Tooth breakage	40	20	60
Soft tissue diseases			
Cataract	28	61	89
Liver (non-cancer)	4	35	39
Kidney (non-cancer)	11	69	80
Diabetes	4	43	47
Cancers of soft tissue	25	102	127
Lung	2	15	17
Breast	9	9	18
Skin	2	3	5
Urogenital tract	4	31	35
Kidney	2	5	7
Bladder	0	8	8
Prostate	0	10	10
Uterus	1	5	6
Fallopian Tube	0	1	1
Ovar	1	2	3
Gastro-intestinal tract	3	21	25
Stomach	1	11	12
Colon	1	6	7
Rectum	1	4	5
Hepato-pancreatic system	2	10	12
Liver	2	5	7
Pancreas	0	5	5
Others (f. e. brain)	2	8	10
Leukaemia	1	5	6

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Project 3

Head of project: *Dr. A. M. Kellerer*

Objectives for the reporting period

There were three main objectives during the reporting period. The first objective was the continuation of methodological work for the analysis of radiation cancerogenesis. The second objective was the data collection and the numerical calculations that were required to provide control rates for solid cancers from population statistics that were to be compared to the observed incidences among the ^{224}Ra patients in project 1 and in project 2. The third objective was preparatory work for new extended investigations on lense opacifications among the ^{224}Ra patients that are followed in project 2. This work was concerned mainly with hardware and software development for a movable Scheimpflug-camerasystem.

Progress achieved including publications

Within the first objective of the project the mathematical and numerical methodological work was continued and extended. One main topic was the creation of pictorial diagrammes for the elucidation of the interplay of essential factors that need to be considered in a modelling of risk. The main factors that were considered apart from sex and original illness, age at exposure and duration of exposure, age attained at diagnosis of the tumour, and time since exposure. The diagrammes are used in a preliminary step of the analysis and facilitates the judgement of the various fairly complex models that are then used in the maximum likelihood analysis. The diagrammes are extended in an intermediate step of the analysis that utilises isotonic regression and can thereby serve as a basis for the selection of appropriate analytical models.

This methodological work is within this project primarily directed towards the completion of a monograph comprising all experience with the ^{224}Ra patients. However, during the reporting period this work has also been applied systematically in analysis of the Czechoslovakian uranium miners, that was performed in close cooporation with the Institute for Radiation Protection, working group on risk analysis, and with the Czechoslovakian colleagues from the Prague Institute of Epidemiology.

The second objective of the project was to prepare the population background rates for Germany for a number of solid tumours that were found within the study of project 1 and project 2 to have apparently elevated incidences. This work also includes the derivation of base line rates for leukaemia. The numerical results are given within the project descriptions of project 1 and project 2.

The third major objective of the programme was concerned with the preparation of an extensive effort to analise the evolution of lense opacifications among the ^{224}Ra patients. For this purpose a Scheimpflug-camera and computer-system was aquired in collaboration with the Ophthalmological Clinic of the University of Munich. At the Institute for Radiation Biology a van was bought and equipped to

house the Scheimpflug-camerasystem and work has begun to change the Scheimpflug-system from a conventional filmtechnique to an electronic camera. This will permit much more flexible operation on the field trips when patients are visited at their homes for the ophthalmological investigations of their lense opacification. This work has been performed with Prof. Stefani of the Ophthalmological Clinic of the University of Munich and with the scientist responsible for project 2.
The Scheimpflug-camerasystem is at present the only Scheimpflug-system in Southern Germany which was an added reason to create a movable instrumentation. It is presently being considered that the same system could be made available also for other investigations such as the German Thorotrast study.

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HEALTH EFFECTS OF CHRONIC EXPOSURE TO LOW DOSE IONIZING RADIATION ON WORKERS OF THE SPANISH NUCLEAR ENERGY INSTALLATIONS

Contract Bi6-229 - Sector C14

1) *Artalejo*, CIEMAT

Summary of project global objectives and achievements

The objectives of the project are:

- To compare the mortality of JEN workers with the national rates
- If there were any evidence that suggested that the mortality at JEN is greater than the spanish rates, to establish whether this difference is related to exposure to ionizing radiation
- To develop and test a system of epidemiologic surveillance of both exposure to risk factors and the occurrence of cases of illness, injury and mortality among workers of JEN.
- To suggest priorities for epidemiological research in the near future on the health of JEN workers.

As stated in the previous reports the project has obtained its objectives to a substantial degree. The following two sections summarize the methods employed and the results so far obtained:

Methods

The study design corresponds to a retrospective cohort study on 5303 JEN workers from 1954 to 1986. This cohort constitutes the 85% of the JEN labor force. Data collection for each worker comprises administrative and clinical data, exposure information (dosimetries) and cause specific mortality data. The statistical analysis has been carried out in two steps:

a) External comparison of the JEN mortality with the mortality of the spanish population, through standardized mortality ratios.

b) Internal comparison of the cohort mortality by radiation exposure, through log-lineal models.

Results

So far the results suggest that the mortality among JEN workers is generally lower than the national rates ("healthy worker effect"). However, it has been observed a significant increase in the mortality from cancer among the study cohort (see 1989 report). This increase, which is also probably present in the extension of the follow-up from 1987 to 1991, has not shown a radiation dose-effect relationship.

This project has also served to implement a comprehensive system for the surveillance of the health status and hazards of the workers of JEN. As an appendix to this report, the readers may find a copy of the main questionnaires and the information routes that form this system.

Project 1

Head of project: *Dr. Artalejo*

Objectives for the reporting period

The objectives for this period are:
a) to describe the main features of the system for epidemiological surveillance of health status and hazards among workers of JEN, recently implemented.
b) to present the preliminary results of the analysis of the study cohort with its extended follow-up through December 1991.

Progress achieved

We have implemented a program of epidemiologic surveillance whose objectives are:

a) to plan, implement and evaluate health interventions (primary, secondary and tertiary prevention activities) among the workers of JEN.
b) to improve the amount and quality of the information on our study cohort.

In particular this program of occupational surveillance identifies instances (cases) of death, illness, injury and/or "excessive" exposure to risk factors present in JEN. The 1990 report described the identification of cases of illness and injuries and the hazards assessment. This reports attempts to present the improved system for surveillance of mortality that will allow periodic re-analysis of the effects of chronic low dose exposure to ionizing radiation on mortality among workers of JEN in the future.
The occupational surveillance of mortality among workers of JEN is carried out in three phases:
1. Exclusion of those workers with especial difficulties for follow-up. In particular, we have excluded those workers for whom we do not hope to collect affiliation data that allow posterior follow-up, whose exposure has not been adequately recorded and those who denied to participate in the study.
2. Collection of information that enables the follow-up. These are affiliation data that allow posterior contact with the worker or his relatives, or checking with national directories to verify the vital status of the worker and the date of death.
In particular, we have obtained the following information:

- complete address and telephone number(s) for every worker.
- address and telephone for one or two close friends or relatives who do not live with the subject.
- name, address and telephone number of primary physician.
- National Identity Card and Social Security numbers.

In the case of workers currently employed in JEN, the information was obtained from the records of the Department of Personnel and the Occupational Health Unit. This information is updated in the annual medical examination underwent by every worker.
For those workers already retired from JEN, information has also been cbtained from the records of the Department of Personnel and the Occupational Health Unit. The inquiry has been extended to the corresponding Departments in ENUSA, ENRESA and the Council for Nuclear Safety, institutions which incorporated personnel that

previously worked in JEN. This information has been completed with that provided by a consultation to the Public Pensions Data Bank from the National Institute of Social Security. From information on the name and Social Security number for every worker, this directory has provided the address of a substantial number of workers. This data, in conjunction with the phone number provided by the National Telephone Company, allowed contact with most retired workers and collection of the data described above.
Finally, for those workers currently employed out of JEN, consultation included JEN, ENUSA, ENRESA, the Council for Nuclear Safety and the General Treasury of the Social Security. This institution provides the address for all self-employed workers and farmers. For third party employees, it provides the address of the company where the worker was employed lately.

3. Implementation of the follow-up. The objective of the follow-up is to know the vital status of the workers, and the cause of death if it occurred, as of a certain date. In case the date occurred with anteriority, the date should also be assessed.
Two complementary strategies has been devised to accomplish the follow-up:

a) Direct contact with the workers or their relatives. The result of the consultation may be threefold: the worker is still alive, the vital status is unknown (probably because of a loss of contact between the worker and his relatives) and the worker has died. In this case the information on the place and date of death has facilitated the consultation with the civil register which contains information on the cause of death.

b) Consultation with the National Institute of Statistics. This institution compiles information on all deaths, their causes and dates in a national basis in Spain. We are favoring an agreement with this institution that, while preserving the provisions for statistical secrecy, could provide prospective information on every death, its date and place, that occurs among JEN workers. This information will allow the knowledge of the cause of death through consultation with the civil register of the municipality where death took place.
The information rendered by both strategies will be updated every five years.
So far, this system has produced the following preliminary data on deaths among JEN workers from January 1987 to December 1991:

Year	Number of deaths
1986	14
1987	21
1988	12
1989	18
1990	8
1991	12
TOTAL	85

Distribution by causes of death (ICD 9)

Infectious diseases	1
Malignancies	28
Metabolic diseases	1
Blood diseases	1
Diseases of the central nervous system	1
Cardiovascular diseases	23
Diseases of the lung	10
Diseases of the digestive system	8
Diseases of the urinary system	1
Injuries	6
Ill defined causes	4
Unknown	1

At the present time we are in the process of checking the validity of this data and integrating them in the JEN data base, to provide estimates of the effect of low dose radiation on the health of JEN workers from 1954 through 1991.

THOROTRAST: INVESTIGATIONS TO EVALUATE THE LONG-TERM EFFECTS CAUSED BY ARTIFICIAL RADIATION IN MAN (THOROTRAST PATIENTS FOLLOW-UP STUDY IN GERMANY AND DENMARK)

Contract Bi6-298 - Sector C14

1) *Van Kaick* , Deutsches Krebsforsch.Zent.Heidelberg

Summary of project global objectives and achievements

The intravascular injection of the formerly used contrast medium Thorotrast, a colloidal suspension of thoriumdioxide causes a chronic exposure to alpha-particles especially in the organs of the reticuloendothelial system. The German Thorotrast study comprises 2,326 Thorotrast patients and 1,890 contemporary matched patients in the control group to be evaluated. 899 Thorotrast patients and 662 controls had clinical and biophysical follow-up examinations every two years since 1969.

Liver cancer is the most common Thorotrast induced tumor. 82% of the liver tumors are confirmed by biopsy or autopsy, 14% by clinical follow-up. A clear correlation exists between dose rate of the liver and the cumulative rate of liver cancer. Thorotrast patients have a nearly tenfold higher risk for nonlymphocytic leukaemia (NLL) compared to the controls. The ratio of observed and expected incidence leukaemias was 9.8 and correlated with the results of our own control group, and with the results of the Danish and the Japanese Thorotrast study (in details see Table III).

The still living Thorotrast patients were injected with very low volumes of Thorotrast and are exposed to over more than 45 years (mean-age at injection: 21,9 years). The final fate of those patients are therefore very important. The number of the still living persons in the control group is more than twice compared to the Thorotrast group. The follow-up of these patients is especially necessary for the statistical evaluation of diseases with small excess rate and for the confirmation of the life-shortening effect.

Project 1

Head of project: Prof. *G. van Kaick*

Objectives for the reporting period

- The working program was continued according to the recommendations of the coordinating committee
- Clinical, biochemical and radiological examinations of the Thorotrast patients and the members of the control group
- Biophysical examinations to calculate the tissue dose due to the thoriumdioxide deposits and their radioactive daughter products
- Identification of the causes of death of Thorotrast patients and members of the control group
- Statistical evaluation of the epidemiological, clinical and biophysical data

Progress achieved including publications

In the reporting period we examined 294 patients (143 Thorotrast and 151 control patients). With regard to Thorotrast induced diseases we detected 21 primary liver cancers and 7 recurrencies. Other cancers detected by examination were: renal cell cancer (Thorotrast/control) 1/1; cancer of the prostate 0/3; breast cancer 1/2; carcinoma of the pancreas 1/0; Non-Hodgkin's lymphoma 0/1; cancer of the urinary bladder 1/1; cancer of the stomach 0/1; lung cancer 1/0.

Up to now out of 2,326 Thorotrast patients 118 are still living, and out of 1,890 controls 373 (Table I).

Table I:
German Thorotrast study - patients evaluated

Patients'status	Thorotrast	Control
Examined	899	662
still living	118	373
deceased	781	289
Not examined	1427	1228
Total	2326	1890

During the reporting period 59 Thorotrast patients and 25 control patients have died. The causes of death are summarized in Table II.

Table II:
German Thorotrast study - causes of death 01.01.1990-30.04.1992

Diagnosis	Thorotrast (n=59)	Control (n=25)
Liver cancer	20	0
Cancer of the extrahepatic bile ducts	2	0
Liver cirrhosis	4	0
Chronic myeloid leukaemia	0	2
Chronic lymphatic leukaemia	1	0
Bone marrow failure	0	1
Mal. mesothelioma of the pleura	1	0
Lung cancer	3	1
Cancer of the stomach	0	2
Ca. prostata	1	2
Kidney cancer	1	0
Rectal cancer	1	1
Myocardial infarction	7	10
Cerebral apoplexia	3	3
Others	15	3
Total	59	25

Epidemiological studies

The most important causes of death of all patients are summarized in Table III.
No significant excess was observed with regard to chronic lymphatic leukaemia, Hodgkin's disease, lung cancer, renal cancer, cancer of stomach and colon, prostate, ovary, breast and brain.

Table III: German Thorotrast study - Diseases with high or probable excess rate

Status '92 Cause of death	Thorotrast n=2,326	Control n=1,890
Liver cancer*	425 [+5](18,27%)	2 (0.11%)
Liver cirrhosis	190 [+171](15,52%)	49 [+2](2,7%)
Nonlymphocytic leukaemia	36 [+3](1,68%)	5 (0,26%)
Bone marrow failure+	30 (1,29%)	5 [+1](0,32%)
Extrahepatic bile ducts	28 [+3](1,33%)	6 (0.32%)
Ca. pancreas	18 (0.77%)	5 (0.26%)
Ca. esophagus	7 [+1](0.34%)	1 (0.05%)
Ca. larynx	6 [+1](0.30%	1 [+1](0.11%)
Non-Hodgkin's lymphoma	14 [+2](0.68%)	3 (0.16%)
Bone sarcoma	4 (0,17%)	1 (0.05%)
Plasmacytoma	7 [+2](0,39%)	1 (0.05%)
Mal. Mesothelioma pleura	4 (0.17%	0

[] Additional causes with another disease leading to death
* 5 patients with combined carcinoma and sarcoma
() Inclusive additional cases related to n
+ Aplastic anaemia, agranulocytosis and thrombocytopenia

For comparison with the Japanese Thorotrast study group we focussed our statistical evaluation to the final fate of the war-wounded German soldiers of the examined group aged between 20-34 years. We found a very high incidence of liver cancer depending on the intravascularly injected volume of Thorotrast. Age at injection did not influence the latency period. The excess rate of the total study is reflected in the dates of the soldiers. However due to a smaller size of this subcohort, there are higher variations, but no substantial differences.

We compared the results of our control group with the data of the cancer registry of the state of Saarland. The cancer incidence in both groups were nearly identical so we can state that our control group represents the normal German population.

Publications

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LATE EFFECTS OF THOROTRAST AMONG DANISH PATIENTS

Contract Bi6-333 - Sector C14

1) *Storm* (previous Jensen), Danish Cancer Society

Summary of project global objectives and achievements

The long term health effects of alpha-radiation are much less investigated than the effects of x- or gamma-radiation. Knowledge on such effects is, however, relevant in relation to domestic Radon exposure and in relation to potential effects of exposure to alpha emitting nuclides in case of accidental releases from nuclear installations. Follow-up of persons injected with the x-ray contrast medium Thorotrast is a unique source of information on such aspects.

In the present study, 999 persons injected with Thorotrast 1935-47 for examination of neurological symptoms and signs have been followed up by record linkage with the National Death Index and the Danish Cancer Registry. Mortality and incidence of cancer have been standardised to that of the general population.

Cancer-related mortality was highly increased and standardised mortality ratio (SMR) was significantly related to the injected amount of Thorotrast. SMR for all other categories of causes of death was, however, also increased and significantly related to the Thorotrast dose. Similar observations have been made among German (1) and Japanese (2) Thorotrast patients and a parallel, radiation-dose dependent increased non-cancer mortality has recently been reported among A-bomb survivors (3). These findings are provocative and raise the question whether ionizing radiation may induce shortening of life time independent of carcinogenesis.

The standardised incidence ratio (SIR) for cancer at all sites (except brain and CNS) was significantly increased (cumulative risk after 50 years 86%) mainly due to high risks of liver cancer and leukaemia in accordance to findings from other Thorotrast studies (1,2) but SIR was even elevated for almost all other sites implicating alpha radiation to be one of the most powerful carcinogenic effects known to man.

Histological subtypes of liver tumours were distributed in accordance to findings from German (1) and Japanese (2) patients, i.e. with a preponderance of cholangiocellular carcinomas followed by hemangiosarcomas and hepatocellular carcinomas. These alpha radiation induced liver tumours are currently being screened for p53 mutations which is interesting, in terms of theories of carcinogenesis, in the light of recent findings of specific p53 point mutations in liver tumours supposedly induced by aflatoxin (4).

Lung cancer occurred significantly in excess of the expected and, by revision, anaplastic small cell lung cancer accounted for 50% of the tumours where normally such tumours only account for approximately 25%. Interestingly, similar observations have been made in a Japanese Thorotrast study (5). Underground miners exposed to Radon (mostly Rn-222) have increased risks of,

especially small cell anaplastic, lung cancer. As Thorotrast patients constantly exhale Radon (Rd-220) the findings of a relative preponderance of anaplastic small cell lung cancer in both studies are provocative. Further molecular biological studies of tissue from these lung tumours may be rewarding.

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Project 1

Head of project: *Dr. Storm* (previous Jensen)

Objectives for the reporting period

Objectives for the reporting period have been to:

1. re-establish a historical cohort of persons exposed to intravascular injection with Thorotrast for carotid artery angiography

2. identify all persons in the cohort

3. document the Thorotrast exposure

4. follow-up the cohort by register-linkage procedures with regard to vital status, cause of death, and incidence of cancer

5. standardise pattern of mortality and incidence of cancer to the general population based on register derived incidence rates

6. compare the pattern of morbidity based on hospital discharge diagnoses among Thorotrast patients to that of a control group

7. revise patho-anatomical diagnoses whenever appropriate.

Progress achieved including publications

1+2 Re-establishment of cohort, identification

The original Danish Thorotrast study which had not been followed up since 1983 was kept in a manual card file.
Relevant information from this file have been computerized and by record linkage with the National Death Index and the Central Person Registry most persons were fully identified. For 250 persons, however, identification required manual queries to local population registers and parishes due to incorrect information in the original files.

3. **Documentation of Thorotrast exposure.**

The original hospital records from the departments of neurosurgery where the Thorotrast examinations were performed were retrieved for 75 % of the cases while for the rest information from the original Thorotrast study files were extracted. For all persons, date of injection and the injected amount of Thorotrast was noted. However, for 34 %, the injected amount of Thorotrast was not mentioned in the hospital records, and in these cases the amount have been estimated based on other clinical information (e.g. on numbers of x-rays taken).

Results:

The files of the original Danish Thorotrast study included information on 1095 individuals. However, 96 persons were not eligible for the study for the following reasons: Thorotrast exposure not verified (61), Thorotrast exposure for other purposes than cerebral arteriography (9), identification impossible (7), foreign residents (10), inclusion in study at the time of a cancer diagnosis (7: 4 liver tumours, 2 breast cancers, 1 colon cancer), duplicate registration (2). Thus, the study population consists of 999 Danish residents injected with Thorotrast in the jugular artery in the period 1935-47. All of them were neurosurgical patients presenting with a variety of signs and symptoms often suggestive of intracerebral tumours or cerebro-vascular malformations including palsies, visual disturbances, head aches, epilectic seizures, mental retardation, behavioural disturbances, and others.

From Table 1 can be seen, that the male:female proportion was 564:435 and that most of the patients were older than 29 years at the time of injection.

Table 1 Age at Thorotrast injection

	Number of persons		
age (years)	males	females	total
0 - 4	0	2	2
5 - 9	9	8	17
10-14	27	16	43
15-19	44	31	75
20-29	99	104	203
30-44	188	132	320
45-59	155	112	267
60+	42	30	72
Total	564	435	999

The intravascularly injected amount of Thorotrast is given in Table 2. For 56 persons, information from hospital records, pathology records, and x-rays indicate that a fraction of the injected Thorotrast was spilled extra-vascularly thus not contributing to any systemic effects of Thorotrast. Most persons received less than 11 ml, approximately one third received 11-20 ml and the rest more than 20 ml.

Table 2 Injected Thorotrast volume

Thorotrast Dose (ml)	number of persons males	females	total
1 - 10	231	178	409
11 - 20	210	175	385
21 - 30	65	45	110
31 - 40	34	22	56
41 - 50	14	4	18
51+	5	7	12
total	559	431	990

4+5. Assesment of pattern of mortality and incidense of cancer.

By computerized linkage with the Central Population Registry and the National Death Index (NDI), information on vital status for all persons was achieved. As of 1 January 1989, 64 persons were still alive, 19 had emigrated, 240 had died within three years after injection and 676 had died 3-50 years after injection.

The cause of death was assessed by the NDI for all persons who died more than three years after injection and standardized mortality ratios (SMR) were calculated specified for age, calendar time, sex, and cause of death based on mortality rates of the general population.

Table 3. Number of deaths (n) and standardised mortality ratios (SMR) with 95 % confidence intervals (95 % CI). The female/male proportion is calculated as the rate ratio (RR) of the SMR's.

	Female/male-ratio		All persons		
Cause of death	RR	95 % CI	n	SMR	95 % CI
All Causes Whole period	1.1	0.9-1.2	916	4.2	3.9-4.4
All Causes 0-2 years	0.9	0.7-1.2	240	18.3	16.1-20.9
All Causes >3 years	1.1	0.9-1.3	676	3.3	3.0-3.5
Cancer	1.0	0.8-1.4	254	4.7	4.1-5.3
Cardiac	1.1	0 8-1.6	121	1.6	1 3-1.9
Cerebro-Vascular	0.9	0.5-1.5	65	3.3	2.6-4.2
Other Natural*	1.1	0.8-1.6	170	3.9	3.3-4.5
Accidents	1.2	0.7-2.1	66	4.4	3.4-5.6

*Number of deaths classified as Other Natural Causes: infections: 5, benign tumours: 19, diabetes: 4, hematologic diseases: 10, psychiatric diseases: 3, epilepsy: 9, diseases of nervous system - others: 18, pulmonary diseases: 30, cirrosis of liver: 24, other diseases of digestive organs: 21, genito-urinary diseases: 7, musculo-skeletal diseases: 6, congenital malformations: 3, ill defined conditions: 11.

SMR was significantly increased for all categories of causes of death (Table 3) showing no difference with regard to gender. SMR was generally related to young age at injection, to time since injection, and to the injected amount of Thorotrast. Interestingly, a significant trend (p=.03) between SMR and Thorotrast dose was seen even when only considering non-cancerous deaths.

Incident cancer cases among the Thorotrast patients were identified in the Danish Cancer Registry, which is considered to be very accurate and complete. Standardised incidense ratios (SIR) were calculated by indirect standardisation to the general population controlling for sex, age, calendar period, and site of cancer.

Table 4. Observed (O) numbers of cancer and standardized incidence ratios (SIR) with 95 % confidence intervals (95 % CI) among thorotrast exposed patients.

	TOTAL		
Cancer site	O	SIR	95% CI
All sites	368	4.0	3.6-4.4
All sites minus brain,CNS	297	3.3	3.0-3.7
Buccal cavity and Pharynx	3	1.3	0.3-3.9
Esophagus	1	1.1	0.0-6.2
Stomach	7	1.0	0.4-2.1
Small intestine	2	7.4	0.9-27
Colon	9	1.3	0.6-2.5
Rectum	4	0.8	0.2-1.9
Liver	79	126	100-157
Gallbladder	15	14	8.1-24
Liver, not specified as primary	14	30	17-51
Pancreas	5	1.9	0.6-4.3
Peritoneum	3	8.6	1.8-25
Nasal cavity	2	10	1.2-36
Larynx	1	1.1	0.0-6.1
Lung primary	23	2.3	1.4-3.4
Pleura	1	4.4	0.1-24
Breast	18	1.8	1.1-2.8
Cervix uteri	6	1.2	0.4-2.6
Corpus uteri	1	0.4	0.0-2.1
Ovary	7	2.4	1.0-5.0
Other gynecol.	1	2.2	0.1-12
Prostate	6	1.5	0.6-3.3
Testis	2	3.2	0.4-12
Other male gen.	1	4.4	0.1-24
Kidney	5	2.1	0.7-4.8
Bladder	6	1.4	0.5-3.1
Melanoma of skin	2	1.6	0.2-5.8
Other skin	10	1.2	0.6-2.3
Eye	2	6.5	0.8-23
Brain,CNS	71	28	22-36
Thyroid	1	2.5	0.1-14
Endocrine	1	8.3	0.2-46
Bone	1	5.0	0.1-28
Connect. tissue	1	2.4	0.1-14
Metastases	16	12	6.7-19
Other, unspec.	10	11	5.3-22
Non-Hodgkin Lymphoma	3	2.0	0.4-6.0
Mb Hodgkin	1	1.5	0.0-8.4
Mult. myeloma	4	4.6	1.2-12
Leukemia	23	10	6.5-15

SIR of all sites was significantly increased (Table 4), SIR=4.0. Most of the tumours in brain and CNS were diagnosed shortly after the Thorotrast injection reflecting the underlying conditions,

but even when only considering tumours outside brain and CNS still a significantly increased risk of cancer was seen (SIR=3.3). This was largely accounted for by tumours in the liver, gall bladdder, leukaemia, metastases, and unspecified sites. The incidence of liver tumours and leukaemia was unrelated to age at injection or gender but significantly related to the estimated cumulative alpha-radiation dose to liver and red bone marrow, respectively. For all other sites, SIR was generally increased (57.2 cases in excess of the expected), for breast and lung even significantly. However, no obvius relations with Thorotrast dose or time since injection was seen.

6. Hospital discharge-diagnosis based morbidity analysis
Analysis not completed.

7. Patho-anatomic revision (preliminary results)
Whenever possible, hospital records and pathology reports for deceased patients have been retrieved and histologic specimens have been revised.
Primary liver tumors: A total of 124 cases have been re-classified as primary liver tumours. The diagnoses were based on: new immuno-histochemical and other special paintings, 72%; revision of old tissue slides, 17%; original histology reports: 9%; clinical data: 2%. Histological subtypes: Cholangiocellular carcinoma (CCC): 47%, hemangiosarcoma (HS): 24%, hepatocellular carcinoma: 20%, CCC and HS combined: 1%, malignant fibrous histocytoma: 1%, malignant, NOS: 7%.
The median latency period (range) between injection of Thorotrast and diagnosis of liver tumours was 35 (18-48) years and the cumulative incidence reached 57% (SE: 4%).
Leukaemic complications: Twenty-five cases of leukaemic complications (excluding CLL, 3 cases) were diagnosed. The diagnosis was based on new slides: 10 cases; revision of old slides: 6 cases, revision of original histo/cytological reports: 8 cases. Subtypes: erythroleukaemia: 4 cases, myelo-monocytogenous: 1 case, AML NOS 10 cases, MDS: 6 cases, CML: 1 case, All: 1 case. Median latency period after injection: 25 (9-40) years. Cumulative incidence: 8.0% (SE 1.8%).
Malignant mesothelioma: Seven cases of malignant mesothelioma were diagnosed based on new slides (5 cases) and revision of old slides (2 cases). Five cases were peritoneal, 1 case plural, and one case both peritoneal and pleural. Four cases were biphasic, 2 cases were epithelial, and one case was mesenchymal.
Primary lung cancer: Primary lung cancer was confirmed in 19 cases based on revision of slides (11 cases) and histology reports (8 cases). Histologic subtype: Small cell anaplastic: 10, large cell anaplastic: 1, planocellular carcinoma:4, adenocarcinoma: 4.

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ANNEX A

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ANNEX B

EUROPEAN CHILDHOOD LEUKAEMIAS/LYMPHOMAS INCIDENCE STUDY

21/01/92

Data received

Austria	1980-87 *	Leukaemia/Lymphoma
Bulgaria	-	-
Czechoslovakia, Bohemia	1980-89	Leukaemia/Lymphoma
Czechoslovakia, Moravia	1980-89	Leukaemia/Lymphoma
Czechoslovakia, Slovakia	1980-89	Leukaemia/Lymphoma
Denmark	1980-88	Leukaemia/N.H.L.
Finland	1980-89	Leukaemia/Lymphoma
France, Bas-Rhin	1980-89	Leukaemia/Lymphoma
France, Dijon	1980-88	Leukaemia/Lymphoma
France, Doubs	1980-87 *	Leukaemia
France, Isere	1980-87 *	Leukaemia/Lymphoma
France, Lorraine	1983-89	Leukaemia/Lymphoma
France, PACA & Corsica	1984-88	Leukaemia/Lymphoma
German Dem. Rep.	1980-88	Leukaemia/N.H.L.
Germany, Fed. Rep.	1980-88	Leukaemia/Lymphoma
Hungary	1980-88	Leukaemia
Italy, Piedmont	1980-89	Leukaemia
Italy, Varese	1980-87	Leukaemia/Lymphoma
Netherlands	1980-89	Leukaemia
Norway	1980-87 *	Leukaemia/Lymphoma
Poland	1980-89	Leukaemia/Lymphoma
Sweden	1980-88	Leukaemia
Switzerland, Basel	1980-88	Leukaemia/Lymphoma
Switzerland, Geneva	1980-88	Leukaemia/Lymphoma
Switzerland, Neuchatel	1980-88	Leukaemia/Lymphoma
Switzerland, Saint-Gallen	1980-88	Leukaemia/Lymphoma
Switzerland, Vaud	1980-88	Leukaemia/Lymphoma
Switzerland, Zurich	1980-88	Leukaemia/Lymphoma
UK, England & Wales	1980-88	Leukaemia/Lymphoma
UK, Scotland	1980-88	Leukaemia/Lymphoma
USSR, Byelorussia	-	-
USSR, Estonia	1980-89	Leukaemia/Lymphoma
USSR, Lithuania	1980-88	Leukaemia/Lymphoma
USSR, RFSFR	-	-
Yugoslavia, Slovenia	1980-88	Leukaemia/Lymphoma

* Reminders about 1988 data sent.

ANNEX C CHILDHOOD LEUKAEMIA FOLLOWING THE CHERNOBYL ACCIDENT

THE EUROPEAN CHILDHOOD LEUKAEMIA-LYMPHOMA INCIDENCE STUDY (ECLIS)

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SUMMARY

The objective of the 'ECLIS' study is to investigate trends in incidence rates of childhood leukaemia and lymphoma in Europe, in relation to the exposure to radiation which resulted from the accident at the Chernobyl nuclear power plant in April 1986. In this first report, the incidence of leukaemia in children aged 0-14 is presented from cancer registries in 20 European countries for the period 1980-1988. Risk of leukaemia in 1987-88 (8-32 months post-accident) relative to that before 1986, is compared with estimated average dose of radiation received by the population, in 30 geographic areas. The observed changes in incidence do not relate to exposure. The period of follow-up is so far rather brief, and the study is planned to continue for at least 10 years.

INTRODUCTION

On 26 April 1986, an accident occurred at the Chernobyl nuclear power plant, about 100 km west of Kiev in the Ukraine. One reactor core and part of

its containment building were destroyed, allowing radioactive particles to be released into the atmosphere. Releases continued for nine days after the accident. Exposure to populations living beyond the immediate vicinity of the plant has been extensively reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation in its 1988 report [1].

There were three successive 'plumes' of material affecting (1) the eastern part of what was then the USSR, Poland and Sweden (2), Central Europe, especially Austria, Bavaria, North Italy and part of Switzerland, and finally (3) Romania and Bulgaria.

Most exposure was due to radioactive iodine (^{131}I) and caesium (^{134}Cs, ^{137}Cs). Iodine, which has a half-life of about 8 days, was only important in the first weeks following the accident, while the contribution of caesium to exposure, particularly ^{137}Cs which has a half-life of 30 years, will continue to be important for many years. Humans were exposed externally, from deposition of radionuclides on the ground, and internally from the ingestion of contaminated food (eg milk, leafy vegetables, grains); in the first year, more than two thirds of dose resulted from ingestion of contaminated food [1,2].

There have been many reports on the likely long-term consequences of the accident at Chernobyl, and the appropriate methods of surveillance - reports from international organizations include those from WHO [3], the CEC [4] and IAEA [2]. These reports, and independent evaluations of likely consequences to populations outside the immediate vicinity of the accident (eg Reizenstein [5], Anspaugh et al. [6], Gale & Butturini [7]) suggest that any excess cancer resulting from the levels of exposure to radioactivity from the accident will be undetectable against the expected 'background' incidence. Nevertheless, it

is acknowledged that there is considerable public disquiet about the size of the risk to health. In addition, there are already reports of a raised incidence of leukaemia in young children [8], excess infant mortality [9] and excess premature births among malformed children [10] in sub-national areas where exposure to radiation from the Chernobyl accident was higher than the national average. Even if the occurrence of leukaemia cases was entirely random, their spatial and/or temporal clustering is to be expected, and so too are further reports linking such observations to the Chernobyl accident. Finally, existing knowledge of risk of cancer during the short-term period after exposure is imprecise, because the Japanese 'life span' study did not begin until 5 years after exposure to radiation from the atomic bombs. For all of these reasons, surveillance of exposed populations for the excess occurrence of malignant disease is justified, provided that it can be undertaken with due consideration of the cost and effort involved in relation to the probable statistical power of any study.

We report here the study design and preliminary results of a project to monitor incidence rates of childhood leukaemia and lymphoma in Europe, the 'ECLIS' study.

MATERIALS AND METHODS

Radiation exposure

The estimated dose* from the first year and from the first four years of exposure in different regions of Europe have been obtained from UNSCEAR (Table I). These estimates were based on direct measurements carried out in 34 countries in the first year. Doses from external exposures were calculated, making assumptions about average shielding by buildings and average time spent indoors. Doses from internal contaminations were based on radioactivity of

*In this paper, the term 'dose' is used to denote the individual committed effective dose equivalent resulting from exposure in a given time period.

various foodstuffs and assumptions about average consumption. The measurements indicated the general climatic and geographical factors which prevailed during the first year following the accident. After the first year, the contributions to external and internal doses resulting from deposited radioactive materials (mainly ^{137}Cs) were estimated from models derived by UNSCEAR from fallout measurement experience.

Average doses were estimated for all European countries. However, in several countries where the distribution of exposures was very uneven, doses were estimated for 2-4 sub-regions where they were more homogenous. Figure 1 shows the countries and sub-regions for which these dosimetric estimates were produced.

For second and subsequent years, the projected contribution to exposure from ingestion was relatively smaller than that from external radiation. The transfer factors used to calculate internal exposures were higher in the more southerly latitudes because of the more advanced stage of the agricultural cycle in spring, when the accident occurred.

Cancer data

Data on cases of leukaemia and lymphoma occurring in children aged less than 15 years are supplied from population-based cancer registries in all of the countries listed in Table I, although for some of the geographic regions only part of the population was covered by participating registries (France, region 3; Italy, region 1; Switzerland, regions 2-4; ex-USSR, regions 3 and 4). A map and a full list of participating centres is given in Annex A. These registries record data either for all cancers, or only for paediatric cancers or leukaemia/lymphoma cases, from geographically defined populations, and use multiple source reporting, including death certificates, as recommended by IARC/IACR [11]. All participants were required to have collected data

according to these criteria for a period of at least six years prior to the accident (i.e. since 1980), although there were two general exceptions to this condition:

(1) For some regions important contributions to the incidence data were provided by registries which had begun subsequent to 1980, and these were included, most notably two large paediatric cancer registries in France.

(2) For certain parts of the Russian Federation, and for Belarus, special retrospective verification of recorded leukaemia cases was considered necessary.

Data are submitted each year in the form of a case listing, with for each case: date of incidence, date of birth, sex, place and type (urban/rural) of residence, place of birth (if available), basis of diagnosis (eg clinical examination, haematology/cytology, histology) and diagnosis. Diagnosis was noted as site (for lymphomas) and morphology, and was either already coded according to the International Classification of Diseases - Oncology [12,13], or converted from local codes to ICD-O.

The estimated size of the population-at-risk - children aged 0-14 - was also supplied for each area every year, by district and type (urban/rural) of residence, sex and with maximum available detail on age (single year, if possible).

Analysis

Incidence rates were calculated for all forms of leukaemia and lymphoma, and for subgroups as defined by the ICD-O morphology codes [14]. Rates were calculated per million person-years for age-groups 0, 1-4, 5-9 and 10-14, and

the cumulative rate (0-14) was calculated as a summary index (this is effectively a direct standardization, with the same weighting applied to each individual year of age [15].

The main objective of this preliminary analysis was to see whether there was any evidence of a change in incidence of leukaemia in the first 3 years following the Chernobyl accident. In each country or region, the observed number of cases and incidence rate for the period 1987-88 (8 months - 32 months post-accident) were therefore compared with the 'expected' value. In this preliminary analysis, the expected values were based on the average incidence rate in the six years pre-accident (1980-85).

The excess risk (difference between the observed incidence rates (1987-88) and those expected), and the excess relative risk [(Observed Rate/ Expected Rate) - 1], were considered as a function of the first-year dose given in Table I.

RESULTS

Radiation exposure

Table I shows the estimated radiation doses in the first year and first four years of exposure for the countries and sub-regions participating in the study. Outside the former USSR, the highest first-year dose exposures were for southeastern, central and northern Europe. The highest country average (760μSv) in Bulgaria is about one third of the natural background annual dose (2400μSv), a level which corresponds to the average first-year dose in Belarus (region 1 of the ex-USSR).

Leukaemia

Figure 2 illustrates the incidence of all leukaemia in children (0-14) by sex in the 18 countries for which data were available for the period 1980-85.

The cumulative rates are generally in the range 400 to 700 per million, although somewhat lower in Poland. With a few exceptions rates are slightly higher in boys than in girls; however, since there appears to be no difference in leukaemogenicity of radiation between the sexes, further results are presented for both sexes combined.

Acute lymphocytic leukaemia accounted for 72-83% of leukaemia cases in almost all of the registries, with the exception of Poland (54.2% in 1980-85), where the percentage of 'unspecified' leukaemias was also high. Since chronic lymphocytic leukaemia is extremely rare in children, and for all other forms of leukaemia the risk is known to be enhanced by exposure to radiation, further analysis was for leukaemia as a whole.

Table II presents some indicators of quality of data in the different countries, as a guide to interpretation of results, for the baseline period (1980-85) and for 1987-88. For several registries, there have been improvements in the quality of data, as reflected by these three indicators. The largest change, for Austria, is based on data from a single year (1987), for which there was a lower than expected incidence (Table III). The data from Poland suggest some improvement in quality (lower percentages of unspecified leukaemia and DCO cases), and the possibility that some of the increase in incidence (rates were 13% higher in 1987-88 than in 1980-85) is due to improved ascertainment should be considered.

Table III presents the number of cases registered, by region, in 1980-85 and 1987-88, together with the cumulative incidence rates per million. The 'expected' number of cases in 1987-88 is also shown, based on the age-specific rates from the baseline period (1980-85).

For the entire study population for which data were available for 1987/88, 3679 cases were observed, compared with 3540.5 expected on the basis of the 1980-85 rates. This small increase in overall incidence (3.9%) is statistically significant ($\chi^2 = 5.4$, $p < 0.05$). However, there is no association between the change in incidence, and estimated first year dose for the individual regions. In Figure 3 excess risk and in Figure 4 excess relative risk are plotted against first-year dose equivalent for the 30 countries or sub-regions shown in Table III. Weighted least squares regression lines have been fitted with weights equal to 1/ variance in order to diminish the effect of observations from very small populations (the two outlying points correspond to Sweden (region 2) with nine cases in 1987/88 and Switzerland (region 3) with four cases). Excess risk shows a small non-significant decline with increase in estimated unit dose ($b = -0.017$, $p = 0.82$), as does the excess relative risk ($b = -4.4 \times 10^{-5}$, $p = 0.72$).

A little over half of the leukaemia cases observed in 1987-88 were aged less than five years at diagnosis (n = 1923); this is a significant increase on the number expected, based on pre-accident rates (RR = 1.063, $p < 0.01$). Once again, however, the weighted least squares regression showed no association between dose and excess risk ($b = -1.3 \times 10^{-3}$, $p = 0.90$) or excess relative risk ($b = -2.1 \times 10^{-5}$, $p = 0.91$).

DISCUSSION

Almost all studies and reports dealing with the possible consequences of the accident at the Chernobyl nuclear power plant conclude that, although a substantial number of cancers may be induced by the radioactive material released, any increase in rates outside the regions in the USSR close to the reactor site will not be detectable against the 'normal' incidence of cancer in the general population. Using the estimate of excess relative risk of leukaemia for exposures under the age of 20 from the BEIR V report [16], and assuming that excess risk at 2-5 years is the same as that at 5-10 (to which the BEIR data apply), we estimated that the overall increase in incidence of leukaemia for the area covered by the ECLIS study will be about 0.8% with the most marked increase in Belarus (5.8%) [17]. These estimates were, however, based on the first-year effective dose equivalent. Doses in the subsequent years would be less, with the main decline being in internal radiation. The total effective dose equivalent was estimated to be about three times that of the first-year dose [1]. For cancer cases occurring over several years, a rather more complex calculation is required, estimating the cumulated dose for each individual year of birth cohort. It is unknown, of course, whether the excess risk resulting from a dose cumulated over several years would be the same as the much higher/shorter duration exposures in Hiroshima and Nagasaki, on which the BEIR V estimates are based. However, it does seem that, unless the estimates of relative risk in relation to dose, or estimated doses, are considerably in error, no excess incidence should be detectable anywhere, with the possible exception of Belarus. It has, however, been acknowledged that surveillance is required, provided that this can be undertaken in a relatively cost-effective manner by using existing data collection systems, if only because a bland reassurance that nothing could be found is likely to be

treated with scepticism by a substantial proportion of the European populations most exposed to the Chernobyl fallout.

In the context of monitoring the possible effects of exposure to low levels of radioactivity, there are several advantages to the study of leukaemia, and of cancers in childhood. Leukaemia is one of the earliest malignant neoplasms to demonstrate an increase in incidence following radiation exposure (2-10 years), and provides the largest relative increase of any cancer, at least at low to moderate exposure levels (BEIR V). The relative risk of radiation-induced leukaemia is probably higher for those exposed as children than as adults [18,19], and pre-natal exposure to radiation may carry an even higher risk for childhood leukaemia [20,21]. Some uncertainty, moreover, underlies the dose-response relationship for leukaemia in children (and adults), because of lack of data from the first five years following exposure in the studies of survivors of the atomic bombs in Japan. An additional consideration in the choice of childhood leukaemia was the fact that, for several countries or regions, the only cancer registries with data for the period of interest were restricted to childhood cancer (eg Federal Republic of Germany) or leukaemia/lymphoma (eg Netherlands), or that such data were available for more extensive geographical areas, or were of better quality than comparable data for all cancers (eg Hungary, Austria, France). In Austria, for example, the national cancer registry files were compared systematically with other sources of data on childhood leukaemia (notably from clinical trials series) to produce a combined list of incident cases.

In view of the high level of contamination by 131I, thyroid cancer has been a particular concern following the Chernobyl accident, and prophylactic Iodide was widely administered in several countries. However, the latency period for thyroid cancer following exposure to radiation is thought to be

much longer than for leukaemia. Moreover, there are problems in the uniform registration of thyroid cancer, because of the high prevalence of undiagnosed thyroid nodules in the general population, and the consequent potential for biases due to changes in the level of ascertainment. There is certainly less possibility for cases of leukaemia in the population to be unrecognized, although changes in incidence could still result from changes in the efficiency of case-finding. Although in some registries, there was evidence of improvement in some of the indicators of data quality, there was little suggestion of an association between the quality of diagnostic information and the completeness of registration, as indicated by increases in incidence data. A recent report from three districts in the Ukraine [22] suggests that enhanced surveillance and reporting of cancers after 1986 was responsible for abrupt increases in incidence of leukaemia and other cancers in the age-groups 65+.

The data presented in this report relate only to childhood leukaemia. However, the distinction between non-Hodgkin lymphoma (NHL) and acute lymphocytic leukaemia in childhood is somewhat arbitrary [23,24], based upon the percentage of lymphoblasts in the bone marrow (> 25% in ALL), and NHL may progress to a leukaemic form. For this reason, data on childhood lymphoma have been collected from most centres, so that any trends in leukaemia incidence can be compared with simultaneous changes in the incidence of NHL.

The original objective of the ECLIS study was the surveillance of leukaemia (and lymphoma) incidence in countries outside the USSR. Within the former Soviet Union, a special follow-up was initiated, with a centralized register (the All Union Distributed Registry) containing medical and dosimetric information on some 530,000 individuals, including 230,000 clean-up workers, and 300,000 members of the population living in the 'special control

zones' of the Russian Federation, Ukraine and Belarus which received the highest exposures [25]. It includes some 35,000 people evacuated from the zone 30 km around the reactor site, who received doses of around 400 mGy. A decision has been made recently to include incidence data from the former USSR in the ECLIS study, provided that they fulfil the criteria for the study. To date, only those from Lithuania and Estonia have been analysed. Aggregate data (numbers of leukaemia cases by age-group and sex) have been received for Belarus, and do not suggest any change in incidence between 1987-88 and 1980-85, although since the individual records were unavailable, they are not at present included.

The data analysis comprises a comparison of population-level exposure (radiation) and outcome (leukaemia), and in common with all such 'ecological' analyses is subject to the limitation that cause and effect at the individual level may not be the same as those for group data [26]. However, because we are interested in changes in risk over time within areas, rather than variation between areas, the probably unequal distribution of other determinants of risk for childhood leukaemia between the different regions of Europe, for example differences in the levels of background radiation [27], is not a concern. In this study, we are, clearly, not able to control for the change in exposure to such risk factors within the different regions over time and, as the study duration increases, the observed incidence will be based on data increasingly distant in time from the comparison, pre-accident, period. Future analyses will therefore examine the effect of country-specific pre-accident time trends in incidence on expected incidence post-accident.

The estimates of average radiation dose used in the analysis are those produced by UNSCEAR [1], which are in general rather similar to the earlier estimates from OECD [28]. It must be remembered that these estimates are

derived from complex models involving as input measures of environmental isotopes (mainly 137Cs), and a variety of assumptions about ground deposition, uptake by plants, food consumption, etc. In the absence of direct measurement, this is the only feasible methodology, although measurements close to the reactor site suggest that in the contaminated areas, the environmental transfer models (by assuming no modification of the diet) may overestimate dose [2].

In this report, we have examined data on leukaemia cases occurring up to the end of 1988 (some 32 months after the accident). This is too early to have observed any effect, even if one were anticipated at the low estimated exposure levels. At least 5 years post-accident data are required for a meaningful analysis. At that time, it will be important to examine incidence rates specific for birth cohorts, to separate, for example, children exposed in utero, and those never exposed, even in utero, to radiation within 12 months of the accident (born after January 1988).

The longer the timespan of the study, the more likely is it that discrepancies will arise between place of residence at time of diagnosis, and place of residence since the time of the accident. They will lead to a misclassification of populations by estimated average dose. However, with the large geographical units under consideration, there is unlikely to be much cross-boundary movement within 5 years. Its extent can be gauged by comparing the place of birth and place of residence variables in the listings of leukaemic cases, although time of migration of such cases is unknown, and it will not be possible to allocate person-years according to average level of dose.

ACKNOWLEDGMENTS

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SURVEY ON CHILDHOOD LEUKAEMIA

Contract Bi6-319 - Sector C14

1) *Kaldor*, IARC

Summary of project global objectives and achievements

The objective of the 'ECLIS' study is to investigate trends in incidence rates of childhood leukaemia and lymphoma in Europe, in relation to the exposure to radiation which resulted from the accident at the Chernobyl nuclear power plant in April 1986. Data on cases of leukaemia and the population at risk in children aged 0-14 are collected from cancer registries in 20 European countries since 1980. Risk of leukaemia after 1987 (post accident) relative to that before 1986, is compared with estimated average dose of radiation received by the population. The units of population used in the analysis are the geographical areas for which UNSCEAR has produced estimates of radiation dose equivalents post-accident. During 1991, an ad hoc exercise (via Proposal 90.0334) was undertaken to investigate the feasibility of covering populations within the territory of the former Soviet Union. There are now collaborating centres in 20 European countries. The full list of participants is attached as Annex A.

Since the last progress report, the main activities have been:

1. Continued data collection from participants. The deadline specified within the protocol for data reception is 31st December for case material referring to 2 years earlier. The current status of receipt of case data from participants is shown in a table (Annex B).

2. Visits to the former Soviet Union (Byelorussia (Minsk, Gomel), Russia (St. Petersburg), and Ukraine (Kiev)). The purpose of these visits was to establish the logistic requirements for participation in the study, and the geographical areas from which it might be possible to obtain information on childhood leukaemia incidence of verifiable quality.

3. Production by UNSCEAR of exposure estimates for the sub-areas of Europe, after the first year post-accident.

4. An updated data analysis, involving verification of submitted material, and correction of identified errors in collaboration with participants. Calculation of rates of leukaemia and lymphoma, by age, sex and subtype for national populations, and subnational areas.

5. A first definitive analysis was made for the data collection period 1980-1988. In this analysis, the change in the rate of leukaemia in the period 1987-1988 (8-32 months post-accident) relative to the baseline period (up to end of 1985, minimum of 6 years) was compared with the estimated population level exposure to radiation consequent upon the Chernobyl accident (data supplied by UNSCEAR).

A report of this analysis is included as Annex C. This provides a background description of the study, the methodology, the results of this first analysis, and a discussion of their implications. During the period considered (8-32 months post-accident) the observed changes in incidence do not relate to exposure. The follow-up period is, however, very brief and the study should continue for at least 10 years to provide definitive results.

ENCLS: Annex A (Participant List)
Annex B (Table)
Annex C (Eur. J. Cancer Paper)

EPIDEMIOLOGICAL STUDIES OF RADIATION RISKS (NRPB ASSOCIATION)

Contract Bi6-347h - Sector C14

1) *Muirhead* , NRPB - 2) *Kellerer*, Univ. München
3) *Chmelevsky* , GSF Neuherberg - 4) *Oberhausen* , Univ. Saarlandes
5) *Holm* , Karolinska Hospital - 6) *Becciolini* , Università degli Studi di Firenze

Summary of project global objectives and achievements

This project is concerned with research in three areas.

1. The development of models for radiation-induced cancer risks, based on the analysis of data for populations exposed to high doses such as the Japanese atomic bomb survivors. Part of this work is being performed in preparation for the compilation of 'probability of causation' tables that are specific to European countries and that also cover radon daughter exposures.

2. Conducting epidemiological cohort studies to determine cancer risks following medical exposures:

   (a) to I-131 (as regards thyroid cancer risks);
   (b) from radiotherapy in childhood for skin haemangioma (with particular regard to dose-response relationships);
   (c) from radiotherapy for a first cancer.

3. The assessment of data on populations exposed to low doses, and the development of relevant statistical methods.

Specific achievements within each of these areas have been as follows.

1. Models and "Probability of Causation" tables for radiation-induced cancer risks

Modelling of data on radiation-induced cancer risks among the Japanese atomic bomb survivors has been carried out at NRPB (UK), the University of Munich (Germany) and at GSF Neuherberg (Germany). At NRPB, as part of an update of the report NRPB-R226 (Stather et al, 1988) on health effects models applicable for a UK population, both empirical models and - by way of illustrating the application of mechanistic models - Armitage-Doll multi-stage models have been fitted to the Japanese data. Based on models of the former type, the risk estimates for a UK population have been updated; for exposure of the general population, the total fatal lifetime cancer risk is estimated as $5.9\ 10^{-2}\ Sv^{-1}$.

At the University of Munich a model under which the relative risk decreases with increasing attained age has been shown to provide a good fit to the Japanese data for the grouping of all cancers other than leukaemia. Diagrams to illustrate mortality among the Japanese survivors and among Czechoslovak uranium miners have also been constructed, and non-parametric methods have been used to provide guidance in the choice of risk models.

At GSF some models have been developed for use in the construction of European radioepidemiological ('probability of causation') tables. For leukaemia risk amongst the Japanese survivors, smooth functions describing the variation in relative risk with time since exposure have been obtained. Also, data on lung cancer among Czechoslovak uranium miners have been used to

derive a model under which the risk associated with radon daughter exposure varies as a smooth function of age and temporal variables (rather than as a step function as in the BEIR IV model).

2. Studies of medically irradiated populations

At the Karolinska Institute (Sweden), calculations have been made of doses to various organs for each of 14,357 patients irradiated for skin haemangioma between 1920 and 1959. The organs considered included the thyroid, breast, lung, stomach, colon, gonads and bone marrow. A further four years of follow-up of the patients has shown statistically significant excesses of solid cancers overall, concentrated amongst those treated in the 1920s and 1930s. Some further calculations of organ doses have been made, and detailed analyses to relate cancer risks to factors such as dose, sex and time since exposure are well advanced.

At the University of Saarland (Germany), follow-up of about 12,000 patients in the Saarland with medical exposures to iodine-131 is being performed. Questionnaires were sent to the patients; about 65% of them replied. With the help of registration offices it has been possible to identify individuals who have moved out of the Saarland, and also those who have moved to another address within the Saarland. The registration offices have also provided dates of death for most of those deceased persons for whom this information was missing. The above procedures are important for determining the numbers of person-years. Linkage of the patient database to the Saarland Cancer Register has commenced, with the aim of determining the incidence of thyroid cancer and examining how this risk varies with the level of I-131 activity applied.

The incidence of second cancers among several thousand patients treated by radiotherapy for cancers of the breast, head and neck, endometrium and cervix has been ascertained at the University of Florence (Italy). In particular, examination of 1441 patients given radiotherapy for breast cancer has provided some indication of an excess of leukaemia; 6 cases observed against 1.3 expected on the basis of regional rates. Statistical analyses of the risk of second cancers will also be performed for those treated for the other cancers. Follow-up of these and other patients given radiotherapy at Florence will continue, and it is intended that other centres in Italy will also participate.

3. Assessment of data from populations exposed to low doses

In contrast to the results of an international correlation study, an analysis by NRPB and the Childhood Cancer Research Group (Oxford) showed no statistically significant correlation between childhood leukaemia rates in small geographical areas throughout Britain and other levels of indoor radon. Researchers from NRPB participated in a Comparative Study of Statistical Methodologies for Investigating Localised Clustering of Disease, organised by the International Agency for Research on Cancer. Modifications were made to software for analysing data from cohort studies of radiation workers; these software were used in the first analysis of the UK National Registry for Radiation Workers (funded under contract BI6-213).

Project 1

Head of project: *Dr. C.R. Muirhead*

Objectives for the reporting period

1. To analyse data on populations exposed to high doses of radiation, such as the Japanese atomic bomb survivors, and to develop models for radiation-induced cancer risks.

2. To study data on populations exposed to low doses (for example, from natural radiation) and to examine methods for analysing such data.

Progress achieved including publications

1. Modelling radiation risk in populations exposed to high doses

Since the publication of NRPB report R226 (Stather et al, 1988) dealing with health effects models for a UK population, the International Commission on Radiological Protection (ICRP) has published its new recommendations. Also, the Radiation Effects Research Foundation (RERF) has released detailed data files on cancer mortality among the Japanese atomic bomb survivors up to 1985 based on the DS86 dosimetry, and the BEIR V has used these data in its consideration of risk models. Consequently, on the basis of new information, NRPB has been updating report R226.

Particular attention has been given to models for projecting radiation-induced cancer risks across time and populations. As well as reviewing recent publications, time projection models have been fitted to the RERF data. In addition to empirical models, ie, those derived on the basis of providing a good fit to the data, some models that attempt to describe mechanisms of carcinogenesis were considered, namely Armitage-Doll multi-stage models. The aim was to illustrate the application of mechanistic models, rather than to state a preference for this particular type of model. For most of the solid cancers considered, the data were in accordance with an early stage effect of radiation. However, for lung cancer, there was some suggestion from the data of a late stage effect for males and an early stage effect for females; this may reflect differences between sexes in smoking habits, and it may be that smoking has confounded the results for males. Reasonably in accord with these findings, the preferred empirically-based models for solid cancers were such that the relative risk was taken to be constant over time, with exception of a decreasing relative risk at long times since exposure for lung cancer. More recent work (Little, 1992) suggests that, under the Armitage-Doll formulation, two radiation-affected stages may be required to describe the risk of solid cancers, whereas only one stage is required for leukaemia.

In the course of reviewing the models and risk estimates derived by the BEIR V Committee, it was found that the Committee appeared to have over-estimated the risk of leukaemia. The calculations of leukaemia risk in the BEIR V report were based on applying the Committee's time-varying relative risk model to baseline rates that included those for chronic lymphatic leukaemia (CLL). However, since CLL does not seem to be radiation-inducible, it would have been preferable to have used baseline rates for leukaemia excluding CLL. When this is done for UK baseline rates, the risk of radiation-induced leukaemia death is calculated as $0.6\ 10^{-2}\ Sv^{-1}$ for exposure at low doses/low dose rates (Muirhead, Soz. Prav. Med., 1991), compared with the BEIR V value of at least $0.85\ 10^{-2}\ Sv^{-1}$. The modified calculation formed the basis of the leukaemia risk estimates in the revision to NRPB-R226.

Information from epidemiological studies on the extrapolation of cancer risks to low doses and on the effects of low dose rate exposure was also taken into account in the revision to R226; in particular, the NRPB's recently published analysis of the UK National Registry for Radiation Workers (the subject of contract B16-213). While such studies provide some indication of radiation-induced risks, they lack statistical power to form the basis of risk estimates.

Based on the above empirical models, calculations of radiation-induced cancer risks for exposure of a UK population were made, both for a lifetime projection and for the risk up to 40 years following exposure (the current period of follow-up for the Japanese survivors). The total cancer risks calculated were 5.9 10^{-2} Sv^{-1} and 2.4 10^{-2} Sv^{-1} respectively, based on exposure of a population of all ages to low-LET radiation at low doses/low dose rates, and using a DDREF (dose and dose rate effectiveness factor) of 2. The corresponding values for exposure of a working population aged 18-64 years were 5.0 10^{-2} Sv^{-1} and 3.0 10^{-2} Sv^{-1} respectively, whilst the range of uncertainty associated with the projection of risks over time was greatest for those exposed early in life. The risk estimates based on a lifetime projection are somewhat higher than those of ICRP, owing mainly to higher baseline cancer rates in the UK compared with the world average.

The revision to report R226 will be issued by NRPB in 1992, firstly for consultation and then in the NRPB Document series.

2. Assessment of data from populations exposed to low radiation doses

The results of Henshaw et al (Lancet, 1990) indicated a statistically significant correlation between average values for leukaemia incidence and indoor radon levels in different countries. However, these results were difficult to interpret, owing to differences in data quality between countries. To avoid these problems, a study was conducted by NRPB and the Childhood Cancer Research Group (CCRG) (University of Oxford) using the best available data within Britain; namely, data from the CCRG's recently completed database on the geographical distribution of childhood leukaemia and non-Hodgkin's lymphoma over 1969-83, and the NRPB's data on natural radiation levels (indoor radon, indoor gamma and outdoor gamma) throughout Britain. The results of this study (Muirhead et al, Lancet, 1991) indicated that analyses based on large areas (counties) may be affected by confounding factors, and that more reliance should be placed on an analysis based on smaller areas (districts). The latter analysis showed no statistically significant correlations between childhood leukaemia and natural radiation levels - see Table 1. These results are in contrast to those of Henshaw et al, as well as those of Knox et al (J. Radiol. Prot., 1988), who studied childhood cancer and background gamma dose rate in Britain, but who used a non-standard statistical methodology. Since the childhood leukaemia rates may be correlated with socio-economic variables, an analysis that takes account of these variables as well as natural radiation is currently being conducted in collaboration with CCRG.

There is continuing interest in reports of cancer clusters and in methods to analyse these data. A particular method which can be used to examine whether a disease has a 'natural' tendency to cluster (derived by Potthoff and Whittinghill, Biometrika, 1966 in another context) has been modified to allow it to detect clustering operating over different sizes of area. The modified method (Muirhead and Butland, 1992) was included in a Comparative Study of Statistical Methodologies for Investigating Localised Clustering of Disease, organised by the International Agency for Research on Cancer (IARC). This study, in which various methods were applied to 50 simulated data sets of the geographical distribution of childhood leukaemia, has been completed, and the IARC report is due to be published shortly. Generally the modified Potthoff-Whittinghill method performed satisfactorily. Independent of the IARC study, further examination of the properties of the technique and of possible refinements are in progress, and it is planned to apply the technique to data on childhood leukaemia throughout Britain.

Further modifications have been made to software for analysing data from cohort studies of radiation workers. NRPB has been analysing data from the UK National Registry for Radiation Workers (NRRW) under CEC contract BI6-213. The statistical software that was used in the first analysis (Kendall et al, BMJ, 1992) included the program ARFAR (At Risk For Any Reason) and related programs. These software allow an analysis to be made of any trends in mortality rates with radiation dose, after adjusting for factors such as age and calendar period. The modifications to these programs allow results to be obtained simultaneously both for a number of different causes of death and for various strata defined by, for example, sex, industrial classification, first employer, etc. These modifications brought about considerable savings in the computer time required for the NRRW analysis. It is planned to update the documentation for these programs and ultimately to make them available to other researchers.

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Table 1

Analysis of the Geographical Variation in Rates of Childhood Leukaemia and non-Hodgkin's Lymphoma in Britain, in Relation to Measures of Natural Radiation
(Muirhead et al, 1991)

Radiation Measure	Regression coefficient - Annual No. of Cases per 10^8 per unit radiation level (Standard error in parentheses)
Indoor radon concentration ($Bq\ m^{-3}$)	-9.61 (8.13)
Indoor gamma dose rate ($nGy\ h^{-1}$)	3.98 (5.05)
Outdoor gamma dose rate ($nGy\ h^{-1}$)	-1.04 (7.57)

Note

Analysis based on district-level data, adjusted for county

Project 2

Head of project: *Prof. A.M. Kellerer*

Objectives for the reporting period

The aim of the project has been to improve the quantitative modelling of the risk of radiation-induced cancer in its dependence on dose, age at exposure, time since exposure, and age attained. The main tasks were, to develop better methods for visualising the data, to utilize non-parametric methods, and to compare the different parametric models that provide adequate fits to the observations. The results were to be applied to reach more uniformity between the modelling of risks for radon exposures, on the one hand, and external exposures, as in the atomic bomb survivors, on the other hand. They were furthermore needed for a better assessment of the nominal risk coefficients derived by ICRP and used by ICRP for their new recommendations.

Progress achieved including publications

The methodological work within the project was divided into three aspects. In each of these three aspects the methods were applied to two major sets of epidemiological data, the Czechoslovak study of lung cancer in uranium miners, and the follow-up for cancer mortality (except leukaemia) among the atomic bomb survivors. The three aspects were as follows:

- The complexity of the maximum likelihood fits in terms of different models makes it difficult to judge the validity of the results. New methods have, therefore, been sought to present the essential content and the basic features of the radioepidemiological data sets in terms of a series of illustrative and largely model-free diagrams.

  In the application to the Czechoslovak data on uranium miners of the S-cohort a full set of such diagrams has been generated. It has been one of the aims of this work, to contribute towards a trend that similar information be given for the other major cohorts of uranium miners and a better comparison between the major studies be so achieved.

  In the context of the follow-up of the Japanese atomic bomb survivors a set of cumulative hazard functions for different age groups, the two sexes, the two cities, and the major sites of tumours has been compiled.

- The familiar models to represent the observed data for radiation carcinogenesis, postulate either analytical expressions for the implied dependencies or simple step functions. These assumptions can lead to bias or to loss of information. As an intermediate step before the application of parametric models, we have therefore employed the method of isotonic regression which is a parameter-free maximum likelihood method based merely on the assumption that the studied function, for example the cancer mortality rate, has a monotonic dependence on the reference variables, for example age attained and dose. The somewhat complex algorithm for two-dimensional isotonic regression has been implemented and has been applied both to the Czechoslovak lung cancer data and to the information on solid cancer mortality among the atomic bomb survivors. In both applications the results have provided guidance in the subsequent choice of parametric models.

Different parametric models are currently used to fit the radon exposure studies, on the one hand, and the data on the solid cancer mortality among the atomic bomb survivors, on the other hand. The choice of these models appears somewhat accidental. In the radon studies one postulates a dependence of the excess cancer rate on age attained and on lagged cumulated exposure. For the atomic bomb survivors the favoured model postulates a dependence on age at exposure and dose. The BEIR V report uses a mixture of different models, but the reason for the choices remain unclear. ICRP in its new recommendation emphasises the age at exposure model and justifies it by comparison to a simple additive model which is in fact too poor to serve as a basis for the comparison. We have, therefore, examined various parametric models in their application to the Czechoslovak data and, especially, to the solid cancer mortality among the atomic bomb survivors. The conventional age at exposure model and the simpler age attained model were found to be equally applicable to the overall cancer mortality among the atomic bomb survivors. Both models fit the observations equally well up to 1985. However the age attained model agrees better with the trend of decreasing relative risks among those who were exposed at young ages. The important difference between the two models is that the age attained model predicts substantially lower lifetime attributable risks for those exposed at younger ages. The nominal risk coefficients of ICRP have been variously criticised because of the postulate of a dose reduction factor that is not directly supported by the epidemiological data. Our studies show that the same nominal risk coefficients are obtained if one assumes no dose reduction factor, but replaces the age at exposure model with the age attained model. This has given added credibility to the current nominal risk coefficients that are the basis of the new ICRP recommendations.

The parametric analyses of the cancer mortality among the atomic bomb survivors and the utilisation of the results towards the computation of probabilities of causation have been performed in co-operation with the Institute of Radiation Protection of the GSF.

The work on the Czechoslovak data for uranium miners has been performed in collaboration with the Czech colleagues. The parametric models are similar to those utilised in the BEIR IV report but utilise analytical functions which are more meaningful than step functions in the application of the results to the computation of probabilities of causation.

Publications

Kellerer, A.M. The new Estimates of Radiation Risks. Kerntechnik 55, 198-203 (1990).

Kellerer, A.M. Cancer Mortality in Hiroshima and Nagasaki - The New Assessment of Radiation Risks. Strahlenschutz für Mensch und Unwelt. 25 Jahre Fachverband für Strahlenschutz, (Eds: Jacobs, H. Bonka), Verlag TÜV Rheinland, 47-62 (1991).

Kellerer, A.M. Consequences, Countermeasures and Observed or Suspected Effects in the USSR after the Reactor Accident at Chernobyl. Nucl. Med. 30, 233-240 (1991).

Kellerer, A.M., Gr. Stock, D. Chmelevsky and D. Barclay. Exploratory Analysis - A visualisation of the data from RERF by non-parametric methods. British Institute of Radiobiology, Report 22, 147-154 (1991).

Kellerer, A.M. and D. Barclay. Age-dependencies in the Modelling of Radiation Carcinogenesis. Radiation Protection Dosimetry 41, numbers 2-4, 273-282.

Ševc, J., Tomášck, L., Kunz, E., Plaček, V., Chmelevsky, D., Barclay, D. and Kellerer, A.M. A Survey of the Czechoslovak Follow-up of Lung Cancer Mortality in Uranium Miners. Health Physics, to appear.

Project 3

Head of project: *Dr. Chmelevsky*

Objectives for the reporting period

To perform preparatory work for the compilation of 'probability of causation' tables that are specific to EC countries, with particular emphasis on lung cancer following radon daughter exposures, and on leukaemia.

1. Report for period 1990-1992

Lung cancer after exposure to radon daughters and leukaemias were given special attention in establishing probabilities of causation (PC tables). For leukaemia, even at relatively small doses, high values of the probabilities of causation are possible, and leukaemias are therefore critical. As PC tables for lung cancer, the German reunification has created a new situation. In the ex-GDR a considerable number of uranium miners were exposed to high levels of radon in the years followi World War II. For many of these miners, the excess risk to develop lung cancer as a result of thei past work is not low, and many of them may, therefore, have -in case of lung cancer- a justified claim for compensation.
For both leukaemia and lung cancer, methods similar to those utilized by the BEIR Committees I\ and V were used. Models were adapted to the specific requirements of probabilities of causation tables.

2. PC Tables for lung cancer after inhalation of radon daughters

An analysis of the S-cohort of Czechoslovakian uranium miners was performed in collaboration with the Institute for Hygiene and Epidemiology in Prague. These data were not included in the analyses of the BEIR IV Committee and have been now thoroughly described. As in the BEIR IV analysis, a relative risk strongly dependent on age attained, and also on time since exposure fits th data well. However, our analyses revealed significant non-linear dependences on cumulated exposure, but this cannot be ruled out to be artefactual . Also, a dependence on duration of exposu was observed, in disagreement with other cohort studies. As a compromise between the BEIR IV model, based on several studies, and the model fitting best the S cohort data, the following analytical excess risk expression was proposed:

$$\Delta r(C,a,t) = r_0(a)\cdot\alpha\cdot C\cdot e^{-\beta\cdot a}\cdot e^{-\gamma t},$$

where a is the attained age, C the cumulated exposure 5 years before age a, and t the time since median exposure:

$$t = \begin{cases} a-\bar{e}, & a-\bar{e} > 15 \text{ years} \\ 0, & a-\bar{e} \leq 15 \text{ years} \end{cases}$$

$\bar{e}$ represents the age at median exposure (age when 50% of the total exposure has been cumulated), $r_0(a)$ the age specific lung cancer mortality rate. Best central parameters (for a in years, C in WLM) are:

$\alpha = 0{,}5$/WLM
$\beta = 0{,}05$/year
$\gamma = 0{,}09$/year.

PC calculations were made under the assumption of a multiplicative model for the joint effect of radon and smoking. Several studies indicate that this effect is greater than additive, not inconsistent with the multiplicative model, and that it is likely to be between the two. No special attention to the problem of risk transfer seem to be needed in view of the population similarities. Fig. 1 shows PC values as function of attained age, for different ages at beginning of exposure and for a total cumulated exposure of 100 WLM. PC tables will consider various exposure scenarios.

3. PC Tables for Leukaemia

In the preceding period, provisional tables were established according to the lognormal absolute risk model used by the NIH Working Group, and incorporating the updated risks based on new DS86 dosimetry. The BEIR V Committee proposed as preferred model an apparently quite different relative risk model with step functions to describe the wavelike changes in risk with time since exposure; it used two temporal patterns, one for ages below 20 and one for ages above 20 at exposure.

We also found that multiplicative models are more parsimonious than additive models. As a result, we preferred a relative risk model, and used gamma funtions dependent on exposure age instead of the step functions of the BEIR V Committee -which are unacceptable for PC tables- to describe the temporal patterns (for ease of implementation in the EPICURE package). The excess relative risk is given by

$$\Delta r(e,t,s,D) = r_0(a,s)\cdot K(e)\cdot f(D)\cdot T(t,e)$$

(e=age at exposure, t=time since exposure, s=sex, a=e+t), no modification for sex is required in the coefficient K(e) or in the normalized time distribution $T(\cdot,e)$. T itself is expressed by

$$T(t,e) = \frac{t^{\alpha}\cdot e^{\beta\cdot t}}{\Gamma(\alpha,\beta)}$$

with a normalizing factor $\Gamma(\alpha,\beta)$, and with $\alpha=\alpha(e)$, $\beta=\beta(e)$ dependent on e.

However, this dependence on age at exposure classes e is well represented by two gamma distributions for the two age at exposure classes $e < 30$ and $e \geq 30$ years. They are shown in Fig. 2. As in the preferred model of the BEIR V Committee, a linear quadratic response was found to attain a better fit.

The risk inferred from the Japanese survivors 40 years after bombing is too low because of the missing first 5 years. The BEIR V Committee, interpreting the results of the Ankylosing Spondylit Study in the UK, decided to maintain the same level of relative risk before the fifth year, and this means an increase in risk of about 15%. We have, instead, added to the risk the proportion of the surface under the gamma distributions which corresponds to the 5 missing years after exposure. Th correction is close to the 15% of the BEIR V report. The same procedure was used to project the risk beyond 40 years after exposure, this however implies that the fitted distributions are valid beyond the observation period. A substantial risk remains after 40 years only for e > 30, and this is i accordance with the observations in the Japanese cohort.

Fig. 3 shows the annual absolute risk for some studies in comparison to that obtained with the gamma functions.
PC calculations were tentatively done by simply transferring the relative risk to the German population. This point will be further investigated.

There are no national German cancer incidence data. The collecting of incidence and mortality dat for Germany (including data from the former GDR), as well as data from other European countrie has been continued.

Publications

1. Sevc, J., Tomásek, L., Kunz, E., Placek, V., Chmelevsky, D., Barclay, D. Kellerer, A.M.
   A Survey of the Czechoslovak Follow-up of Lung Cancer Mortality in Uranium Miners (submitted to Health Phys.).

2. Exploratory Analysis - A Visualization of the Data from RERF by Non-Parametric Methods.
   Kellerer, A.M., Stock, G., Chmelevsky, D., Barclay, D. In G.B. Berger *et al.* (Hrsg.) BIR Report 22. The Future Human Radiation Research. London, BIR (1991).

3. Age Dependences in the Modelling of Radiation Carcinogenesis.
   Kellerer, A.M., Barclay, D. (to appear in Radiat. Prot. Dosim.).

4. Verursachungs-Wahrscheinlichkeit von Lungenkrebs durch die berufliche Strahlenexposition von Uran-Bergarbeitern der WISMUT-AG. Gutachterliche Stellungnahme im Auftrage der Berufsgenossenschaften von W Jacobi in Zusammenarbeit mit K. Henrichs und D. Barclay. Institut für Strahlenschutz der Berufsgenossenschaft der Feinmechanik un Elektrotechnik und der BG der chemischen Industrie. (1991).

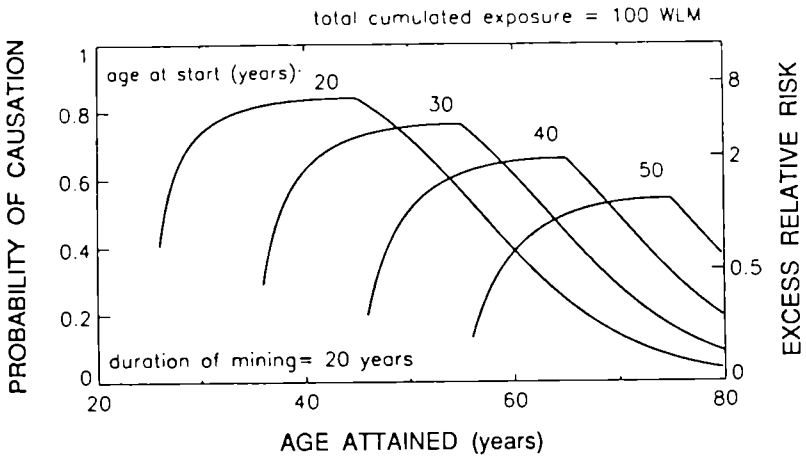


Fig. 1 Probability of causation (left y-ordinate) and the corresponding excess relative risk (right-y ordinate) in their dependence on age attained for different ages at start of mining.

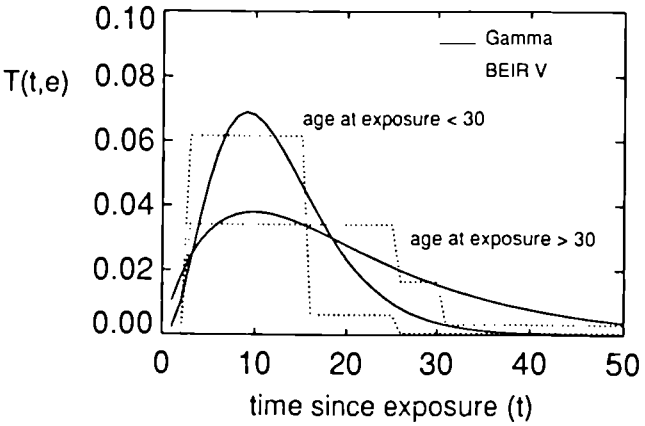


Fig. 2 Normalized distributions of time to leukemia diagnose:
Full lines: gamma-distributions selected for the present work;
Dotted lines: distributions used by the BEIR-V Committee.

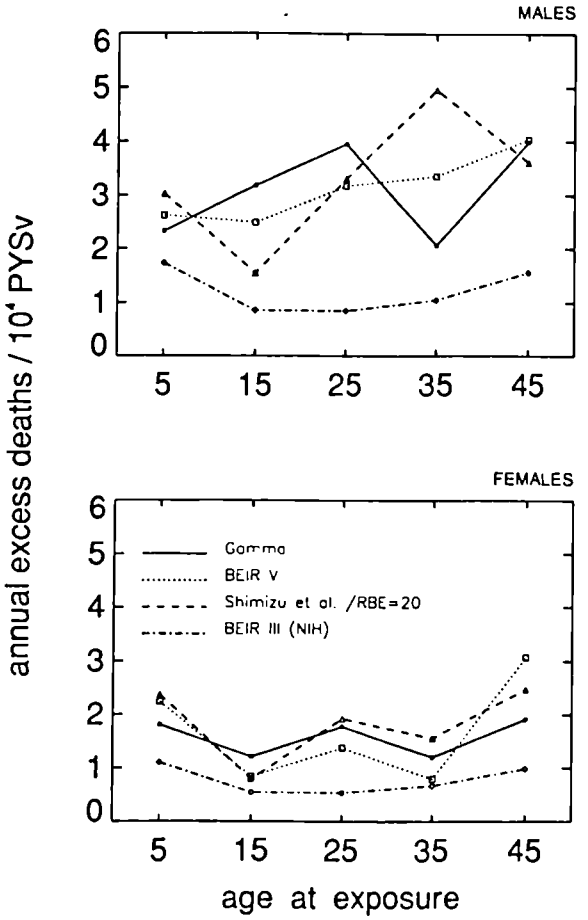


Fig. 3 Annual excess deaths per 10^4 Sv as a function of age at exposure
Full line: results obtained with the present mode
Dotted line: results from the BEIR V Committee;
Broken line: results from the RERF analysis;
Broken dotted line: results from the BEIR III Committee.

Project 4

Head of project: *Prof. E. Oberhausen*

Objectives for the reporting period

Epidemiological research with the aim of determining the morbidity and mortality risks of thyroid gland carcinoma caused by uptake of I-131.

The basis for our epidemiological study is a cohort of about 24,000 former patients of the Department of Nuclear Medicine at Homburg/Saar. All these persons have been treated with I-131 for reasons of diagnostics and/or therapy. The applied activity is in the range of MBq for out-patients and GBq for in-patients. Because the Saarland has a good functioning cancer registry (about 99% of all incident carcinomas in the Saarland are registered) we considered as a first step all persons who lived at the time of examination in the Saarland. The number of these persons is about 12,000.

Progress achieved

The basis of our study is a cohort of former patients of the Department of Nuclear Medicine at the University Clinic in Homburg/Saar. These persons were treated with I-131 for diagnostic purposes in the years between 1962 and 1977 and/or therapeutic purposes in the years between 1962 and 1989.

Of these persons we consider only those who lived at the time of treatment in the Saarland and whose diagnosis at the time of first treatment was not 'thyroid carcinoma'.

The reason for the first condition is that we have selected the population of the Saarland as a comparative population. Using the Cancer Registry of Saarland permits investigation of possible effects of radiation exposure on cancer incidence rates (about 99% of all cases of carcinoma occurring in the Saarland are registered). The registry was established in 1965.

The reason for the second condition is that in cases for which the diagnosis at the time of first treatment was 'thyroid carcinoma' there can not be a connection between treatment of I-131 and thyroid carcinoma.

As a first step we wrote to all our former patients who lived in the Saarland at the time of first treatment and sent them a questionnaire. With the help of that questionnaire we checked our data concerning name, address and date of birth and we asked our former patients about the course of their illness and the name and address of their family doctor. About 65% of all persons to whom we wrote have answered.

Name, address and possibly the date of death of the remaining 35% (about 4000 persons) were examined with the help of the registration offices of the Saarland. As a result of that examination, we found that 733 persons had moved to another town in the Saarland. For that reason we contacted 19 registration offices for a second time.

All the registration offices have now answered. The result of the questionnaire action and the complete examination with the registration offices of the Saarland is:

- 1291 persons have moved out of the Saarland or the up-to-date address is unknown. For these persons we have obtained from the family or from the registration offices a new address outside the Saarland or the information that the person isn't known at the address registered in our data bank.
- 1591 persons are reported dead. The date of death is known in 1419 cases and unknown in 172 cases.
- 8893 persons are still living in the Saarland.

In cooperation with the Cancer Registry of Saarland we want now to compare the persons in the two last groups (together 10484 persons) with those persons with a cancer registered.

At present the comparison between the persons registered in the Cancer Registry and our former patients has partly been carried out. With the help of a computer-aided record linkage the 8893 persons who are still living in the Saarland have been compared with the registered persons at the Cancer Registry. The staff of the Cancer Registry will shortly carry out a record linkage of the group of 1591 persons among our former patients who are reported dead on the basis of death certificates for all residents of the Saarland.

The result of the computer-aided comparison of our former patients who are still living in the Saarland with the persons registered in the Cancer Registry is:

- 645 of the 8893 persons are found in the Cancer Registry
- 24 of these 645 persons are registered with the diagnosis 'thyroid gland carcinoma' (ICD-Code: 193).

The following Table shows the distribution of the 24 cases of thyroid carcinoma over the total range of activity:

Range of activity [MBq]	Number of persons (women/men)	Number of thyroid carcinomas (women/men)	Carcinoma/ persons [%] (women/men)
<0.925	205 (160/45)	0	0
0.925 -1.85	2473 (1869/604)	4 (2/2)	0.2 (0.1/0.3)
1.85 -3.7	3944 (3061/883)	13 (10/3)	0.3 (0.3/0.3)
3.7 -18.5	1186 (931/255)	7 (5/2)	0.6 (0.5/0.8)
18.5 -37	2 (1/1)	0	0
37 -370	28 (23/5)	0	0
370 -3700	1027 (887/140)	0	0
≥3700	28 (25/3)	0	0

Project 5

Head of project: *Prof. Lars-Erik Holm*

Overall objectives of project: To study cancer risks in patients irradiated for skin hemangioma and to relate cancer risks to radiation absorbed doses.

Specific objectives for reporting period:

- to perform individual radiation dosimetry in a cohort of 16,530 patients who were admitted do Radiumhemmet during the years 1920-1959 for skin hemangioma and received radiotherapy in the majority of cases,
- to match the cohort with the Swedish Cancer Register and relate cancer incidence to radiation absorbed doses, and
- to study dose-response relationships.

Progress achieved including publications

Between 1920 and 1959, a total of 16,500 children less than 18 months old were admitted to Radiumhemmet at Karolinska Hospital, Stockholm, for a skin hemangioma. Nearly 90% of them received some form of external radiotherapy with gamma rays or beta rays. The most commonly used treatment modality was 226-radium therapy with needles or tubes which were applied to the hemangioma.

Dosimetry has been performed on a phantom moulded to resemble a 6-month old child, which corresponds to the median age of the patients at the time of the treatment. Dose calculations have been made for three different age-groups: < 4 months, 5-11 months, and 12-18 months. Correction for body size has been based on data concerning growth development of Swedish children. The radiation absorbed doses in the thyroid, breast, lung, stomach, colon, gonads, and bone marrow have been calculated individually for each child.

The cohort has been matched with the Swedish Cancer Registry for the period 1958-1987. During this period, more than 300 malignant tumours including leukemia were observed among the 16,530 patients. This figure can be comparade with the 224 cases observed in the total cohort including irradiated children and adolescents up till 1982 (Fürst *et al*, Cancer incidence after radiotherapy for skin hemangioma: A retrospective cohort study in Sweden, J. Natl Cancer Inst 80: 1387-92, 1988). The highest cancer risk was found among those treated in the 1920s and 1930s, whereas no increased risk has yet been observed among those treated in the 1950s.

During the reporting period, we have begun analysing cancer risks in more detail and in relation to sex, radiation dose, and time since exposure. We have been particularly interested in cancer incidence after exposure to low doses and are studying which projection model has the best fit. Ms Marie Lundell is a hospital physicist who is analysing the data as part of her doctoral thesis in radiophysics. Cancer risks are being analysed with the statistical package GLIM (Generalized Linear Interactive Modelling). The expected numbers of cancers have up till now been based on cancer incidence data from the whole country. However, the majority of patients came from the Stockholm region, and we have therefore decided to use population-based data from this region.

In 1991, an international workshop was arranged with the purpose of discussing how to best analyse the epidemiologic data of the hemangioma cohort. The participants were Timo

Hakulinen, Sarah Darby, Charles Land, Bo Lindell, Marie Lundell, and Lars-Erik Holm. Questions discussed included uncertainties as to how to best calculate expected numbers of cancer, what weighting factors to use, and the fact that many patients with the lowest radiation doses also have the longest follow-up, and are consequently the oldest subjects in the cohort.

The workshop recommended that more organ doses be calculated. Individual organ doses have therefore also been calculated for brain, maximum doses to bone marrow (previously only mean dose), and organ doses to both breasts and to both lungs (previously only mean breast and lung doses). This work has been quite time consuming since we have had to go through the dose charts of all patients once again. Treatment time and number of treatments have also been recorded for each patient, since the workshop considered this to be of potential interest.

The lowest dose-category has since the workshop also been subdivided further to take into account that the radiation doses to other parts of the body in patients receiving radiotherapy to arms and legs are less certain (depending on how arms/legs were positioned during the radiotherapy). Analyses have therefore also been done by treating these patients separately, but this has not considerably affected the results.

Analyses of cancer risks continues and it is expected that a manuscript describing cancer risks and dose-response relationships will be available in the autumn of 1992. So far, Ms Lundell has prepared two manuscripts describing dose distribution around radium applicators and organ dose rates in the treated children (1-2). Data from the hemangioma study was presented at a meeting arranged by the International Society for Pediatric Oncology on Rhodes in October 1991 (3).

List of Publications

1. Lundell, M., Dose distribution around radium applicators, Manuscript.

2. Lundell, M., Organ dose rates in children treated with radium for hemangioma, Manuscript.

3. Lundell, M., Holm, L.E., Fürst, C.J., Lundell, G., Cancer incidence in patients irradiated during infancy for skin hemangioma, Abstract presented at the International Society of Pediatric Oncology, SIOP XXII Meeting, Rhodes, Greece, 1991.

Project 6

Head of project: *Prof. A. Becciolini*

Objectives for the reporting period

To examine the incidence of second tumours among patients in Italy given radiotherapy, with particular reference to treatment for cancers of the breast, head and neck, endometrium and uterine cervix.

Progress achieved including publications

1. Treatment for breast cancer

From March 1970 to August 1990, 1449 breast cancer patients (pts) were referred to and irradiated at the Department of Radiation Oncology (University and General Hospital) of Florence. In 8 out of the 1449 considered pts., a second tumour other than breast cancer was diagnosed at the same time of or within 1 year from the end of irradiation. These pts. were excluded from the present analysis.

All the considered 1441 pts. had been submitted to surgery (594 radical and 847 conservative mastectomy), 203 pts. received adjuvant chemotherapy (usually CMF) and 313 hormonotherapy (castration ± tamuxifen). Age ranged from 23 to 82 years (mean: 52 years, median 51 years). The status of the pts. was assessed in August 1991 and the follow-up period ranged from 1 to 21.5 years (mean 5 years, median 6.7 years).

Different volumes were irradiated: breast (829 pts.); mammary chain, supraclavicular region and axilla (229 pts.); mammary chain, supraclavicular region, axilla and chest wall (156 pts); mammary chain and supraclavicular region (150 pts.); mammary chain, supraclavicular region and chest wall (10 pts.); other volumes, usually limited to the supraclavicular fossa or the mammary chain, (67 pts.). Doses ranged from 44 to 60 Gy, higher dose levels being delivered to limited volumes.

Twenty-two pts. were affected by a bilateral synchronous (time to detection ≤ 1 year) breast cancer. These pts. received radiotherapy only to one side of the chest and are considered in the study. Forty-four cases of metachronous controlaterial breast cancer and 26 cancers other than breast cancer were detected in the study period. These 26 cases were represented by: leukaemia (6), stomach (5), colorectal (3), endometrium (3), lung (2) and 1 case each of cervix, skin, thymus, oesophagus, ovary, bladder and carcinoid cancers. Time to detection ranged from 3 to 13 years (mean: 6.9 years, median: 5 years).

The risk of developing a radiotherapy-related second cancer was expressed as the observed/expected ratio. Expected values were drawn from data, corrected according to sex and age, for the Florentine Cancer Register. The results are reported in the following Table.

	Observed	Expected	Relative Risk
1) Cancers other than breast	26	51.0	0.51
2) Metachronous breast cancer	44	18.4	4.20
3) All cancers (1+2)	70	69.4	1.01
4) Leukaemia	6	1.3	4.60

2. Treatment for endometrial cancer

Among patients treated for cancer of the uterus at the University and General Hospital of Florence between 1973 and 1985, the cancer was diagnosed as arising in the uterine body for 429 of the cases. Of these, 247 were primitive endometrial adenocarcinomas, while 32 were local recurrences after surgery among patients who had not been submitted to post-operative radiation therapy. Fifty-one patients were not evaluated owing to reasons such as a histology other than adenocarcinoma or an age of 80 years or older; another 100 patients were not considered because of unknown or uncertain site of origin of the tumour, lack of histological definition of the tumour, etc.

The overall 10-year survival for those with endometrial adenocarcinoma was 71%. Post-operative radiation therapy was performed on 212 patients, all of whom received external beam therapy with doses ranging between 50 and 56 Gy and conventional fractionation. Thirteen cases were submitted to radiation therapy only (12 with external beam and 1 with intracavity treatment only). No treatment was performed in the remaining 22 cases after surgery.

Among the 225 patients treated with radiation therapy, 10 new malignancies were diagnosed. Of these, 4 were of the breast, 3 of the large bowel, 2 of the intestine, and 1 was an *in situ* carcinoma of the cervix. The intestinal tumours and the *in situ* carcinoma of the cervix were diagnosed within 2-7 years of the completion of the radiotherapy course, and were included in the treatment volume.

Among the 22 patients not submitted to radiotherapy after surgery, only one second tumour arose; a breast tumour, three years after treatment.

3. Treatment for head and neck tumours

We analysed data for 1311 patients treated for head and neck cancer with radiation therapy alone at the Radiotherapy Department in Florence from 1960 to 1984. The series of patients consisted of the following:

- 223 cases of nasopharyngeal carcinoma
- 282 cases of oropharyngeal carcinoma
- 80 cases of hypopharyngeal carcinoma
- 368 cases of laryngeal carcinoma
- 229 cases of oral cavity carcinoma
- 60 cases of salivary gland carcinoma
- 69 cases of paranasal sinuses carcinoma

All cases were histologically verified and they were classified, in part retrospectively, according to TNM System of UICC 1978. The second malignancy was defined according to the concepts of Warren and Gates and classified as previous, synchronous or metachronous according to the neoplasia for which the patients were originally treated.

We found 52 second malignancies (4%), distributed as follows: 10 nasopharyngeal tumours with a mean latency of 5.7 yrs, 11 oropharyngeal tumours with a mean latency of 4.1 yrs, 2 hypopharynx tumours with a mean latency of 3.5 yrs, 7 oral cavity tumours with a mean latency of 4.2 yrs and 22 laryngeal tumours with a mean latency of 5 yrs.

We found no second malignancies in the salivary glands, nor in the paranasal sinuses.

We evaluated the second tumours according to the origin of the first tumour and according to the treatment volume:

Site of Origin	In Field	Outside Field
Nasopharynx	0	10
Oropharynx	5	6
Hypopharynx	0	2
Oral cavity	0	7
Larynx	3	19

We obtained an actuarial survival for the overall series of 42% (± 2 of SD) at 10 and 20 years post treatment, and the corresponding values of actuarial incidence of second malignancies were 17% and 22% respectively.

4. Treatment for cervical cancer

Records for 614 patients, referred to the Radiation Therapy Department of the University of Florence between 1977 and 1985, have been reviewed. An adenocarcinoma of the cervical canal was diagnosed in 30 cases while a squamous cell carcinoma was found in the remaining patients. All the patients were treated with radiation therapy and some of them were also submitted to surgery. Preoperative radiation therapy was performed in patients with a tumour confined to the cervix (clinical stage IB) or with limited extension to the fornix or parametrium (clinical stage IIA and IIB). Preoperative treatment was performed with intracavity radiation therapy and doses ranging between 50 and 60 Gy to point A. In cases not suitable for intracavity treatment external beam therapy (40-50 Gy) was employed before surgery.

Patients with bulky tumours (clinical stage IB or IIA > 4 cm; bulky IIB tumours or involvement of both parametrial) or with clinical stage III were submitted to radiation therapy alone. A high energy photon beam was used in all cases and a conventional fractionation (2 Gy a day; 5 sessions a week) was employed. A box technique was used only in cases submitted to radiation therapy alone and when the total dose delivered to the pelvis was greater than 50 Gy.

In the group of 614 patients irradiated for uterine cervix carcinoma, 4 second tumours were observed during follow-up. Two of them were localised at the breast and appeared after 4 and 7 years after treatment. The other two were localised at the nasopharynx and oral cavity, and appeared 3 years and 1 year respectively following treatment. There were no diagnoses of leukaemia, nor of second tumours within the irradiated volume.

In a group of the patients, urinary polyamine concentrations were evaluated by the HPLG technique. The study showed differences in behaviour for primary and recurrent tumours. Moreover, polyamine increased markedly during the radiotherapy treatment in patients who remained disease-free for at least 5 years but not in patients with progressive disease or relapse. The increase of urinary polyamines, but not the baseline values, seemed to be correlated with the response after radiotherapy.

Compared with previous results obtained for 225 patients submitted to radiotherapy for endometrial carcinoma during the same period, the incidence of a second primary tumour was much lower for patients treated for cervical cancer. In both groups breast cancer was the single most frequent tumour.

Publication

Becciolini, A., Porciani, S., Lanini, A., Santoni, R and Cionini, L. Urinary polyamines in patients with advanced cervical cancer or pelvic cancer recurrence during and after radiotherapy. Acta. Oncol. 31, 327-331 (1992).

RADON AND LUNG CANCER IN THE ARDENNES AND EIFEL REGION

Contract Bi7-007 - Sector C14

1) *Poffijn*, Univ. Gent - 2) *Tirmarche*, CEA - FAR
3) *Wichmann*, Univ. Wuppertal - 4) *Kayser*, Dir. de la Santé Div. Radioprot.
5) *Darby*, Imperial Cancer Research Fund. - 6) *Tirmarche*, CEA-FAR

Summary of project global objectives and achievements

Global objectives

Development of a common protocol and common "core" questionnaire for the Ardennes-Eifel study. Use had to be made of the expertise gained from setting up the case-control study in southwest England and from the pilot study on radon and lung cancer previously conducted in the Belgian Ardennes.

Selection of the hospital(s) of interest in the study area, contact with the local medical staff and organisation of the field work.

Organisation of radon intercomparisons quality control exercises both under controlled laboratory and normal living conditions.

Setting-up a draft version for a common coding schedule.

Global achievements

During the first year of the reporting period a draft version of the common protocol was set-up and agreed upon between all participants to this study.
Based upon the experience gained during the following test period minor changes and specifications were made to this draft version.
In the final version (see appendix I) the recruitment area in Luxemburg was extended to the whole country, in order to arrive at the planned total of 50 cases per year. In Germany the administrative district of Saarbrücken was included in the study area, while the district of Köln was dropped.
Although it was originally planned to use the same type of detector in all participating countries, it was decided to replace the Karlsruhe detector by the Kodak device in France. In this way the high refusal rate encountered in the beginning in the French Ardennes, could be reduced substantially.

In all participating countries the field work started in autumn 1990.

As already stated in the progress report a quality assurance exercise under controlled conditions was organised at the laboratory of the radon research group of the university of Gent. This intercomparison was immediately followed by an exposure at a similar level for the same time in a well-known high radon house in the Belgian Ardennes. Out of these tests it became very clear that the results of one of the devices was out of range as compared to the others, and it was therefore excluded for this study.In a second phase, five detectors of each type were exposed for a three and six month period in the homes of the principal collaborators to the study. The overall results (except for Oxford) of this exercise are presented in appendix II.
In the Oxford house - for an undeclarable reason- the spread in individual detector result was unacceptably high for all participants. It was therefore decided to do this exercise over. The results as available for the moment,indicate now a much more homogeneous distribution.

A first draft for a common coding schedule was edited and a first filter exercise for the transfer of data was organised. For the moment the outcome of these preliminary test is being analysed. These items will be studied in more detail in the next period.

Appendix I :protocol

Appendix II :intercomparison

Project 1

Head of project: *Dr. Poffijn*

Objectives for the reporting period

The university of Gent is acting as coordinator and Belgian participant in this multi-center case-control study on radon and lung cancer in the Ardennes-Eifel region.

The principal objectives for this reporting period were :

* to study the entry-rate of patients in the departments - suitable for the recruitment of cases and controls - of the clinics situated in the study area;
* to select the hospitals, to establish the necessary contacts and to start the field work, along the general lines as put forward in the common protocol;
* to organise and participate in different types of radon intercomparison exercises;
* to set up, in collaboration with the other participants, a first draft of common coding schedule;
* to construct a filter for data transfer to Wuppertal; and :
* to test this filterprogramme on a first series of data, transmitted by the different participants.

Progress achieved including publications

After studying the available mortality data and minimal medical data (to be registrated now by all hospitals in Belgium), the clinics of Mont Godinne, La Citadelle, Warquignies and Jolimont were selected for recruiting patients out of the study area (the provinces of Hainaut, Liège, Luxembourg and Namur). The field work started between september 1990 and february 1991, except in the clinic of La Citadelle, where the interviewing for the radon study could only start in February '92. Up to now 485 persons have been contacted. The general features of the outcome of this approach and the distribution of the smoking status of cases and controls for both sexes are represented in Table I and Table II.

Almost at te same time the installation of radon detectors was started in the current as well as in the previous (if necessary) houses of the patients. The inhabitants of the previous houses were contacted with the collaboration of the patient himself or through the intermediation of the local authorities. In general radon measurements have to be performed in 1.8 dwellings to reconstruct the radon situation for a 25 year period out of the last 35 years.

Table I - Basic patient information

Patients approached	485
Refusals (participation)	45
Excluded	59
Interviews completed	381
Refused installation detector	8

Table II - Smoking status for cases and controls among both sexes

	MALE			FEMALE		
	Current	Past	Never	Current	Past	Never
CASES	97	69	3	7	3	6
CONTROLS	48	49	18	12	9	60

The distribution of the available radon data in the current houses of the patients (Fig. I) indicates that almost 9% of the patients is living in houses with radon concentrations surpassing 400 Bq/m^3 (the upper level of the CEC recommendation on indoor radon).

As it was agreed upon that the overall final statistical analysis should be performed by the team of Wuppertal, a common coding schedule was set up by the teams of Gent, Wuppertal and Oxford. A first test as to the construction of a common data-set was organised. Therefore as a first test, every participant was asked to send a partial set of house records (coded in an appropriated way) to the coordinator in Gent. Here a filterprogramme was developped to test the quality and consistency of the different data-set, before transfer to Wuppertal.

As stated in the section about the global achievements, the University of Gent did - beside participate - organise the first quality control exercise (laboratory and high exposure conditions) and did also coordinate the next intercomparison experiment, whereby 5 detectors of each laboratory were installed in the homes of the different scientific responsibles for this project, for an exposure time of 3 and 6 months.

Publications

A. Poffijn, M. Tirmarche, L. Kreienbrock, P. Kayser, S. Darby Radon and Lung Cancer : Protocol and procedures of the multi-center studies in the Ardennes-Eifel region, Brittany and the Massif Central region (in press).

A. Poffijn, The Role of Radon in the Etiology of Lung Cancer, Annals Belgian Radioprotection Association Vol. 15, 3 (1990).

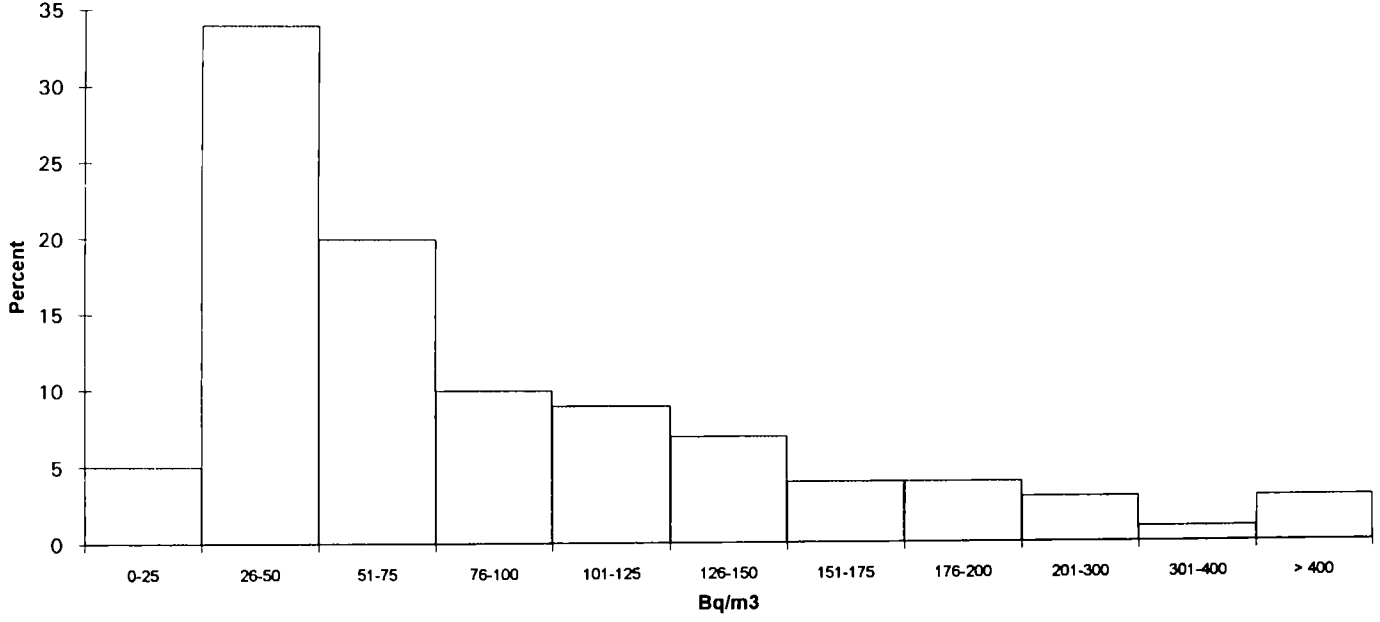


Figure 1 - Radon distribution in current houses

Project 2

Head of project: *Dr. Tirmarche*

Objectives for the reporting period

1. Analyse de la mortalité par cancer d'un groupe de mineurs d'uranium en France

L'analyse descriptive de cette étude de cohorte regroupe des mineurs d'uranium dont la date de début de travail au fond se situe entre 1946, date d'ouverture des premières mines d'uranium en France, et 1972. Le but de cette analyse a été la mise en évidence d'un risque de décès par cancer du poumon sur un groupe de mineurs ayant eu une exposition au radon faible et cumulée sur une période d'exposition longue: l'exposition cumulée moyenne de cette cohorte est de 70 WLM pour une durée moyenne d'exposition de 14,5 ans. L'appréciation de la relation dose-effet pour le risque de cancer du poumon a été approchée par une régression de type Poissonnienne en supposant une relation linéaire entre l'exposition au radon et le risque de décès par cancer, exprimé sous forme de rapport de mortalité standardisé, la population française masculine servant de référence.

Cette analyse s'est déroulée parallèlement à l'analyse de l'étude des mineurs d'uranium de Tchécoslovaquie conduite par le Dr. E. KUNZE et Mr. L. TOMASEK en collaboration avec Mme CHMELEVSKI-KELLERER du GSF à Munich.

Progress achieved including publications

Le rapport de l'analyse de l'étude française est joint à ce document; il a servi de base à l'article soumis actuellement au BRITISH JOURNAL OF CANCER.

Project 3

Head of project: *Prof. Wichmann*

Objectives for the reporting period

The University of Wuppertal should acting as the German participant of the study.

After study of the available mortality data on lung cancer in the areas of concern, the group should select and contact the hospital(s) of interest and arrange the work on the spot.

The German team is responsible for the personnel involved in the study in his subregion(s). All the local data will be collected at the regional center and sent to the coordinator. Each participant will give special attention to the distribution and collection of the radon detectors. The team from Wuppertal will analyse the data in close collaboration with the coordinator and the team of Oxford.

Progress achieved

In the reporting periods case- and control-hospitals were selected and the interviewing team was set up. In autum 1990 interviews and radon measurement started, 148 cases and 129 controls are interviewed up to now.

With the team of Oxford and Gent a core coding schedule was set up. Data Filter exercises were started and intercomparison experiments were analysed.

1. General

The University of Wuppertal was acting as the German participant on this mulitnational case-control-study on the etiology of lung cancer in the Ardennes Eifel Region.

In the common protocol the responsibility of the German study group includes the selection of cases and controls in the German study region which was defined as the three administrative destricts of Trier, Koblenz and Saarbrücken. In this area interviews were done in the two main hospitals in Homburg and Bad Ems; additional cases were recruited from hospitals in Cologne, Essen and Trier. In the reporting period 148 cases and 129 population-controls were

interviewed and radon-measurement was done in the homes of these participants.

In addition to the field work responsibility in the German study area the group of the University of Wuppertal was involved in coordinating purposes, data handling and statistical analysis. These topics were done in close collaboration with the teams of Gent and Oxford.

2. Field work

In the reporting period 148 cases and nearly the same number of population controls were interviewed in the German study area. Figure 1 shows the distribution of interviews from November 1990 up to February 1992 documented in the German study base. Table 1 gives an overview on the distribution of cases and controls in relation to sex and the smoking status.

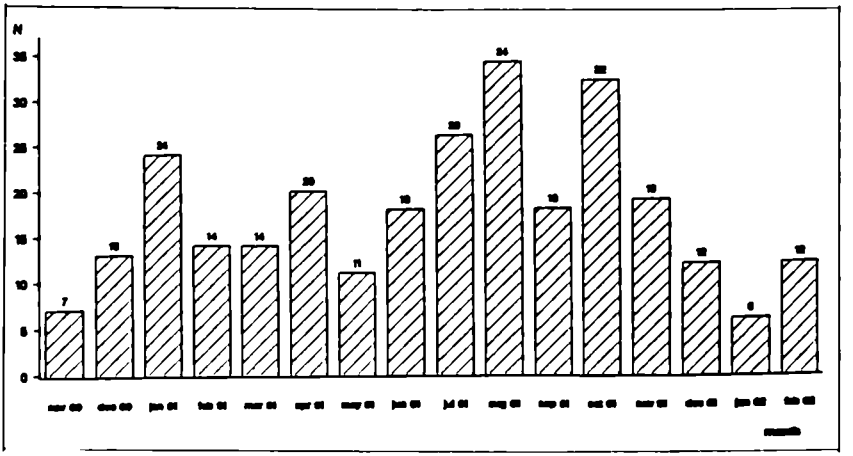


Figure 1: Interviews by month in the German study area

Table 1: Cases and controls by smoking status and sex

	male		female	
	smoker	never-smoker	smoker	never-smoker
cases	118	3	19	8
controls	78	22	14	15

Table 2: Cases and controls by years of education

	< 8	8	10	12	> 13	others
cases	2	129	7	4	3	3
controls	1	75	21	5	25	2

Table 2 gives an indication of the social status of the participants which is defined as years in school reported in the questionnaire. Both tables 1 and 2 show the known distributions related to case-control-studys and lung cancer. From this point of view no bias could be expected in the German study-base.

To get a life time exposure from residential radon all houses the participants lived in since 1965 were listed in the interview. Because the study area in Germany is very rural there is a mean of 2.79 houses from 1955 up to now. More than 40% of the participants are living more than 25 years in their actual home. Therefore 40% of the participants give a good approximation on their live time exposure with the Radon measurement of only one house.

Radon measurement was done up to now only in the actual houses of the participants. Two types of Radon detectors were used. A charcoal-canister to give a first impression of the Radon environment in the house and an alpha-track-detector from Karlsruhe. Figure 2 gives the distribution of the Radon concentration in the houses of the participants.

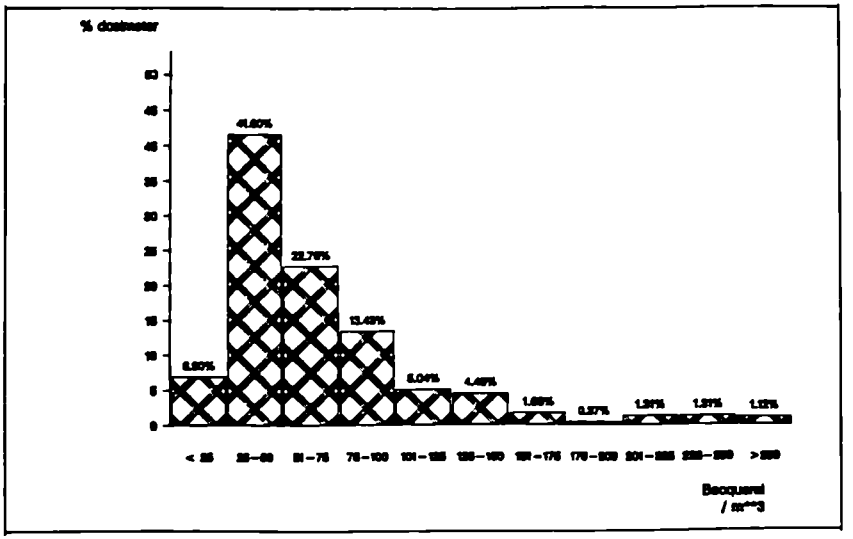


Figure 2: Distribution of Radon concentration (charcoal-canisters) in the German study area

3. Coordination work

Because in the common protocol it is fixed that the common statistical analysis of all participants countries is done at the University in Wuppertal, preparing this analysis, the German group was working with the group of Gent and Oxford and preparing a common data-base.

Therefore on different meetings a consensus on common questions in the different questionnaires was discussed and a core coding schedule to realize the common data-base was designed. To improve the mechanism of constructing a common data-base first data exercises were done on the residential part of the German questionnaire. The relating data filter which is constructed by the University of Gent was tested with German data and will be finished in summer 1992. Meanwhile first programs to do descriptive statistical analysis on the common data bases are evaluated with the statistical software SAS.

4. Outlook

Statistical analysis facilities could be finished in late summer 1992. The enrolment of the study participants is as planed. Recruitement of cases and controls have to be done additional two years to get the expected sample size calculated at the beginning of the study.

Project 4

Head of project: *Dr. Kayser*

Objectives for the reporting period

Depuis fin 1990 la division de la radioprotection de la direction de la Santé, équipée d'un laboratoire de radiophysique, mêne et coordonne au Luxembourg l'étude épidémiologique sur le radon.

Les buts principaux pour la période passée étaient les suivants:

* prendre contact avec les responsables des différent hôpitaux;
* engager le personnel nécessaire pour faire les enquêtes et la lecture des dosimètres;
* tester la faisabilité du protocole commun;
* participer aux études d'intercomparaison des méthodes de dosage du radon.

Progress achieved

A cette étude participent un hôpital du nord du pays ainsi que les médecins-pneumologues du pays. Une enquêteuse a été engagée qui procède aux enquêtes auprès des cas et des contrôles, conformement au protocole établi d'un commun accord entre les 5 institutions des pays participants.

Dans un premier temps la faisabilité du protocole commun a été testée et une étude d'intercomparaison (voir compte rendu général) des méthodes de mesures du radon a été menée à bien.

Jusqu'à présent 120 personnes (93 hommes et 27 femmes) ont été soumises à l'enquête et 6 personnes ont été exclues.

Le résumé de l'analyse tabac parmi les personnes interviewées jusqu'à présent est présenté dans le Tableau I.

La répartition du radon montre (Tableau II) que presque 10% des personnes soumises à l'enquête vivent dans des maisons où la recommendation européenne est dépassée.

Publications

A. Poffijn, M. Tirmarche, L. Kreienbrock, P. Kayser, S. Darby Radon and Lung Cancer : Protocol and procedures of the multi-center studies in the Ardennes-Eifel region, Brittany and the Massif Central region (in press).

Tableau I : Répartition tabac

	Fumeurs	Ex-Fumeurs	Non-Fumeurs
Hommes	22	47	24
Femmes	5	2	20

Tableau II : Distribution radon

Radon (Bq/m^3)	Pourcentage
0 - 50	20
51 - 100	36
101 - 400	35
401 - 1200	09

Project 5

Head of project: *Dr. Darby*

Objectives for the reporting period

The objective of this reporting period was to provide expertise gained from setting up the case-control study of radon and lung cancer in southwest England to the local investigators of the Ardennes-Eifel study.

Progress achieved including publications

The protocol of the Ardennes-Eifel study has been developed making use of many of the features of the study in southwest England.

Data for an intercomparison of radon detectors has also been gathered.

Preliminary discussions as to the possibilities for an eventual joint analysis of European radon studies have taken place, and a meeting of those involved has been planned for the autumn of 1993.

Publications

- A. Poffijn, M. Tirmarche, L. Kreienbrock, P. Kayser, S. Darby. Radon and Lung Cancer: Protocol and procedures of the multi-center studies in the Ardennes-Eifel region, Brittany and the Massif Central region (in press).
- S.C. Darby, R. Doll. Radiation and exposure rate. Nature 1990; 344: 824.
- S.C. Darby, R. Doll. Radon in houses: how large is the risk? Radiation Protection in Australia 1990; 8: 83-88.
- A.J. Gunby, S.C. Darby, J.C.H. Miles, B.M.R. Green, D.R. Cox. Factors affecting indoor radon concentrations in the UK (in press).

Project 6: Etude du risque de cancer du poumon en fonction de l'exposition domestique au radon (Bretagne - Vendée et Ardennes)

Head of project: *Dr. Tirmarche*

Objectives for the reporting period

La périod de mai 1990 à mai 1992 concerne la période de faisabilité d'une étude cas-témoin, réalisée sur la base d'un protocole commun, établi en collaboration avec les partenaires d'Allemagne, de Belgique, de Luxembourg et un expert du Royaume Uni. Elle porte à la fois sur les conditions de l'interrogatoire des malades dans les hôpitaux et sur les mesures de radon dans les habitations.

Le but de cette étude internationale est l'estimation du risque en fonction de l'exposition domestique au radon, aussi bien pour les non-fumeurs que pour différents degrés de tabagisme; l'estimation de ce risque, à priori relativement faible, demande un nombre éléve de cas et de témoins et le choix d'une étude large et internationale s'impose pour donner une puissance suffisante à cette évaluation du risque de cancer bronchique.

Progress achieved

En France les deux régions choisies durant cette première étape sont d'une part le nord du département des Ardennes, faisant partie du complexe géologique Ardennes et Eifel et d'autre part la région Bretagne Vendée renfermant 6 départements dont les caractéristiques géologiques du sous-sol permettent de prévoir de grandes variations des expositions domestiques au radon.

Le protocole définissant l'étude menée en France est en tous points conforme à celui adapté en Belgique, au Luxembourg et à la partie "EIFEL" de l'étude allemande. En France l'étude se déroule uniquement à l'hôpital, le choix de témoins provenant de la population générale n'ayant pas été retenu, à la fois pour des raisons de méthodologie et de réalisation pratique. Un minimum de deux témoins par cancer du poumon est retenu et les critères de choix des témoins sont conformes à ceux retenus dans le protocole international.

Un questionnaire établi en accord avec les autres partenaires de cette étude internationale, a été testé dans les hôpitaux de Charleville-Mézières pour l'étude des Ardennes et dans les hôpitaux de Brest pour la région Bretagne-Vendée. Il précise les caractéristiques des différentes habitations de chaque malade, notre but étant de mesurer l'exposition domestique au radon au minimum pendant 25 ans durante les 30 dernières années. Le comportement tabagique est également retenu; pour les non-fumeurs, des questions concernant le tabagisme passif sont posées. Un historique des différentes expositions professionnelles est également demandé afin de pouvoir standardiser en fonction d'un certain nombre de cancérigènes pulmonaires présents dans l'environnement professionnel. Un exemplaire du questionnaire utilisé dans les Ardennes et en Bretagne-Vendée est joint.

Point actuel de l'étude

Dans les Ardennes, nous avons établi un contrat de collaboration scientifique avec la Société Ardennes-Epidémiologie. Cette société met à notre disposition deux enquêtrices à mi-temps, formées par nos soins, ainsi que deux personnes travaillant à temps partiel pur la mise en place des dosimètres dans les différentes maisons décrites par les malades. Durant la période de faisabilité, en 1990, un sondage auprès des médicins généralistes et pneumologues nous a permis de déteminer les principaux hôpitaux où sont dépistés et soignés les malades ayant

un cancer du poumon: nous avons retenues deux hôpitaux à Charleville Mézières; nos interlocuteurs sont le Dr. Cohen-Laroque et le Pr. Duclos. Notre enquête cas-témion est réalisée également en étroite collaboration avec la Société Ardennaise de Cancérologie qui gère un régistre des cancers dans la région; une évaluation du nombre de perdus de vue comparativement à ce registre nous a permis de constater que, durant la période de déménagement du service du Pr. Duclos, un certain nombre de cas de cancer du poumon n'ont pas pu être inclus dans notre étude. Dupuis, l'enquête en région Ardennes se déroule de manière satisfaisante.

Le refus de la mise en place d'un dosimètre a été également fréquent durant les premiers mois de notre étude. Une présentation externe différente (choix du dosimètre KODALPHA), une formation spéciale de nos enquêteurs ainsi qu'une information écrite aux maires nous ont permis d'avoir une meilleur acceptabilité auprès des habitants des maisons retenues.

Une cinquantaine de cancers du poumon ont été interrogés et l'appariement avec des témoins de même âge (+ ou - 5 ans) est actuellement réalisé pour 2/3 d'entre-eux. 38 cas n'ont pas pu être interrogés pour les raisons suivantes: 9 étaient âgés de plus de 75 ans; 8 n'ont pas habité un minimum de 25 ans dans la région; 3 ont refusé de participer; 13 ont été jugés ininterrogeables pour des raisons de santé (surdité, trachéotomie...); 5 pour des raisons diverses: congé annuel de l'enquêteur, connus personnellement par l'enquêteur, preuve du cancer primitif impossible.

Dans la région Bretagne-Vendée, beaucoup plus large (6 départements), la faisabilité de l'enquête a été testée notamment à Brest, dans le service du Pr. Clavier. Actuellement une cinquantaine de malades atteints de cancer bronchique primitif ont été interrogés ainsi qu'un nombre équivalent de témoins. La mise en place des dosimètres et la logistique sont assurés par l'université de Brest, Faculté de Sciences, avec laquelle l'IPSN a conclu un contrat de collaboration. Une dizaine de service de pneumologie ont donné leur accord de participation à cette étude. Pour une bonne représentation des différents départements et en l'absence d'un registre des cancers, la période de faisabilité nous a appris que le seul recrutement dans les hôpitaux universitaires est insuffisant pour représenter la population dans son ensemble; nous avons donc étendu notre étude aux hôpitaux régionaux, ce qui, au niveau organisation pratique, est évidemment plus lourd. Une nouvelle réunion d'enquêteurs est prévue courant juillet 1992 et l'étude Bretagne-Vendée devrait se dérouler sur une échelle plus large à partir de début septembre. L'organisation de cette étude au niveau régional demande également une information constante des médecins impliqués afin de stimuler leur participation.

Actuellement 35 cas de cancer du poumon ont pu être interrogés sur les hôpitaux de Brest et Quimper. Du fait des critères d'exclusion des témoins, le recrutement de ces derniers s'avère difficile et se limite en moyenne à 2 ou 3 malades par service par semaine. Au total, au mois de mai 1992, 30 cas de cancer du poumon ont été appariés avec leur témoins, et 40 dossiers (cas et témoins) sont en attente d'appariement.

Dans le protocole initial, l'interrogatoire de 600 cas et de leurs témoins était prévu. La région Bretagne-Vendée étant une région où le taux de cancer du poumon est peu élevé, cet interrogatoire devra certainement continuer au-delà de 1994, à moins que l'inclusion de la région du Massif Central nous permette d'augmenter notre recrutement.

Le dosimètre KODALPHA, utilisé dans le cadre de cette étude française, a fait partie de nombreuses comparaisons internationales et est reconnu par l'EPA aux USA. Dans le cadre de cette étude internationale, nous avons testé régulièrement les différents dosimètres utilisés dans les pays participants en les exposant dans des conditions standards dans une maison type dans chaque pays pendant une durée de 3 et de 6 mois.

Les résultats de ces intercomparaisons ainsi que le détail du protocole de cette étude ont été présentés au 5e symposium international sur la radioactivité naturelle à Salzburg en Autriche (22 au 28 septembre 1991) et sont soumis à publication dans RADIATION PROTECTION DOSIMETRY.

Appendix I Last revised 13 December 1991

CASE-CONTROL STUDY OF RADON AND LUNG CANCER IN THE ARDENNES-EIFEL REGION
COMMON PROTOCOL.

Residential Criteria

1. All subjects, whether cases or controls, should be currently living within the defined study area which corresponds roughly to the geological Ardennes and Eifel region.

2. In Belgium the study area comprises the four provinces of Hainault, Liège, Luxembourg and Namur. In Germany the study area comprises the three administrative districts of Trier, Koblenz, and Saarbrücken. In Luxembourg the study area comprises Ösling* (i.e. the northern part of the country). In France the study area comprises the northern half of the département of the Ardennes.

3. Only subjects who have lived in the study area for at least 25 out of the last 35 years will be included.

4. In Belgium, France and Luxembourg there will be no exclusion criteria based on ethnic origin or nationality. In Germany only persons with a German passport who have lived in the Federal Republic of Germany since 1965 will be included.

5. There will be no exclusion criteria based on occupation.

Cases

1. Within each country a starting date and a finishing date for the study will be defined, and attempts will be made to identify all the incident (i.e. newly diagnosed) cases of lung cancer satisfying the residential criteria occurring in between these two dates. In Belgium and Luxembourg* case enrolment began on 1 September 1990. In Germany case enrolment began on 1 November 1990. In France case enrolment began on 1 October 1990 in 1 hospital, and 1 October 1991 in the other.

2. Cases aged 75 years or over on their date of diagnosis with lung cancer will be excluded.

3. In each centre patients with lung cancer will be interviewed as early as practicable in their clinical history, to minimise the risk that the patient will die before the measurement in his home is complete. In Germany, patients who are not interviewed within three months of diagnosis are excluded.

4. The aim is to include all cases with primary lung cancer, with reliability of diagnosis grade 1 or 2 on the Oxford classification (see Appendix A).

5. If, in some centres, patients are interviewed before a definite diagnosis is made, those who subsequently turn out not to have lung cancer will, if their disease is eligible, eventually be transferred to the hospital control group.

* An extention to the whole country of Luxembourg is being considered.

6. In Belgium the clinical notes of each patient will be reviewed by the study physician to obtain the final diagnosis. In Germany and Luxembourg the final diagnosis of lung cancer will be based chiefly on the histology or cytology report. In France the final diagnosis will be based on the histology report and clinical opinion.

7. In each country one local pathologist will review all the pathological material for that centre.

Hospital Controls

1. All participating countries will include for each case of lung cancer entered into the study 2 hospital controls (3 in Belgium and France). Each hospital control will be a person who is a hospital in-patient who has not had lung cancer, whose current hospital admission is for a disease that is not strongly related to tobacco and who is not suffering from a disease that is likely to render them incapable of participating in the study. The detailed disease criteria are given in Appendix B. In each centre attempts will be made to include patients with a wide variety of diseases in the hospital control group.

2. The matching criteria for hospital controls are age (in 5 year groups: ... 35-39, 40-44, 45-49, ... 65-69, 70-74), sex and broad area of residence. In Belgium the broad areas of residence will comprise "local" areas defined around each hospital where cases are recruited and the remaining area will be subdivided by province. In Germany they will be counties. In Luxembourg and France it will not be necessary to match by area of residence. In Germany, Belgium and Luxembourg frequency matching based on the margins will be carried out. In France individual matching will be carried out.

3. It is likely that for many hospital controls the final diagnosis will not be available at the time of interview. In Belgium the case notes of each hospital control will be reviewed by the study physician to obtain the final diagnosis. In France and Luxembourg the local physician will confirm the diagnosis. In Germany the final diagnosis will be taken from the hospital records as soon as it is available.

Community Controls

In Germany and Luxembourg community controls will also be included.

In Germany community controls will be identified via a sampling modification of random digit dialling (rural areas) or using information from the town registries (urban areas).

For random digit dialling a simple random sample of private numbers (=households) from all telephone books of the study area will be used to form the primary units. Within these units controls persons are selected as secondary units.

For selecting controls from the town registries a method of double phase sampling is used. In the first phase an overall sample of persons in all

towns is taken; in the second phase the sample of control persons is chosen.

To control the matching criteria (sex, age and region) both samples are designed using a stratified sampling scheme with a quota plan to fit the frequencies of the matching variables.

In Luxembourg the selection will take place using a population list from the local authorities. Individual matching will be carried out (5 years age groups and same sex). The controls will be identified randomly on this list. The detailed method of selection has not been worked out.

Questionnaire

1. There will be a "core" questionnaire including items such as residential history since birth, occupational history, smoking history, and exposure to passive smoke (for non-smokers and occasional smokers only). As far as possible this "core" section of the questionnaire will be identical in all four countries, and the code generated from these core questions will be identical.

2. In addition each country will include some questions on educational attainment and current occupation of the subject and his/her current partner (or last partner in the case of widows/widowers) to allow classification of social status into high (i.e. professional), middle (i.e. intermediate), low (i.e. manual). If the subject and his/her partner would be classified differently then the subject will always be assigned to the higher of the two.

3. Each country is also free to include additional items in its own questionnaire.

Radon Measurements

1. For each subject (case or control) included in the study an attempt will be made to measure the radon concentration in each home in the study area where the subject has lived for more than 1 year during the last 35 years. (In Belgium if 1 extra measurement will give a lifetime exposure, an attempt will be made to get it).

2. Detectors will be of the Karlsruhe or LR-115 type. In each house that is measured two detectors will be placed, one in the living room and one in the subject's bedroom (major bedroom for past houses).

3. The period of measurement will be six months in all centres except Germany where it will be 2 consecutive six month periods. Where the period of measurement is only six months, seasonal adjustments will be estimated from the study data e.g. by assuming that the true radon concentration in houses measured at different times of the year is the same.

4. The comparability of the detectors and associated procedures used by the different centres will be investigated by intercomparisons carried out both in the laboratory and in the field.

5. For periods of residence outside the study area but within the last 35 years an attempt will be made to measure the likely exposure to radon. In cases where measurement is not feasible, the possibility of estimation will be reviewed later.

Additional Data

In all centres some basic data will be recorded on potential cases who live in the study area, but who do not meet the criterion of having lived there for at least 25 years in the last 35 years or who die before they can be interviewed, and also on potential cases and controls who refuse to take part in the study, or who are too ill to be interviewed or who are not interviewed for any other reason. The data will include the reason that no interview was obtained, the date that an attempt was made to carry out the interview, and the patient's sex, age, current address, and final diagnosis. These items are necessary to calculate the refusal rate in the study, and also to demonstrate good coverage of the numbers of lung cancers occurring in the study area during the time period of the study e.g. by comparison with official mortality or cancer registration data. In addition for each such person the total number of years lived in the study area will be collected wherever possible.

Pooling of data

Each centre will submit data periodically to the co-ordinator in Gent for validation and consolidation into a single database before transfer to Wuppertal for analysis. It is intended that submissions should occur approximately every six months, approximately 1 month before each meeting of the collaborators, so that the co-ordinator can present some tabulations of the accumulating data to the group for discussion.

GRADING RELIABILITY OF LUNG CANCER DIAGNOSIS

Grade		Criteria
1	a)	Biopsy of primary tumour confirms.
	b)	Cytology from lung/pleura, PLUS operative, bronchoscopic or X-ray examination of the primary (i.e. lung) confirms.
	c)	Biopsy of a secondary, plus operative, bronchoscopic or X-ray examination of the primary (i.e. lung) confirms.
	d)	Autopsy confirmation.
2	a)	Cytology only confirms.
	b)	Operative, bronchoscopic or X-ray examination of lung the only evidence.
3	a)	Case history and physical examination the only evidence.
	b)	Death certificate the only evidence.

Adapted from: Council for the Organisation of Medical Sciences Paris (1953): Cancer of the Lung (epidemiology).

Appendix B
Last revised 31 October 1990

LIST OF INELIGIBLE DISEASES FOR HOSPITAL CONTROLS

1. Patients whose current admission is for a specific disease EITHER strongly related to smoking OR with a prognosis comparable with or worse than that of lung cancer.

   i) Coronary heart disease (SYN myocardial infarction, angina, ventricular fibrillation, congestive cardiac failure, left ventricular failure).

   ii) Chronic bronchitis or emphysema (SYN chronic obstructive airways disease-COAD, chronic obstructive lung disease-COLD, acute on chronic bronchitis. Also the complication cor pulmonale).

   iii) Peripheral vascular disease.

   iv) Aortic aneurysm (any type) including aortofemural atherosclerosis (precursor condition for aortic aneurysm).

   v) Stroke (SYN cerebrovascular accident-CVA, cerebral infarct, cerebral haemorrhage).

   vi) Peptic ulcer (duodenal ulcer or gastric ulcer).

   vii) Cancer of: lip, mouth (tongue, gum, inside of cheek),
   pharynx and larynx
   stomach
   pancreas
   kidney
   bladder

   viii) Patients whose current admission is for a chest infection will also be excluded because of the difficulty of deciding whether or not this is a consequence of chronic bronchitis.

   NB: It does not matter if hospital controls have one of the diseases on the list, provided their current admission is not for an ineligible disease.

2. Patients who are unlikely to give a satisfactory history or who may fail to comply with the measurement procedure.

   i) A history of psychosis (mania, manic depression, endogenous depression, schizophrenia).

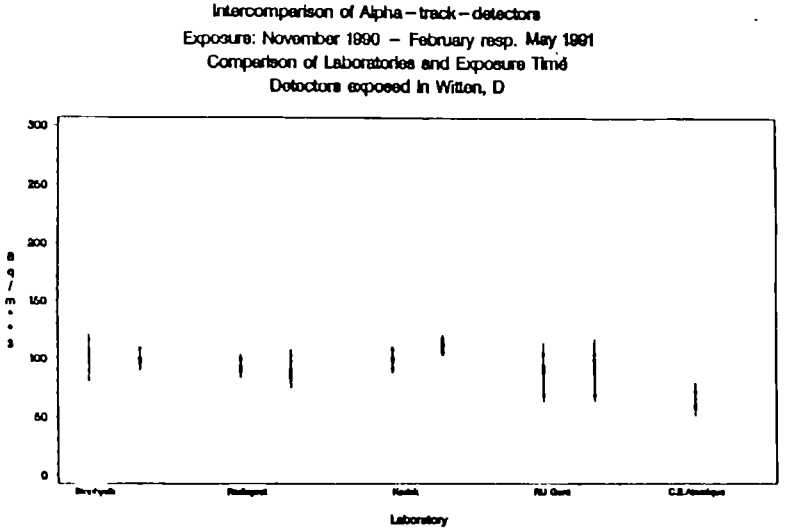
   ii) A history of dementia (senile or presenile dementia, Alzheimer's disease, arteriosclerotic dementia, Huntington's chorea).

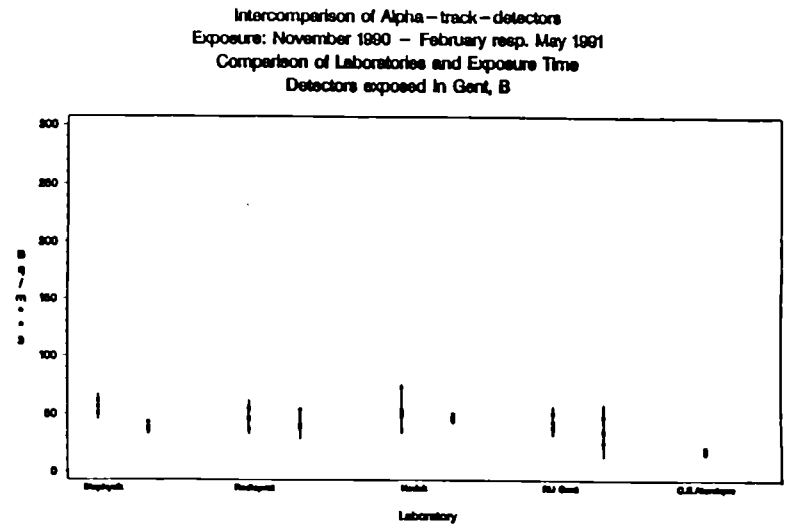
   Patients in the above two categories will largely be excluded by omitting psychiatric and geriatric wards from the sampling frame.

iii) Patients who are profoundly deaf or who have great difficulty in speaking.

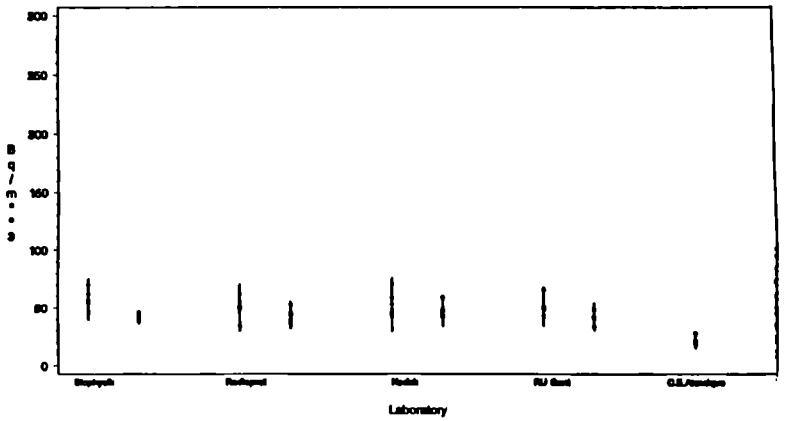
iv) Patients who are thought to be too ill to be interviewed (these may be reconsidered later if their condition improves).

Appendix II

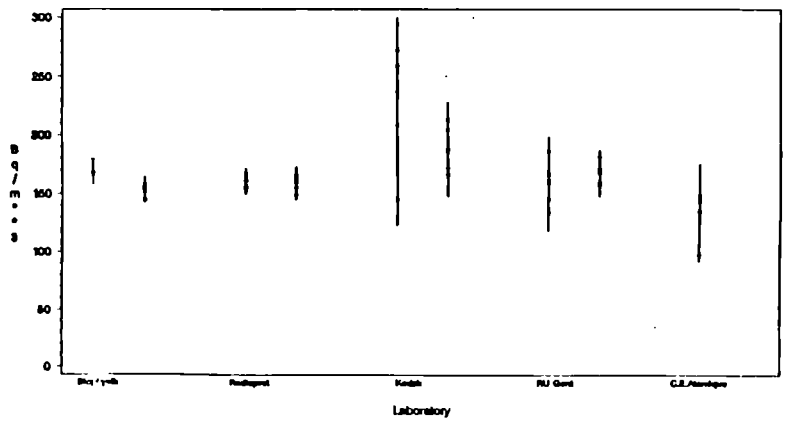


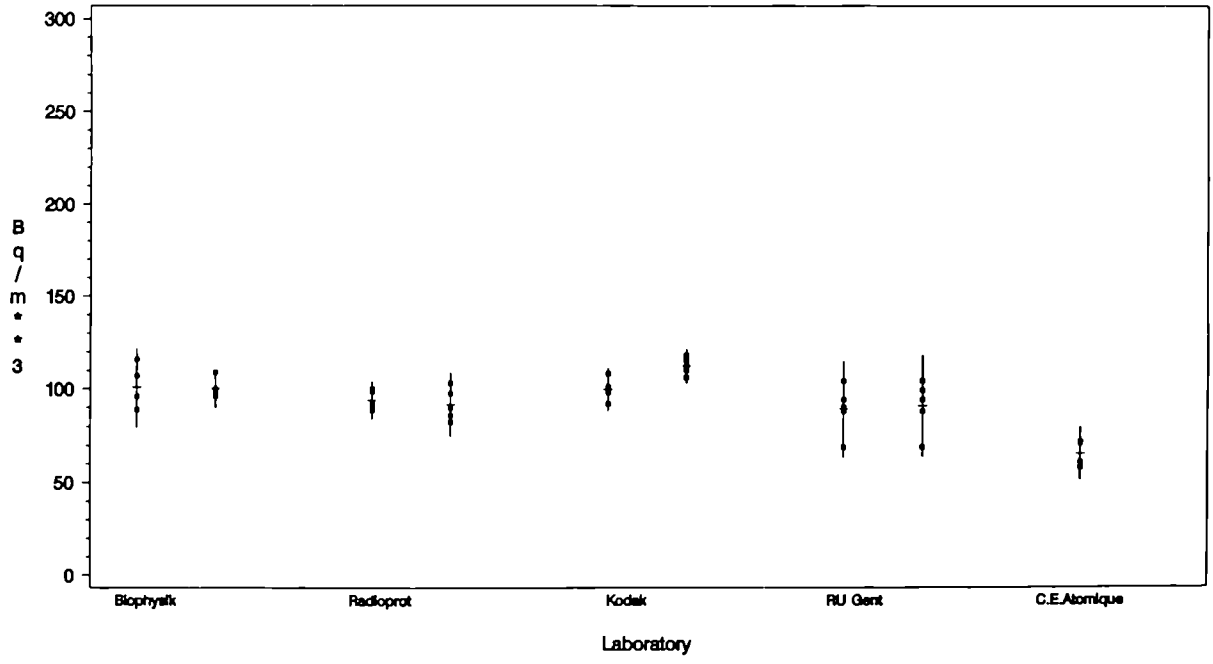


Lung Cancer and Radon in the Ardennes and Eifel Region
Intercomparison of Alpha-track-detectors
Exposure: November 1990 - February resp. May 1991
Comparison of Laboratories and Exposure Time
Detectors exposed in Paris, F



Lung Cancer and Radon in the Ardennes and Eifel Region
Intercomparison of Alpha-track-detectors
Exposure: November 1990 - February resp. May 1991
Comparison of Laboratories and Exposure Time
Detectors exposed in Luxemburg





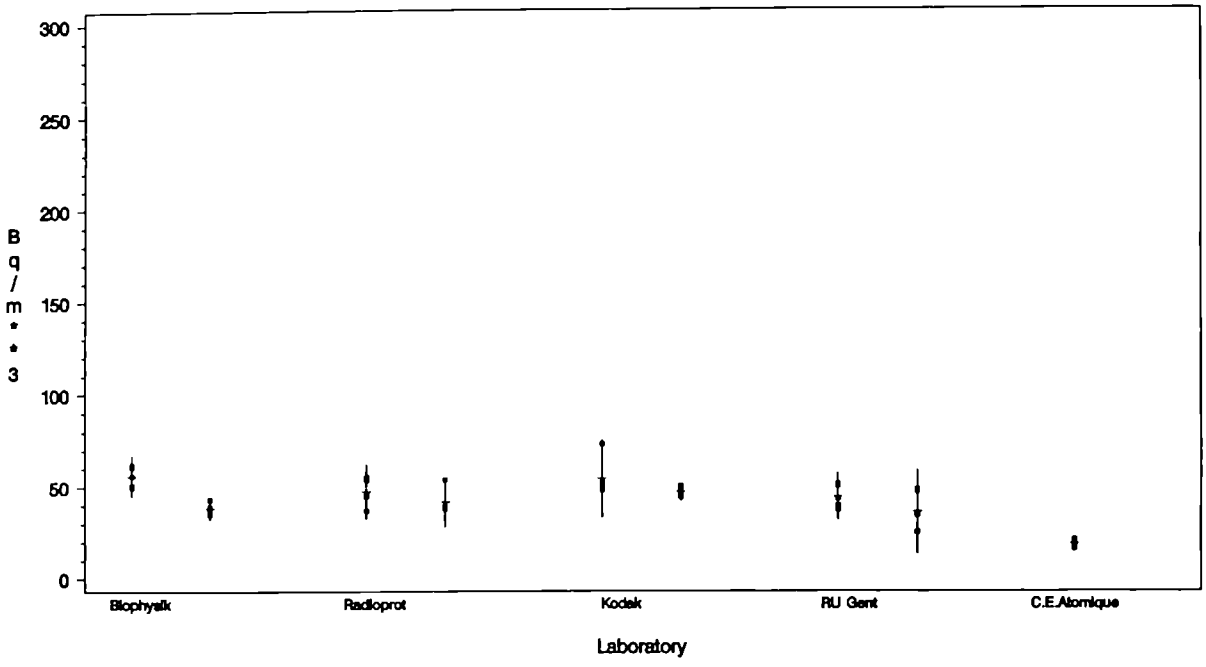
eg_ring2.sas: Figure 1

Lung Cancer and Radon in the Ardennes and Eifel Region
Intercomparison of Alpha – track – detectors
Exposure: November 1990 – February resp. May 1991
Comparison of Laboratories and Exposure Time
Detectors exposed in Witten, D

EG-Ringversuch mit alpha-Spur-Dedektoren
Mittelwertvergleich der Aufstellorte nach Expositionszeit und Labor

Aufstellort=Witten, D, Analysis Variable : BQ Bq/m**3

N	Mean	Std Dev	CV
LABOR=Biophy Expositionszeit in Monaten=3			
5	100.8	10.7	10.6
LABOR=Biophy Expositionszeit in Monaten=6			
5	100.2	5.2	5.2
LABOR=Radprot Expositionszeit in Monaten=3			
5	94.0	5.0	5.4
LABOR=Radprot Expositionszeit in Monaten=6			
5	91.6	8.4	9.2
LABOR=Kodak Expositionszeit in Monaten=3			
5	99.6	5.8	5.8
LABOR=Kodak Expositionszeit in Monaten=6			
5	112.2	4.6	4.1
LABOR=RU Gent Expositionszeit in Monaten=3			
5	89.0	12.8	14.3
LABOR=RU Gent Expositionszeit in Monaten=6			
5	90.8	13.6	14.9
LABOR=CEA Expositionszeit in Monaten=3			
4	65.5	7.0	10.8



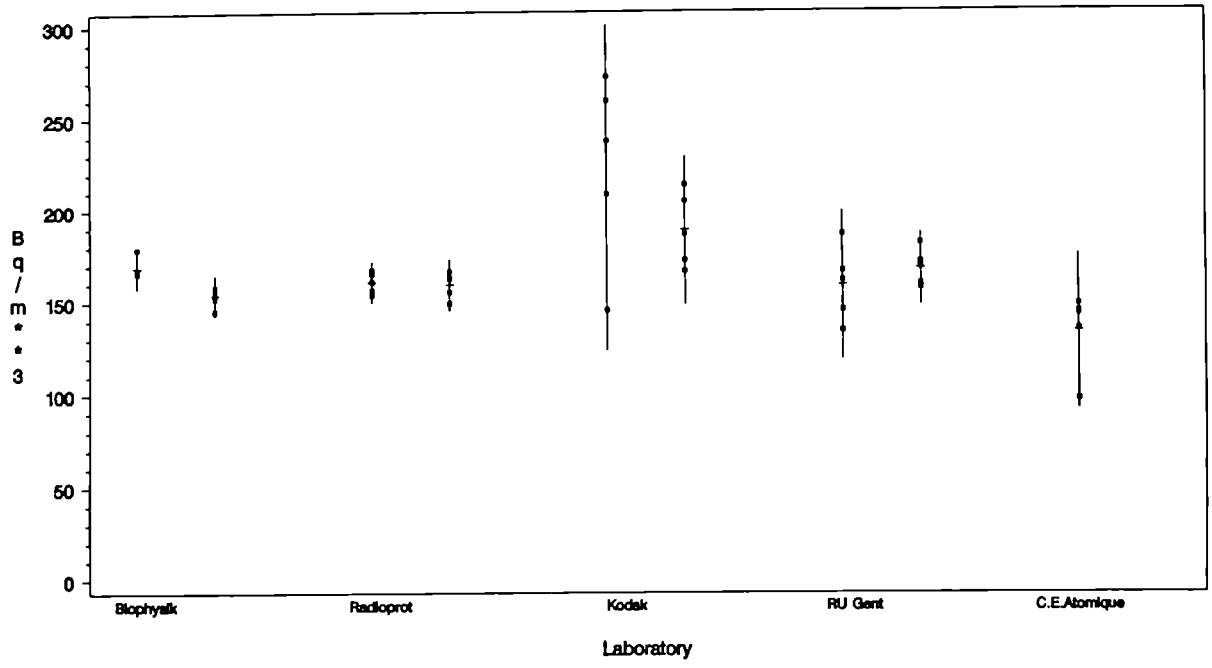
eg_rng2.sas: Figure 3

Lung Cancer and Radon in the Ardennes and Eifel Region
Intercomparison of Alpha – track – detectors
Exposure: November 1990 – February resp. May 1991
Comparison of Laboratories and Exposure Time
Detectors exposed in Gent, B

EG-Ringversuch mit alpha-Spur-Dedektoren
Mittelwertvergleich der Aufstellorte nach Expositionszeit und Labor

Aufstellort=Gent, B, Analysis Variable : BQ Bq/m**3

N	Mean	Std Dev	CV
LABOR=Biophy Expositionszeit in Monaten=3			
5	56.0	5.5	9.9
LABOR=Biophy Expositionszeit in Monaten=6			
5	38.2	3.0	7.9
LABOR=Radprot Expositionszeit in Monaten=3			
5	47.3	7.4	15.6
LABOR=Radprot Expositionszeit in Monaten=6			
5	41.5	6.7	16.3
LABOR=Kodak Expositionszeit in Monaten=3			
5	54.2	10.6	19.6
LABOR=Kodak Expositionszeit in Monaten=6			
5	46.6	2.4	5.2
LABOR=RU Gent Expositionszeit in Monaten=3			
5	44.0	6.3	14.4
LABOR=RU Gent Expositionszeit in Monaten=6			
5	35.8	11.3	31.6
LABOR=CEA Expositionszeit in Monaten=3			
5	18.6	2.1	11.1



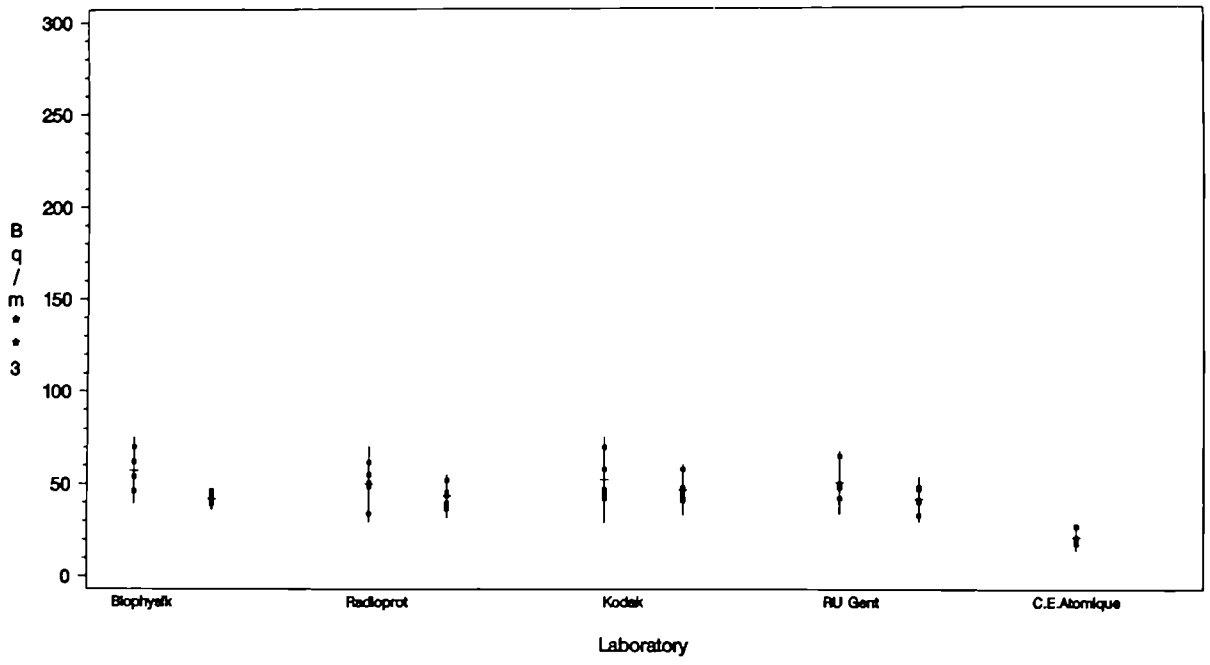
eg_ring2.sas: Figure 2

Lung Cancer and Radon in the Ardennes and Eifel Region
Intercomparison of Alpha-track-detectors
Exposure: November 1990 - February resp. May 1991
Comparison of Laboratories and Exposure Time
Detectors exposed in Luxemburg

SG-Ringversuch mit alpha-Spur-Dedektoren
Mittelwertvergleich der Aufstellorte nach Expositionszeit und Labor

Aufstellort=Luxemburg, LUX, Analysis Variable : BQ Bq/m**3

N	Mean	Std Dev	CV
LABOR=Biophy Expositionszeit in Monaten=3			
5	169.0	5.6	3.3
LABOR=Biophy Expositionszeit in Monaten=6			
5	153.8	5.5	3.6
LABOR=Radprot Expositionszeit in Monaten=3			
5	160.5	5.6	3.5
LABOR=Radprot Expositionszeit in Monaten=6			
5	159.0	7.0	4.4
LABOR=Kodak Expositionszeit in Monaten=3			
5	224.2	50.5	22.5
LABOR=Kodak Expositionszeit in Monaten=6			
5	188.2	20.2	10.7
LABOR=RU Gent Expositionszeit in Monaten=3			
5	158.4	20.0	12.6
LABOR=RU Gent Expositionszeit in Monaten=6			
5	167.2	9.7	5.8
LABOR=CEA Expositionszeit in Monaten=3			
5	133.4	20.9	15.7



eg_ring2.sas: Figure 4

Lung Cancer and Radon in the Ardennes and Eifel Region
Intercomparison of Alpha – track – detectors
Exposure: November 1990 – February resp. May 1991
Comparison of Laboratories and Exposure Time
Detectors exposed in Paris, F

Jmwelt und Gesundheit - eg_ring1.sas 19:53 Tuesday, July 14, 19
EG-Ringversuch mit alpha-Spur-Dedektoren
Mittelwertvergleich der Aufstellorte nach Expositionszeit und Labor

Aufstellort=Paris, F Analysis Variable : BQ Bq/m**3

N	Mean	Std Dev	CV
LABOR=Biophy Expositionszeit in Monaten=3			
5	57.2	9.1	15.9
LABOR=Biophy Expositionszeit in Monaten=6			
5	41.6	3.0	7.1
LABOR=Radprot Expositionszeit in Monaten=3			
5	49.8	10.3	20.7
LABOR=Radprot Expositionszeit in Monaten=6			
5	43.4	5.9	13.6
LABOR=Kodak Expositionszeit in Monaten=3			
5	52.2	11.7	22.4
LABOR=Kodak Expositionszeit in Monaten=6			
5	46.8	6.8	14.6
LABOR=RU Gent Expositionszeit in Monaten=3			
5	50.6	8.6	17.0
LABOR=RU Gent Expositionszeit in Monaten=6			
5	41.8	6.1	14.5
LABOR=CEA Expositionszeit in Monaten=3			
5	21.2	3.5	16.5

2

Table 1 : Nuclear installations included in the study

Name of installation, type of activity*, name of company	Type of installation +	Name of the reactors	Date of first operation
Chinon, PE, EDF	GGR	Chinon A1-3	16-09-62
Chooz, PE, EDF	PWR	Chooz A1	18-10-66
La Hague, R, COGEMA	Reprocessing	La Hague	1968
Marcoule, PE+R,	GGR + FBR	Marcoule G1-3	09-56
COGEMA	Reprocessing	Phénix	
St Laurent, PE, EDF	GGR	St Laurent A1-2	07-01-69
St Vulbas, PE, EDF	GGR	Bugey 1	07-12-71

* PE : Production of electricity
R : Reprocessing
EDF : Electricité de France,
\+ PWR : Pressurised Water Reactor
GGR : Graphite-Gaz Reactor
FBR : Fast Breeder Reactor

Sources : two anonymous documents from Commissariat à l'Energie Atomique.

Table 2: French population at census (PC) and population on January 1 (PJ)

Sex	Year	Age 0-4	5-9	10-14	15-19	20-24
Males						
PJ	1968	2 166 950	2 119 613	2 095 934	2 174 178	1 814 075
PC	1968	1 772 140	2 136 008	2 103 636	2 146 908	1 934 952
PJ	1975	2 134 751	2 141 754	2 192 937	2 153 793	2 167 570
PC	1975	1 752 645	2 138 455	2 196 590	2 162 380	2 127 530
PJ	1982	1 917 758	2 029 982	2 185 514	2 221 497	2 132 195
PC	1982	1 605 824	1 952 904	2 196 596	2 224 932	2 141 600
Females						
PJ	1968	2 079 115	2 040 697	2 021 547	2 090 862	1 719 705
PC	1968	1 699 284	2 055 024	2 024 858	2 070 432	1 850 840
PJ	1975	2 035 533	2 048 409	2 102 316	2 078 572	2 092 594
PC	1975	1 671 565	2 047 490	2 102 675	2 079 875	2 083 655
PJ	1982	1 825 664	1 936 974	2 070 334	2 139 251	2 105 642
PC	1982	1 531 460	1 862 272	2 087 972	2 132 820	2 115 652

From INSEE 1977, 1985.

Table 3 : French population on January 1

Sex	Year	Age 0-4	5-9	10-14	15-19	20-24
Males						
	1982	1917758	2029982	2185544	2221497	2132195
	1983	1944731	1963665	2203536	2220748	2130046
	1984	1948758	1903705	2212086	2203359	2142652
	1985	1948107	1882746	2188687	2184511	2153734
	1986	1929653	1909901	2131765	2175039	2164522
	1987	1916699	1950336	2049556	2182768	2165171
	1988	1902623	1974578	1981240	2198673	2162997
	1989	1911543	1977246	1920227	2206393	2145928
Females						
	1982	1825664	1936974	2070334	2139251	2105642
	1983	1851144	1872757	2088260	2133614	2107436
	1984	1856653	1814397	2096433	2111740	2124163
	1985	1857599	1793347	2074050	2090023	2134535
	1986	1840215	1818063	2021761	2080184	2138780
	1987	1826939	1855238	1942905	2086571	2133752
	1988	1814047	1878074	1877019	2102235	2124183
	1989	1823343	1881524	1817759	2109254	2099679

From INSEE 1985, 1986, 1987, 1988,1989.

Table 4 : Causes of deaths included in the analysis

Cause of death	ICD8	ICD9
Overall mortality		
All malignant tumors	140-207	140-208
Malignant brain tumor	191	191
Brain tumor of unspecified type	238.1	239.6
Lung cancer	162	162
Hodgkin's disease	201	201
Non Hodgkin lymphoma	200+202	200+202
Myelomas	203	203
Leukaemia	204-207	204-208
Lymphoid leukaemia	204	204

Table 5 : Observed (O) and expected (E) number of deaths, and Standardised mortality ratio (SMR) in exposed communes *

Cause of death	O	E	SMR (%)
Overall mortality	3 064	3 093.7	99
All malignant tumors	166	171.7	97
Malignant brain tumor	6	14.5	41
Brain tumor of unspecified type	16	14.1	113
Lung cancer	2	2.1	94
Hodgkin's disease	12	6.1	197
Non Hodgkin lymphoma	16	15.5	103
Myeloma	0	0.3	0
Leukaemia	58	66.9	87
Lymphoid leukaemia	13	19.0	68
Person-years (in thousands)	2 892		

* All SMR's are not statistically different from 1

Table 6 : Observed (O) and expected (E) number of deaths, and Standardised mortality ratio (SMR) in exposed and control communes

Cause of death	Exposed		Control		RR
	O	SMR (%)	O	SMR (%)	
Overall mortality	3 064	99	2 828	102	0.97
All malignant tumors	166	97	160	102	0.95
Malignant brain tumor	6	41	13	97	0.42
Brain tumor of unspecified type	16	113	15	114	1.00
Lung cancer	2	94	5	258	0.36
Hodgkin's disease	12	197	5	89	2.22
Non Hodgkin lymphoma	16	103	9	63	1.63
Myeloma	0	0	0	0	-
Leukaemia	58	87	62	101	0.86
Lymphoid leukaemia	13	68	14	80	0.85
Person-years (in thousands)	2 892		2 658		

* SMR's in exposed and control communes are not statistically different for each cause of death considered

Table 7.1 : Overall mortality

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	1946	1974	99
Females	1 406	1118	1120	100
Age				
0- 4	583	1443	1636	88
5- 9	588	178	197	90
10-14	613	180	181	99
15-19	589	512	470	109
20-24	519	751	609	123
Type of installation				
Reprocessing	1 576	1687	1712	99
Other	1 316	1377	1382	100
Distance (km)				
< 5	260	259	280	92
5- 9.9	982	1149	1049	110
10-12.9	373	366	381	96
13-15.9	748	771	781	99
16-21	530	519	603	86
Total	2 892	3064	3094	99

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.2 : Mortality from malignant tumors

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	96	102.5	94
Females	1 406	70	69.2	101
Age				
0- 4	583	38	35.5	107
5- 9	588	25	33.8	74
10-14	613	22	28.4	78
15-19	589	36	36.1	100
20-24	519	45	37.9	119
Type of installation				
Reprocessing	1 576	90	94.4	95
Other	1 316	76	77.3	98
Distance (km)				
< 5	260	11	15.4	71
5- 9.9	982	61	58.3	105
10-12.9	373	16	21.8	74
13-15.9	748	51	44.2	115
16-21	530	27	32.0	84
Total	2 892	166	171.7	97

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.3 : Mortality from malignant brain tumor

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	3	8.3	36
Females	1 406	3	6.2	48
Age				
0- 4	583	0	2.7	0
5- 9	588	2	3.5	57
10-14	613	2	2.9	69
15-19	589	1	2.8	36
20-24	519	1	2.7	37
Type of installation				
Reprocessing	1 576	3	7.8	38
Other	1 316	3	6.7	45
Distance (km)				
< 5	260	0	1.3	0
5- 9.9	982	2	4.9	41
10-12.9	373	2	1.9	105
13-15.9	748	2	3.8	53
16-21	530	0	2.6	0
Total	2 892	6	14.5	41

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.4 : Mortality from brain tumor of unspecified type

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	8	8.0	101
Females	1 406	8	6.2	130
Age				
0- 4	583	6	0.0	-
5- 9	588	2	1.3	157
10-14	613	2	5.5	37
15-19	589	3	4.0	75
20-24	519	3	3.4	89
Type of installation				
Reprocessing	1 576	8	7.8	102
Other	1 316	8	6.3	127
Distance (km)				
< 5	260	2	1.3	159
5- 9.9	982	4	4.8	83
10-12.9	373	0	1.8	0
13-15.9	748	6	3.7	164
16-21	530	4	2.6	154
Total	2 892	16	14.1	113

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.5 : Lung cancer mortality

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	2	1.4	139
Females	1 406	0	0.7	0
Age				
0- 4	583	0	0.5	0
5- 9	588	0	0.3	0
10-14	613	0	0.2	0
15-19	589	0	0.4	0
20-24	519	2	0.7	277
Type of installation				
Reprocessing	1 576	0	1.2	0
Other	1 316	2	0.9	222
Distance (km)				
- < 5	260	1	0.2	525
5- 9.9	982	0	0.7	0
10-12.9	373	0	0.3	0
13-15.9	748	1	0.5	186
16-21	530	0	0.4	0
Total	2 892	2	2.1	94

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.6 : Hodgkin's disease mortality

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	7	3.8	186
Females	1 406	5	2.3	215
Age				
0- 4	583	0	0.1	0
5- 9	588	0	0.3	0
10-14	613	2	0.5	427
15-19	589	3	1.7	175
20-24	519	7	3.5	202
Type of installation				
Reprocessing	1 576	10	3.5	287
Other	1 316	2	2.6	77
Distance (km)				
- < 5	260	0	0.5	0
5- 9.9	982	7	2.1	338
10-12.9	373	1	0.7	139
13-15.9	748	2	1.5	131
16-21	530	2	1.2	162
Total	2 892	12	6.1	197

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.7 : Mortality from non Hodgkin lymphoma

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	10	10.8	92
Females	1 406	6	4.7	128
Age				
0- 4	583	5	2.8	178
5- 9	588	2	3.1	64
10-14	613	3	2.8	109
15-19	589	2	3.4	58
20-24	519	4	3.4	119
Type of installation				
Reprocessing	1 576	6	8.5	71
Other	1 316	10	7.0	143
Distance (km)				
- < 5	260	0	1.4	0
5- 9.9	982	6	5.3	114
10-12.9	373	4	2.0	203
13-15.9	748	4	4.0	100
16-21	530	2	2.9	70
Total	2 892	16	15.5	103

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.8 : Leukaemia mortality

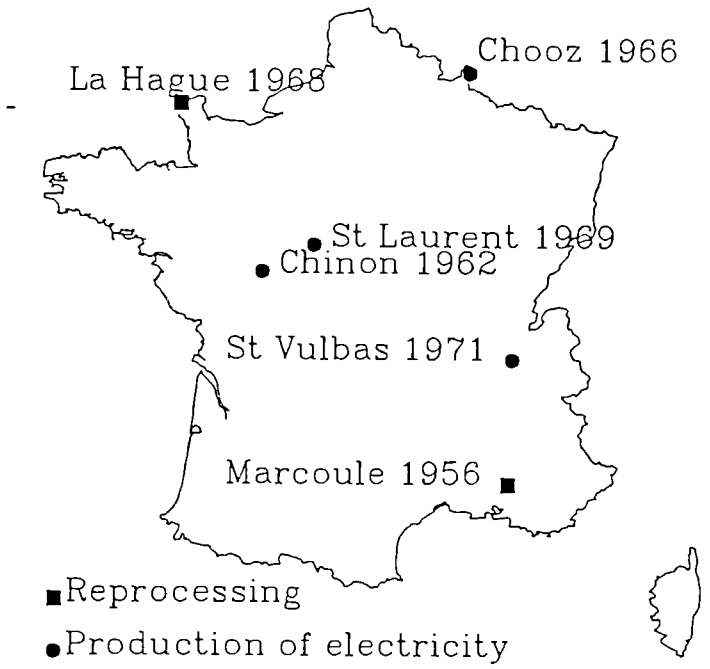
Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	34	39.6	86
Females	1 406	24	27.4	88
Age				
0- 4	583	13	13.9	93
5- 9	588	12	17.5	69
10-14	613	7	13.6	52
15-19	589	16	12.4	129
20-24	519	10	9.6	105
Type of installation				
Reprocessing	1 576	30	36.7	82
Other	1 316	28	30.2	93
Distance (km)				
- < 5	260	5	6.1	82
5- 9.9	982	21	22.7	93
10-12.9	373	4	8.5	47
13-15.9	748	17	17.3	98
16-21	530	11	12.3	90
Total	2 892	58	66.9	87

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio

Table 7.9 : Lymphoid leukaemia mortality

Characteristics	Person-years in thousands	O	E	SMR (%)
Sex				
Males	1 486	11	11.8	94
Females	1 406	2	7.2	28
Age				
0- 4	583	1	3.5	29
5- 9	588	1	5.8	17
10-14	613	4	4.2	94
15-19	589	4	3.3	122
20-24	519	3	2.2	136
Type of installation				
Reprocessing	1 576	7	10.2	69
Other	1 316	6	8.8	68
Distance (km)				
- < 5	260	2	1.7	117
5- 9.9	982	5	6.4	78
10-12.9	373	0	2.5	0
13-15.9	748	2	5.0	40
16-21	530	4	3.4	119
Total	2 892	13	19.0	68

O : observed number of deaths, E : expected number of deaths
SMR (%) = 100 * O/E : Standardised mortality ratio



La Hague: reprocessing, Marcoule: reprocessing and reactors
Chooz: PWRs, other sites: Graphite Gaz and later PWRs

Nuclear sites and year of first operation

Overall mortality

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	185	241.39	77	156	193.78	81	0.95
	5-9	30	30.07	100	24	26.34	91	1.10
	10-14	30	27.19	110	28	25.19	111	0.99
	15-19	70	66.99	105	88	65.99	133	0.78
	20-24	99	85.91	115	94	82.91	113	1.02
	Total	414	451.55	92	390	394.21	99	0.93
Chinon								
	<5	175	197.93	88	171	218.05	78	1.13
	5-9	31	24.66	126	29	28.51	102	1.24
	10-14	35	23.73	148	29	27.75	104	1.41
	15-19	78	62.64	125	79	70.52	112	1.11
	20-24	82	73.90	111	92	76.31	121	0.92
	Total	401	382.86	105	400	421.13	95	1.10
Chooz								
	<5	138	131.62	105	148	129.72	114	0.92
	5-9	20	15.81	127	14	16.42	85	1.48
	10-14	17	15.10	113	10	15.52	64	1.75
	15-19	31	38.64	80	36	39.98	90	0.89
	20-24	44	47.39	93	42	47.62	88	1.05
	Total	250	248.56	101	250	249.26	100	1.00
La Hague								
	<5	349	389.82	90	275	290.24	95	0.94
	5-9	28	42.33	66	28	31.32	89	0.74
	10-14	24	37.47	64	27	28.11	96	0.67
	15-19	77	101.88	76	71	76.66	93	0.82
	20-24	129	146.96	88	95	107.21	89	0.99
	Total	607	718.46	84	496	533.54	93	0.91
Marcoule								
	<5	455	513.47	89	417	436.50	96	0.93
	5-9	56	64.23	87	56	55.47	101	0.86
	10-14	53	60.42	88	64	54.31	118	0.74
	15-19	207	156.05	133	187	144.39	130	1.02
	20-24	309	199.69	155	238	179.52	133	1.17
	Total	1080	993.85	109	962	870.20	111	0.98
Saint Laurent								
	<5	141	161.73	87	146	153.57	95	0.92
	5-9	13	20.03	65	15	19.89	75	0.86
	10-14	21	17.54	120	26	18.92	137	0.87
	15-19	49	43.57	112	64	52.49	122	0.92
	20-24	88	55.56	158	79	58.95	134	1.18
	Total	312	298.42	105	330	303.82	109	0.96
All centers								
	<5	1443	1635.95	88	1313	1421.85	92	0.96
	5-9	178	197.12	90	166	177.95	93	0.97
	10-14	180	181.45	99	184	169.81	108	0.92
	15-19	512	469.77	109	525	450.03	117	0.93
	20-24	751	609.41	123	640	552.52	116	1.06
	Total	3064	3093.70	99	2828	2772.16	102	0.97

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Overall mortality

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	12	11.00	109	7	6.91	101	1.08
	5-9.9	140	139.07	101	114	121.18	94	1.07
	10-12.9	97	128.59	75	105	104.80	100	0.75
	13-15.9	165	172.89	95	164	161.32	102	0.94
	Total	414	451.55	92	390	394.21	99	0.93
Chinon								
	<5	70	72.45	97	91	77.09	118	0.82
	5-9.9	200	181.23	110	162	209.44	77	1.43
	10-12.9	53	48.22	110	56	48.60	115	0.95
	13-15.9	78	80.97	96	91	86.00	106	0.91
	Total	401	382.86	105	400	421.13	95	1.10
Chooz								
	<5	100	118.84	84	127	112.96	112	0.75
	5-9.9	52	45.24	115	47	47.63	99	1.16
	10-12.9	29	20.67	140	15	25.98	58	2.43
	13-15.9	69	63.81	108	61	62.68	97	1.11
	Total	250	248.56	101	250	249.26	100	1.00
La Hague								
	<5	21	23.62	89	11	15.93	69	1.29
	5-9.9	12	13.86	87	7	10.29	68	1.27
	10-12.9	16	23.05	69	23	13.79	167	0.42
	13-15.9	39	55.10	71	50	43.28	116	0.61
	16-21	519	602.81	86	405	450.25	90	0.96
	Total	607	718.46	84	496	533.54	93	0.91
Marcoule								
	<5	19	19.58	97	23	16.44	140	0.69
	5-9.9	578	522.90	111	483	413.69	117	0.95
	10-12.9	135	121.88	111	134	128.02	105	1.06
	13-15.9	348	329.50	106	322	312.04	103	1.02
	Total	1080	993.85	109	962	870.20	111	0.98
Saint Laurent								
	<5	37	34.87	106	24	28.29	85	1.25
	5-9.9	167	146.32	114	144	147.85	97	1.17
	10-12.9	36	38.46	94	46	37.12	124	0.76
	13-15.9	72	78.78	91	116	90.57	128	0.71
	Total	312	298.42	105	330	303.82	109	0.96
All centers								
	<5	259	280.36	92	283	257.62	110	0.84
	5-9.9	1149	1048.62	110	957	950.08	101	1.09
	10-12.9	366	380.86	96	379	358.32	106	0.91
	13-15.9	771	781.05	99	804	755.90	106	0.93
	16-21	519	602.81	86	405	450.25	90	0.96
	Total	3064	3093.70	99	2828	2772.16	102	0.97

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	4	5.47	73	4	4.39	91	0.80
	5-9	9	5.31	169	2	4.66	43	3.95
	10-14	4	4.35	92	6	4.02	149	0.62
	15-19	1	5.15	19	8	5.06	158	0.12
	20-24	4	5.20	77	6	5.01	120	0.64
	Total	22	25.48	86	26	23.14	112	0.77
Chinon								
	<5	6	4.24	142	4	4.70	85	1.66
	5-9	5	4.20	119	2	4.88	41	2.91
	10-14	3	3.69	81	4	4.33	92	0.88
	15-19	4	4.81	83	7	5.43	129	0.65
	20-24	7	4.58	153	8	4.75	168	0.91
	Total	25	21.51	116	25	24.10	104	1.12
Chooz								
	<5	2	2.81	71	0	2.77	0	-
	5-9	3	2.68	112	1	2.79	36	3.12
	10-14	1	2.34	43	2	2.41	83	0.52
	15-19	3	2.98	101	3	3.09	97	1.04
	20-24	4	2.96	135	2	2.97	67	2.00
	Total	13	13.78	94	8	14.03	57	1.66
La Hague								
	<5	10	8.38	119	3	6.28	48	2.50
	5-9	3	7.22	42	8	5.36	149	0.28
	10-14	5	5.82	86	5	4.37	114	0.75
	15-19	7	7.85	89	5	5.96	84	1.06
	20-24	6	9.31	64	5	6.91	72	0.89
	Total	31	38.58	80	26	28.88	90	0.89
Marcoule								
	<5	10	11.04	91	14	9.40	149	0.61
	5-9	4	10.94	37	9	9.49	95	0.39
	10-14	6	9.41	64	9	8.47	106	0.60
	15-19	18	12.02	150	8	11.15	72	2.09
	20-24	21	12.40	169	14	11.27	124	1.36
	Total	59	55.82	106	54	49.77	108	0.97
Saint Laurent								
	<5	6	3.52	171	5	3.33	150	1.14
	5-9	1	3.46	29	0	3.42	0	-
	10-14	3	2.75	109	0	2.95	0	-
	15-19	3	3.33	90	8	3.98	201	0.45
	20-24	3	3.46	87	8	3.63	220	0.39
	Total	16	16.52	97	21	17.31	121	0.80
All centers								
	<5	38	35.46	107	30	30.87	97	1.10
	5-9	25	33.82	74	22	30.60	72	1.03
	10-14	22	28.36	78	26	26.56	98	0.79
	15-19	36	36.14	100	39	34.66	113	0.89
	20-24	45	37.92	119	43	34.54	124	0.95
	Total	166	171.70	97	160	157.24	102	0.95

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR ratio of SMRs in exposed and control communes

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.62	0	0	0.40	0	-
	5-9.9	6	7.71	78	8	7.24	110	0.70
	10-12.9	7	7.34	95	11	6.19	178	0.54
	13-15.9	9	9.81	92	7	9.31	75	1.22
	Total	22	25.48	86	26	23.14	112	0.77
Chinon								
	<5	5	4.01	125	7	4.36	161	0.78
	5-9.9	16	10.16	158	8	12.09	66	2.38
	10-12.9	0	2.74	0	5	2.76	181	0.00
	13-15.9	4	4.60	87	5	4.88	102	0.85
	Total	25	21.51	116	25	24.10	104	1.12
Chooz								
	<5	2	6.54	31	4	6.27	64	0.48
	5-9.9	5	2.59	193	2	2.76	73	2.66
	10-12.9	1	1.16	87	1	1.52	66	1.32
	13-15.9	5	3.49	143	1	3.48	29	4.98
	Total	13	13.78	94	8	14.03	57	1.66
La Hague								
	<5	1	1.24	81	0	0.90	0	-
	5-9.9	1	0.77	130	0	0.57	0	-
	10-12.9	0	1.28	0	1	0.77	130	0.00
	13-15.9	2	3.26	61	4	2.40	167	0.37
	16-21	27	32.03	84	21	24.25	87	0.97
	Total	31	38.58	80	26	28.88	90	0.89
Marcoule								
	<5	2	1.13	178	1	0.94	107	1.66
	5-9.9	24	29.00	83	29	23.47	124	0.67
	10-12.9	5	7.05	71	5	7.49	67	1.06
	13-15.9	28	18.65	150	19	17.87	106	1.41
	Total	59	55.82	106	54	49.77	108	0.97
Saint Laurent								
	<5	1	1.89	53	3	1.59	188	0.28
	5-9.9	9	8.04	112	9	8.49	106	1.06
	10-12.9	3	2.18	137	2	2.21	91	1.51
	13-15.9	3	4.41	68	7	5.02	140	0.49
	Total	16	16.52	97	21	17.31	121	0.80
All centers								
	<5	11	15.42	71	15	14.47	104	0.69
	5-9.9	61	58.27	105	56	54.63	103	1.02
	10-12.9	16	21.76	74	25	20.94	119	0.62
	13-15.9	51	44.22	115	43	42.95	100	1.15
	16-21	27	32.03	84	21	24.25	87	0.97
	Total	166	171.70	97	160	157.24	102	0.95

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from malignant brain tumor ICD8-191 ICD9-191

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.46	0	0	0.36	0	-
	5-9	2	0.60	331	0	0.53	0	-
	10-14	0	0.49	0	0	0.45	0	-
	15-19	0	0.43	0	0	0.41	0	-
	20-24	0	0.39	0	1	0.37	267	0.00
	Total	2	2.36	85	1	2.14	47	1.81
Chinon								
	<5	0	0.31	0	1	0.35	287	0.00
	5-9	0	0.43	0	0	0.51	0	-
	10-14	0	0.37	0	0	0.44	0	-
	15-19	0	0.36	0	0	0.41	0	-
	20-24	1	0.32	312	0	0.33	0	-
	Total	1	1.79	56	1	2.04	49	1.14
Chooz								
	<5	0	0.20	0	0	0.20	0	-
	5-9	0	0.27	0	0	0.28	0	-
	10-14	0	0.23	0	1	0.24	421	0.00
	15-19	0	0.22	0	1	0.23	433	0.00
	20-24	0	0.21	0	0	0.21	0	-
	Total	0	1.13	0	2	1.15	173	0.00
La Hague								
	<5	0	0.61	0	1	0.47	213	0.00
	5-9	0	0.74	0	2	0.55	360	0.00
	10-14	1	0.58	174	0	0.44	0	-
	15-19	0	0.58	0	1	0.44	225	0.00
	20-24	0	0.65	0	0	0.49	0	-
	Total	1	3.16	32	4	2.39	167	0.19
Marcoule								
	<5	0	0.82	0	1	0.70	144	0.00
	5-9	0	1.11	0	0	0.98	0	-
	10-14	1	0.94	106	0	0.86	0	-
	15-19	1	0.92	108	1	0.85	117	0.92
	20-24	0	0.87	0	0	0.79	0	-
	Total	2	4.67	43	2	4.17	48	0.89
Saint Laurent								
	<5	0	0.27	0	1	0.25	395	0.00
	5-9	0	0.37	0	0	0.36	0	-
	10-14	0	0.29	0	0	0.30	0	-
	15-19	0	0.26	0	1	0.31	324	0.00
	20-24	0	0.25	0	1	0.26	383	0.00
	Total	0	1.44	0	3	1.48	202	0.00
All centers								
	<5	0	2.67	0	4	2.33	172	0.00
	5-9	2	3.52	57	2	3.21	62	0.91
	10-14	2	2.89	69	1	2.72	37	1.88
	15-19	1	2.78	36	4	2.66	150	0.24
	20-24	1	2.69	37	2	2.45	81	0.46
	Total	6	14.54	41	13	13.38	97	0.42

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from malignant brain tumor ICD8-191 ICD9-191

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.06	0	0	0.04	0	-
	5-9.9	0	0.72	0	0	0.66	0	-
	10-12.9	2	0.69	292	1	0.57	176	1.66
	13-15.9	0	0.90	0	0	0.87	0	-
	Total	2	2.36	85	1	2.14	47	1.81
Chinon								
	<5	0	0.34	0	1	0.38	265	0.00
	5-9.9	1	0.84	119	0	1.03	0	-
	10-12.9	0	0.23	0	0	0.23	0	-
	13-15.9	0	0.38	0	0	0.40	0	-
	Total	1	1.79	56	1	2.04	49	1.14
Chooz								
	<5	0	0.54	0	2	0.52	388	0.00
	5-9.9	0	0.21	0	0	0.23	0	-
	10-12.9	0	0.09	0	0	0.12	0	-
	13-15.9	0	0.29	0	0	0.28	0	-
	Total	0	1.13	0	2	1.15	173	0.00
La Hague								
	<5	0	0.10	0	0	0.07	0	-
	5-9.9	0	0.07	0	0	0.05	0	-
	10-12.9	0	0.11	0	0	0.06	0	-
	13-15.9	1	0.27	370	1	0.20	512	0.72
	16-21	0	2.61	0	3	2.01	149	0.00
	Total	1	3.16	32	4	2.39	167	0.19
Marcoule								
	<5	0	0.09	0	0	0.08	0	-
	5-9.9	1	2.40	42	2	1.97	102	0.41
	10-12.9	0	0.61	0	0	0.62	0	-
	13-15.9	1	1.57	64	0	1.50	0	-
	Total	2	4.67	43	2	4.17	48	0.89
Saint Laurent								
	<5	0	0.17	0	0	0.14	0	-
	5-9.9	0	0.70	0	2	0.72	278	0.00
	10-12.9	0	0.19	0	0	0.19	0	-
	13-15.9	0	0.39	0	1	0.43	231	0.00
	Total	0	1.44	0	3	1.48	202	0.00
All centers								
	<5	0	1.30	0	3	1.22	246	0.00
	5-9.9	2	4.93	41	4	4.66	86	0.47
	10-12.9	2	1.91	105	1	1.80	56	1.88
	13-15.9	2	3.79	53	2	3.69	54	0.97
	16-21	0	2.61	0	3	2.01	149	0.00
	Total	6	14.54	41	13	13.38	97	0.42

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from brain tumor of unspecified type ICD8-238.1 ICD9-239.6

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	1	0.00	-	0	0.00	-	1.00
	5-9	0	0.21	0	2	0.18	1089	0.00
	10-14	0	0.79	0	0	0.73	0	-
	15-19	0	0.54	0	0	0.54	0	-
	20-24	1	0.43	231	0	0.42	0	-
	Total	2	1.97	101	2	1.87	107	0.95
Chinon								
	<5	1	0.00	-	0	0.00	-	1.00
	5-9	0	0.16	0	1	0.18	544	0.00
	10-14	1	0.72	139	2	0.84	238	0.58
	15-19	1	0.54	186	0	0.61	0	-
	20-24	0	0.41	0	0	0.42	0	-
	Total	3	1.82	164	3	2.06	146	1.13
Chooz								
	<5	1	0.00	-	0	0.00	-	1.00
	5-9	0	0.10	0	0	0.10	0	-
	10-14	0	0.46	0	0	0.47	0	-
	15-19	1	0.34	298	0	0.35	0	-
	20-24	0	0.27	0	1	0.27	372	0.00
	Total	2	1.16	172	1	1.20	83	2.06
La Hague								
	<5	1	0.00	-	1	0.00	-	1.00
	5-9	1	0.27	370	0	0.20	0	-
	10-14	1	1.15	87	0	0.86	0	-
	15-19	0	0.89	0	0	0.68	0	-
	20-24	1	0.84	119	0	0.63	0	-
	Total	4	3.15	127	1	2.36	42	3.00
Marcoule								
	<5	1	0.00	-	1	0.00	-	1.00
	5-9	1	0.41	244	2	0.36	561	0.44
	10-14	0	1.83	0	3	1.65	182	0.00
	15-19	1	1.34	75	0	1.24	0	-
	20-24	1	1.10	91	0	1.01	0	-
	Total	4	4.68	85	6	4.26	141	0.61
Saint Laurent								
	<5	1	0.00	-	0	0.00	-	1.00
	5-9	0	0.13	0	2	0.13	1562	0.00
	10-14	0	0.53	0	0	0.57	0	-
	15-19	0	0.36	0	0	0.44	0	-
	20-24	0	0.30	0	0	0.31	0	-
	Total	1	1.32	76	2	1.45	138	0.55
All centers								
	<5	6	0.00	-	2	0.00	-	1.00
	5-9	2	1.28	157	7	1.16	605	0.26
	10-14	2	5.48	37	5	5.12	98	0.37
	15-19	3	4.01	75	0	3.86	0	-
	20-24	3	3.36	89	1	3.06	33	2.74
	Total	16	14.12	113	15	13.19	114	1.00

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from brain tumor of unspecified type ICD8=238.1 ICD9=239.6

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.05	0	0	0.03	0	-
	5-9.9	0	0.59	0	1	0.60	168	0.00
	10-12.9	0	0.57	0	1	0.51	198	0.00
	13-15.9	2	0.77	261	0	0.73	0	-
	Total	2	1.97	101	2	1.87	107	0.95
Chinon								
	<5	0	0.33	0	1	0.36	274	0.00
	5-9.9	1	0.87	115	2	1.03	194	0.59
	10-12.9	0	0.24	0	0	0.24	0	-
	13-15.9	2	0.39	507	0	0.42	0	-
	Total	3	1.82	164	3	2.06	146	1.13
Chooz								
	<5	2	0.54	368	1	0.53	188	1.95
	5-9.9	0	0.23	0	0	0.24	0	-
	10-12.9	0	0.10	0	0	0.13	0	-
	13-15.9	0	0.29	0	0	0.29	0	-
	Total	2	1.16	172	1	1.20	83	2.06
La Hague								
	<5	0	0.10	0	0	0.08	0	-
	5-9.9	0	0.06	0	0	0.05	0	-
	10-12.9	0	0.11	0	0	0.07	0	-
	13-15.9	0	0.29	0	0	0.20	0	-
	16-21	4	2.60	154	1	1.97	51	3.04
	Total	4	3.15	127	1	2.36	42	3.00
Marcoule								
	<5	0	0.10	0	0	0.08	0	-
	5-9.9	2	2.41	83	5	2.00	250	0.33
	10-12.9	0	0.60	0	0	0.66	0	-
	13-15.9	2	1.57	128	1	1.52	66	1.94
	Total	4	4.68	85	6	4.26	141	0.61
Saint Laurent								
	<5	0	0.15	0	0	0.13	0	-
	5-9.9	1	0.64	156	0	0.72	0	-
	10-12.9	0	0.18	0	0	0.19	0	-
	13-15.9	0	0.35	0	2	0.41	491	0.00
	Total	1	1.32	76	2	1.45	138	0.55
All centers								
	<5	2	1.26	159	2	1.22	164	0.97
	5-9.9	4	4.80	83	8	4.63	173	0.48
	10-12.9	0	1.80	0	1	1.79	56	0.00
	13-15.9	6	3.67	164	3	3.58	84	1.95
	16-21	4	2.60	154	1	1.97	51	3.04
	Total	16	14.12	113	15	13.19	114	1.00

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Lung cancer mortality ICD8=162 ICD9=162

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.07	0	0	0.06	0	-
	5-9	0	0.04	0	0	0.04	0	-
	10-14	0	0.03	0	0	0.03	0	-
	15-19	0	0.05	0	0	0.05	0	-
	20-24	0	0.09	0	0	0.09	0	-
	Total	0	0.29	0	0	0.26	0	-
Chinon								
	<5	0	0.06	0	0	0.07	0	-
	5-9	0	0.03	0	0	0.04	0	-
	10-14	0	0.02	0	1	0.03	3461	0.00
	15-19	0	0.06	0	0	0.07	0	-
	20-24	2	0.09	2247	1	0.09	1089	2.06
	Total	2	0.27	743	2	0.30	678	1.10
Chooz								
	<5	0	0.04	0	0	0.04	0	-
	5-9	0	0.02	0	0	0.02	0	-
	10-14	0	0.02	0	0	0.02	0	-
	15-19	0	0.04	0	0	0.04	0	-
	20-24	0	0.06	0	0	0.06	0	-
	Total	0	0.17	0	0	0.18	0	-
La Hague								
	<5	0	0.12	0	0	0.09	0	-
	5-9	0	0.06	0	0	0.04	0	-
	10-14	0	0.04	0	0	0.03	0	-
	15-19	0	0.10	0	1	0.08	1294	0.00
	20-24	0	0.18	0	0	0.13	0	-
	Total	0	0.50	0	1	0.37	270	0.00
Marcoule								
	<5	0	0.16	0	1	0.14	735	0.00
	5-9	0	0.09	0	0	0.07	0	-
	10-14	0	0.06	0	0	0.06	0	-
	15-19	0	0.15	0	0	0.14	0	-
	20-24	0	0.24	0	1	0.22	459	0.00
	Total	0	0.70	0	2	0.63	320	0.00
Saint Laurent								
	<5	0	0.05	0	0	0.05	0	-
	5-9	0	0.03	0	0	0.02	0	-
	10-14	0	0.02	0	0	0.02	0	-
	15-19	0	0.04	0	0	0.05	0	-
	20-24	0	0.07	0	0	0.07	0	-
	Total	0	0.20	0	0	0.21	0	-
All centers								
	<5	0	0.51	0	1	0.44	227	0.00
	5-9	0	0.26	0	0	0.24	0	-
	10-14	0	0.19	0	1	0.18	559	0.00
	15-19	0	0.44	0	1	0.42	236	0.00
	20-24	2	0.72	277	2	0.66	305	0.91
	Total	2	2.12	94	5	1.94	258	0.36

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR ratio of SMRs in exposed and control communes

Lung cancer mortality ICD8-162 ICD9-162

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.01	0	0	0.00	0	-
	5-9.9	0	0.09	0	0	0.08	0	-
	10-12.9	0	0.08	0	0	0.07	0	-
	13-15.9	0	0.11	0	0	0.10	0	-
	Total	0	0.29	0	0	0.26	0	-
Chinon								
	<5	1	0.05	2030	0	0.05	0	-
	5-9.9	0	0.13	0	2	0.15	1362	0.00
	10-12.9	0	0.03	0	0	0.03	0	-
	13-15.9	1	0.06	1739	0	0.06	0	-
	Total	2	0.27	743	2	0.30	678	1.10
Chooz								
	<5	0	0.08	0	0	0.08	0	-
	5-9.9	0	0.03	0	0	0.03	0	-
	10-12.9	0	0.01	0	0	0.02	0	-
	13-15.9	0	0.04	0	0	0.04	0	-
	Total	0	0.17	0	0	0.18	0	-
La Hague								
	<5	0	0.02	0	0	0.01	0	-
	5-9.9	0	0.01	0	0	0.01	0	-
	10-12.9	0	0.02	0	0	0.01	0	-
	13-15 9	0	0.04	0	0	0.03	0	-
	16-21	0	0.42	0	1	0.31	320	0.00
	Total	0	0.50	0	1	0.37	270	0.00
Marcoule								
	<5	0	0.01	0	0	0.01	0	-
	5-9.9	0	0.37	0	1	0.30	338	0.00
	10-12.9	0	0.09	0	0	0.09	0	-
	13-15.9	0	0.23	0	1	0.22	449	0.00
	Total	0	0.70	0	2	0.63	320	0.00
Saint Laurent								
	<5	0	0.02	0	0	0.02	0	-
	5-9.9	0	0.10	0	0	0.10	0	-
	10-12.9	0	0.03	0	0	0.03	0	-
	13-15.9	0	0.05	0	0	0.06	0	-
	Total	0	0.20	0	0	0.21	0	-
All centers								
	<5	1	0.19	525	0	0.18	0	-
	5-9.9	0	0.72	0	3	0.67	449	0.00
	10-12.9	0	0.26	0	0	0.25	0	-
	13-15.9	1	0.54	186	1	0.52	191	0.98
	16-21	0	0.42	0	1	0.31	320	0.00
	Total	2	2.12	94	5	1.94	258	0.36

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Hodgkin's disease mortality ICD8=201 ICD9=201

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.01	0	0	0.01	0	-
	5-9	0	0.03	0	0	0.03	0	-
	10-14	0	0.06	0	0	0.05	0	-
	15-19	0	0.22	0	0	0.22	0	-
	20-24	1	0.45	223	1	0.43	232	0.96
	Total	1	0.77	130	1	0.74	135	0.96
Chinon								
	<5	0	0.02	0	0	0.02	0	-
	5-9	0	0.04	0	0	0.05	0	-
	10-14	0	0.06	0	0	0.07	0	-
	15-19	0	0.23	0	1	0.26	382	0.00
	20-24	0	0.42	0	0	0.44	0	-
	Total	0	0.78	0	1	0.84	120	0.00
Chooz								
	<5	0	0.01	0	0	0.01	0	-
	5-9	0	0.03	0	0	0.03	0	-
	10-14	0	0.04	0	0	0.04	0	-
	15-19	0	0.15	0	0	0.15	0	-
	20-24	0	0.28	0	1	0.28	361	0.00
	Total	0	0.50	0	1	0.51	196	0.00
La Hague								
	<5	0	0.03	0	0	0.02	0	-
	5-9	0	0.07	0	0	0.05	0	-
	10-14	1	0.10	978	0	0.08	0	-
	15-19	1	0.39	257	0	0.29	0	-
	20-24	0	0.87	0	0	0.64	0	-
	Total	2	1.46	137	0	1.09	0	-
Marcoule								
	<5	0	0.04	0	0	0.04	0	-
	5-9	0	0.11	0	0	0.09	0	-
	10-14	1	0.16	622	0	0.14	0	-
	15-19	2	0.58	348	0	0.54	0	-
	20-24	5	1.14	438	1	1.04	96	4.58
	Total	8	2.02	395	1	1.85	54	7.30
Saint Laurent								
	<5	0	0.01	0	0	0.01	0	-
	5-9	0	0.03	0	0	0.03	0	-
	10-14	0	0.04	0	0	0.05	0	-
	15-19	0	0.16	0	0	0.19	0	-
	20-24	1	0.31	319	1	0.33	307	1.04
	Total	1	0.55	181	1	0.60	166	1.09
All centers								
	<5	0	0.13	0	0	0.11	0	-
	5-9	0	0.30	0	0	0.27	0	-
	10-14	2	0.47	427	0	0.44	0	-
	15-19	3	1.72	175	1	1.65	61	2.88
	20-24	7	3.47	202	4	3.16	127	1.59
	Total	12	6.09	197	5	5.62	89	2.22

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Hodgkin's disease mortality ICD8-201 ICD9-201

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.02	0	0	0.01	0	-
	5-9.9	0	0.23	0	1	0.24	410	0.00
	10-12.9	1	0.21	469	0	0.20	0	-
	13-15.9	0	0.31	0	0	0.29	0	-
	Total	1	0.77	130	1	0.74	135	0.96
Chinon								
	<5	0	0.13	0	0	0.15	0	-
	5-9.9	0	0.38	0	0	0.41	0	-
	10-12.9	0	0.10	0	0	0.10	0	-
	13-15.9	0	0.16	0	1	0.18	568	0.00
	Total	0	0.78	0	1	0.84	120	0.00
Chooz								
	<5	0	0.24	0	1	0.23	440	0.00
	5-9.9	0	0.10	0	0	0.10	0	-
	10-12.9	0	0.04	0	0	0.06	0	-
	13-15.9	0	0.12	0	0	0.13	0	-
	Total	0	0.50	0	1	0.51	196	0.00
La Hague								
	<5	0	0.04	0	0	0.03	0	-
	5-9.9	0	0.03	0	0	0.02	0	-
	10-12.9	0	0.04	0	0	0.03	0	-
	13-15.9	0	0.12	0	0	0.09	0	-
	16-21	2	1.23	162	0	0.92	0	-
	Total	2	1.46	137	0	1.09	0	-
Marcoule								
	<5	0	0.04	0	0	0.03	0	-
	5-9.9	6	1.07	561	1	0.87	115	4.89
	10-12.9	0	0.25	0	0	0.28	0	-
	13-15.9	2	0.67	300	0	0.66	0	-
	Total	8	2.02	395	1	1.85	54	7.30
Saint Laurent								
	<5	0	0.06	0	0	0.05	0	-
	5-9.9	1	0.27	368	1	0.30	328	1.12
	10-12.9	0	0.07	0	0	0.07	0	-
	13-15.9	0	0.15	0	0	0.17	0	-
	Total	1	0.55	181	1	0.60	166	1.09
All centers								
	<5	0	0.53	0	1	0.51	196	0.00
	5-9.9	7	2.07	338	3	1.95	154	2.20
	10-12.9	1	0.72	139	0	0.74	0	-
	13-15.9	2	1.53	131	1	1.51	66	1.97
	16-21	2	1.23	162	0	0.92	0	-
	Total	12	6.09	197	5	5.62	89	2.22

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from non Hodgkin lymphoma ICD8=200+202 ICD9=200+202

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	1	0.43	233	1	0.34	291	0.80
	5-9	2	0.50	398	0	0.44	0	-
	10-14	0	0.42	0	0	0.39	0	-
	15-19	1	0.50	201	1	0.49	205	0.98
	20-24	0	0.46	0	0	0.44	0	-
	Total	4	2.31	173	2	2.10	95	1.82
Chinon								
	<5	0	0.34	0	0	0.37	0	-
	5-9	0	0.38	0	1	0.45	223	0.00
	10-14	1	0.36	278	0	0.42	0	-
	15-19	0	0.46	0	2	0.52	388	0.00
	20-24	1	0.41	243	0	0.42	0	-
	Total	2	1.95	103	3	2.18	137	0.75
Chooz								
	<5	0	0.22	0	0	0.22	0	-
	5-9	0	0.25	0	0	0.26	0	-
	10-14	0	0.23	0	0	0.23	0	-
	15-19	0	0.28	0	1	0.29	343	0.00
	20-24	1	0.26	378	0	0.27	0	-
	Total	1	1.24	80	1	1.27	79	1.02
La Hague								
	<5	1	0.66	151	0	0.50	0	-
	5-9	0	0.66	0	0	0.49	0	-
	10-14	1	0.57	177	0	0.42	0	-
	15-19	0	0.74	0	0	0.56	0	-
	20-24	0	0.82	0	0	0.60	0	-
	Total	2	3.46	58	0	2.58	0	-
Marcoule								
	<5	1	0.87	114	0	0.75	0	-
	5-9	0	1.01	0	0	0.87	0	-
	10-14	0	0.92	0	0	0.82	0	-
	15-19	1	1.14	88	0	1.06	0	-
	20-24	2	1.11	180	1	1.00	100	1.81
	Total	4	5.05	79	1	4.50	22	3.56
Saint Laurent								
	<5	2	0.28	712	2	0.27	751	0.95
	5-9	0	0.32	0	0	0.32	0	-
	10-14	1	0.27	371	0	0.29	0	-
	15-19	0	0.32	0	0	0.38	0	-
	20-24	0	0.31	0	0	0.32	0	-
	Total	3	1.50	200	2	1.58	126	1.58
All centers								
	<5	5	2.81	178	3	2.45	123	1.45
	5-9	2	3.12	64	1	2.82	35	1.81
	10-14	3	2.76	109	0	2.58	0	-
	15-19	2	3.44	58	4	3.29	121	0.48
	20-24	4	3.37	119	1	3.06	33	3.63
	Total	16	15.50	103	9	14.21	63	1.63

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from non Hodgkin lymphoma ICD8=200+202 ICD9=200+202

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.06	0	0	0.04	0	-
	5-9.9	1	0.69	144	0	0.66	0	-
	10-12.9	2	0.66	301	0	0.57	0	-
	13-15.9	1	0.89	112	2	0.84	238	0.47
	Total	4	2.31	173	2	2.10	95	1.82
Chinon								
	<5	0	0.36	0	0	0.39	0	-
	5-9.9	2	0.92	218	2	1.10	183	1.20
	10-12.9	0	0.25	0	1	0.25	397	0.00
	13-15.9	0	0.42	0	0	0.44	0	-
	Total	2	1.95	103	3	2.18	137	0.75
Chooz								
	<5	0	0.59	0	0	0.57	0	-
	5-9.9	0	0.24	0	0	0.25	0	-
	10-12.9	1	0.10	960	0	0.14	0	-
	13-15.9	0	0.32	0	1	0.31	318	0.00
	Total	1	1.24	80	1	1.27	79	1.02
La Hague								
	<5	0	0.11	0	0	0.08	0	-
	5-9.9	0	0.07	0	0	0.05	0	-
	10-12.9	0	0.12	0	0	0.07	0	-
	13-15.9	0	0.30	0	0	0.22	0	-
	16-21	2	2.86	70	0	2.16	0	-
	Total	2	3.46	58	0	2.58	0	-
Marcoule								
	<5	0	0.10	0	0	0.09	0	-
	5-9.9	1	2.62	38	1	2.11	47	0.81
	10-12.9	0	0.64	0	0	0.68	0	-
	13-15.9	3	1.69	178	0	1.62	0	-
	Total	4	5.05	79	1	4.50	22	3.56
Saint Laurent								
	<5	0	0.17	0	0	0.15	0	-
	5-9.9	2	0.73	276	1	0.78	128	2.15
	10-12.9	1	0.20	499	0	0.20	0	-
	13-15.9	0	0.40	0	1	0.46	219	0.00
	Total	3	1.50	200	2	1.58	126	1.58
All centers								
	<5	0	1.39	0	0	1.31	0	-
	5-9.9	6	5.26	114	4	4.95	81	1.41
	10-12.9	4	1.97	203	1	1.91	52	3.87
	13-15.9	4	4.02	100	4	3.88	103	0.97
	16-21	2	2.86	70	0	2.16	0	-
	Total	16	15.50	103	9	14.21	63	1.63

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Leukaemia mortality ICD8=204 to 207 ICD9=204 to 208

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	2	2.10	95	3	1.68	178	0.54
	5-9	4	2.71	148	1	2.37	42	3.50
	10-14	0	2.06	0	3	1.91	157	0.00
	15-19	0	1.74	0	4	1.71	234	0.00
	20-24	1	1.32	76	1	1.27	79	0.97
	Total	7	9.93	71	12	8.95	134	0.53
Chinon								
	<5	0	1.68	0	1	1.85	54	0.00
	5-9	2	2.18	92	1	2.53	40	2.32
	10-14	1	1.76	57	3	2.07	145	0.39
	15-19	2	1.65	121	1	1.86	54	2.26
	20-24	2	1.15	173	1	1.20	84	2.07
	Total	7	8.43	83	7	9.50	74	1.13
Chooz								
	<5	2	1.11	180	0	1.10	0	-
	5-9	3	1.40	215	1	1.45	69	3.12
	10-14	1	1.12	89	1	1.15	87	1.03
	15-19	2	1.02	196	0	1.06	0	-
	20-24	1	0.74	134	0	0.74	0	-
	Total	9	5.40	167	2	5.51	36	4.60
La Hague								
	<5	4	3.31	121	1	2.46	41	2.98
	5-9	1	3.75	27	3	2.77	108	0.25
	10-14	1	2.79	36	4	2.09	191	0.19
	15-19	5	2.70	185	0	2.05	0	-
	20-24	1	2.34	43	2	1.74	115	0.37
	Total	12	14.87	81	10	11.11	90	0.90
Marcoule								
	<5	4	4.34	92	8	3.70	216	0.43
	5-9	1	5.68	18	6	4.92	122	0.14
	10-14	3	4.50	67	6	4.05	148	0.45
	15-19	7	4.12	170	2	3.82	52	3.25
	20-24	3	3.13	96	4	2.83	141	0.68
	Total	18	21.78	83	26	19.32	135	0.61
Saint Laurent								
	<5	1	1.37	73	1	1.30	77	0.95
	5-9	1	1.78	56	0	1.77	0	-
	10-14	1	1.31	76	0	1.41	0	-
	15-19	0	1.14	0	1	1.36	73	0.00
	20-24	2	0.87	230	3	0.92	328	0.70
	Total	5	6.48	77	5	6.76	74	1.04
All centers								
	<5	13	13.90	93	14	12.09	116	0.81
	5-9	12	17.50	69	12	15.82	76	0.90
	10-14	7	13.55	52	17	12.69	134	0.39
	15-19	16	12.38	129	8	11.87	67	1.92
	20-24	10	9.55	105	11	8.70	126	0.83
	Total	58	66.88	87	62	61.16	101	0.86

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Leukaemia mortality ICD8-204 to 207 ICD9-204 to 208

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.24	0	0	0.16	0	-
	5-9.9	2	3.00	67	2	2.78	72	0.93
	10-12.9	1	2.89	35	7	2.40	292	0.12
	13-15.9	4	3.80	105	3	3.62	83	1.27
	Total	7	9.93	71	12	8.95	134	0.53
Chinon								
	<5	2	1.60	125	2	1.71	117	1.07
	5-9.9	4	3.95	101	1	4.79	21	4.85
	10-12.9	0	1.07	0	2	1.09	183	0.00
	13-15.9	1	1.82	55	2	1.91	104	0.53
	Total	7	8.43	83	7	9.50	74	1.13
Chooz								
	<5	2	2.56	78	0	2.46	0	-
	5-9.9	4	1.01	395	2	1.09	184	2.15
	10-12.9	0	0.45	0	0	0.60	0	-
	13-15.9	3	1.38	218	0	1.37	0	-
	Total	9	5.40	167	2	5.51	36	4.60
La Hague								
	<5	1	0.49	204	0	0.35	0	-
	5-9.9	0	0.31	0	0	0.23	0	-
	10-12.9	0	0.51	0	0	0.30	0	-
	13-15.9	0	1.29	0	2	0.94	213	0.00
	16-21	11	12.28	90	8	9.30	86	1.04
	Total	12	14.87	81	10	11.11	90	0.90
Marcoule								
	<5	0	0.44	0	0	0.37	0	-
	5-9.9	9	11.28	80	12	9.10	132	0.60
	10-12.9	2	2.76	72	2	2.91	69	1.05
	13-15.9	7	7.30	96	12	6.95	173	0.56
	Total	18	21.78	83	26	19.32	135	0.61
Saint Laurent								
	<5	0	0.74	0	0	0.63	0	-
	5-9.9	2	3.15	64	3	3.31	91	0.70
	10-12.9	1	0.86	117	1	0.88	114	1.02
	13-15.9	2	1.73	116	1	1.96	51	2.26
	Total	5	6.48	77	5	6.76	74	1.04
All centers								
	<5	5	6.07	82	2	5.67	35	2.34
	5-9.9	21	22.69	93	20	21.28	94	0.98
	10-12.9	4	8.53	47	12	8.17	147	0.32
	13-15.9	17	17.31	98	20	16.74	119	0.82
	16-21	11	12.28	90	8	9.30	86	1.04
	Total	58	66.88	87	62	61.16	101	0.86

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from lymphoid leukaemia ICD8-204 ICD9-204

Center	Age	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.57	0	0	0.46	0	-
	5-9	0	0.98	0	0	0.86	0	-
	10-14	0	0.70	0	1	0.64	155	0.00
	15-19	0	0.51	0	1	0.50	200	0.00
	20-24	0	0.33	0	0	0.32	0	-
	Total	0	3.10	0	2	2.79	72	0.00
Chinon								
	<5	0	0.40	0	0	0.45	0	-
	5-9	1	0.70	142	0	0.83	0	-
	10-14	0	0.54	0	0	0.64	0	-
	15-19	0	0.43	0	0	0.49	0	-
	20-24	1	0.26	379	0	0.27	0	-
	Total	2	2.34	85	0	2.68	0	-
Chooz								
	<5	1	0.27	374	0	0.26	0	-
	5-9	0	0.45	0	0	0.47	0	-
	10-14	0	0.34	0	0	0.35	0	-
	15-19	1	0.26	382	0	0.27	0	-
	20-24	0	0.17	0	0	0.17	0	-
	Total	2	1.49	135	0	1.52	0	-
La Hague								
	<5	0	0.80	0	0	0.61	0	-
	5-9	0	1.22	0	0	0.91	0	-
	10-14	1	0.85	118	3	0.64	467	0.25
	15-19	3	0.68	440	0	0.52	0	-
	20-24	0	0.52	0	1	0.39	257	0.00
	Total	4	4.08	98	4	3.07	130	0.75
Marcoule								
	<5	0	1.06	0	0	0.90	0	-
	5-9	0	1.84	0	3	1.61	187	0.00
	10-14	2	1.39	144	3	1.26	238	0.60
	15-19	0	1.08	0	1	1.00	100	0.00
	20-24	1	0.72	139	1	0.64	156	0.89
	Total	3	6.09	49	8	5.41	148	0.33
Saint Laurent								
	<5	0	0.35	0	0	0.33	0	-
	5-9	0	0.61	0	0	0.60	0	-
	10-14	1	0.42	237	0	0.45	0	-
	15-19	0	0.31	0	0	0.37	0	-
	20-24	1	0.20	492	0	0.22	0	-
	Total	2	1.89	106	0	1.96	0	-
All centers								
	<5	1	3.46	29	0	3.02	0	-
	5-9	1	5.80	17	3	5.27	57	0.30
	10-14	4	4.24	94	7	3.99	175	0.54
	15-19	4	3.28	122	2	3.14	64	1.91
	20-24	3	2.21	136	2	2.01	100	1.36
	Total	13	18.99	68	14	17.42	80	0.85

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

Mortality from lymphoid leukaemia ICD8-204 ICD9-204

Center	Distance (km)	Exposed communes			Control communes			RR
		O	E	SMR(%)	O	E	SMR(%)	
Saint Vulbas								
	<5	0	0.07	0	0	0.05	0	-
	5-9.9	0	0.94	0	1	0.86	116	0.00
	10-12.9	0	0.91	0	1	0.75	134	0.00
	13-15.9	0	1.18	0	0	1.13	0	-
	Total	0	3.10	0	2	2.79	72	0.00
Chinon								
	<5	2	0.45	444	0	0.49	0	-
	5-9.9	0	1.09	0	0	1.36	0	-
	10-12.9	0	0.30	0	0	0.30	0	-
	13-15.9	0	0.50	0	0	0.53	0	-
	Total	2	2.34	85	0	2.68	0	-
Chooz								
	<5	0	0.71	0	0	0.68	0	-
	5-9.9	1	0.28	361	0	0.30	0	-
	10-12.9	0	0.12	0	0	0.16	0	-
	13-15.9	1	0.38	264	0	0.38	0	-
	Total	2	1.49	135	0	1.52	0	-
La Hague								
	<5	0	0.14	0	0	0.10	0	-
	5-9.9	0	0.09	0	0	0.06	0	-
	10-12.9	0	0.15	0	0	0.08	0	-
	13-15.9	0	0.36	0	2	0.26	776	0.00
	16-21	4	3.35	119	2	2.57	78	1.53
	Total	4	4.08	98	4	3.07	130	0.75
Marcoule								
	<5	0	0.12	0	0	0.10	0	-
	5-9.9	3	3.13	96	4	2.54	157	0.61
	10-12.9	0	0.79	0	1	0.81	124	0.00
	13-15.9	0	2.05	0	3	1.95	154	0.00
	Total	3	6.09	49	8	5.41	148	0.33
Saint Laurent								
	<5	0	0.22	0	0	0.18	0	-
	5-9.9	1	0.91	109	0	0.95	0	-
	10-12.9	0	0.25	0	0	0.25	0	-
	13-15.9	1	0.51	196	0	0.57	0	-
	Total	2	1.89	106	0	1.96	0	-
All centers								
	<5	2	1.71	117	0	1.60	0	-
	5-9.9	5	6.43	78	5	6.08	82	0.95
	10-12.9	0	2.51	0	2	2.36	85	0.00
	13-15.9	2	4.98	40	5	4.82	104	0.39
	16-21	4	3.35	119	2	2.57	78	1.53
	Total	13	18.99	68	14	17.42	80	0.85

O : observed number of deaths. E : expected number of deaths. SMR (%) = 100*O/E
RR : ratio of SMRs in exposed and control communes

MORTALITY AROUND FRENCH NUCLEAR SITES IN THE POPULATION AGED 0 TO 24.

Contract Bi7-066 - Sector C14

1) *Hill*, Inst. G. Roussy

Summary of project global objectives and achievements

1. Introduction

Higher than expected mortality from leukaemia has been observed in the population under age 25 living around Sellafield and Dounreay, nuclear reprocessing plants in the United Kingdom (Black 1984, Darby 1987, Forman 1987, Gardner 1984, 1987, 1990).
France derived 75% of its electricity from nuclear energy in 1989, and the first nuclear unit producing electricy started operating industrially in 1962 (Anonymous 1987), although experimental units started earlier. We present a study of mortality in the population age 0 to 24 residing in the vicinity of French nuclear sites.

2. Material and methods

The main sites in operation during 1975 or before were selected for inclusion in the study, in order to have a minimum follow-up of 10 years for mortality. Figure 1 and Table 1 show the six sites selected, together with the year of first operation and the nature of the activity (Anonymous undated).

Four geographical zones were defined around each installation according to the distance from the installation: <5km, 5-10 km, 10-13 km, and 13-16 km. For La Hague, the farthest zone bordered the densely populated suburbs of the city of Cherbourg: an extra zone corresponding to a distance of 16-21 km has been considered for this site. France is divided into 36,500 administrative and electoral units called 'communes'. The average population of a commune is 1,500, and the average area 15 km^2. For each site and each zone, the 'exposed' communes were identified by their national code, and for each exposed commune, a 'control' commune was selected as the commune in the same 'Département' having the closest total population figure. This defines, for each site, four (five for La Hague) exposed zones according to the distance to the installation, and the same number of control zones. The average distance between control communes and installation is 53 km (range 16-133 km, s.d. 24 km).

Census data by commune were obtained from Institut National de la Statistique et des Etudes Economiques (INSEE), for the three censuses of 1968, 1975, and 1982. For each commune the census population was available by sex and 5-year age groups. The three censuses enumerated the population respectively on 1 March, 20 February, and 4 March. We have estimated the populations on 1 January, by sex and 5-year age groups, under the assumption that the ratio of the census population to the 1 January population was the same in each commune and could be estimated by the ratio computed from INSEE publication for the whole of France (Table 2). Yearly populations on 1 January were computed by linear interpolation between the populations on 1 January for census years, for a given sex and age group. After 1982, the 1 January population of each commune for each year was extrapolated from the 1982 1 January population, under the assumption that this population varied like the total French population of the same sex and age group for which extrapolations are published by INSEE (Table 3). For each year and each commune the population at risk is the average of the population on 1 January of that year and of the next year.

From the Institut National de la Santé et de la Recherche Médicale, service commune 8 (E. Michel and F. Hatton, personal communication), we obtained the cause of each death that occurred in the population aged 0-24 between 1968 and 1987, by zone (the precise commune of residence corresponding to each death was not made available to us in order to maintain confidentiality over the cause of death required by French law). The underlying cause of each death was coded according to the International Classification of Diseases (eighth revision before 1979, and ninth revision after). The causes of death included in the analysis are listed in Table 4.

Two sites started operation after 1968: Saint Laurent in January 1969 and Saint Vulbas in December 1971. Deaths occurring before 1969 and before 1972 respectively in these two sites were excluded from our study as well as the corresponding population at risk.

To test the possible existence of an increase in leukaemia mortality between age 0 and 24 around French nuclear sites, we made two comparisons. First, the observed mortality was compared to the mortality expected from national rates (Hill 1989). Second, in an attempt to control for possible systematic differences between death certification procedures in rural, sparsely populated areas and in the country as a whole, the mortality around nuclear sites was compared with the mortality in control communes, matched for total population and large geographical unit (Département).

3. Results

3.1 Main results

Table 5 includes, for each cause of death considered, the observed and expected number of deaths in the exposed communes, and the standardised mortality ratio. The total number of person-years is also given.

Between 1968 and 1987, a total of 2 892 000 person-years of observation were accumulated in the population aged 0 to 24 in the exposed communes; this is equivalent to following 144 600 persons for 20 years. Three thousand and sixty four deaths were observed, which is very close to the expected number from national mortality statistics. Fifty eight leukaemia deaths were observed around nuclear sites, which is slightly less than the 67 expected from national mortality. Among the other causes of death considered, an excess of deaths from Hodgkin's disease (SMR=197), and a deficit of death from malignant brain tumor (SMR=41) were observed. These two differences are not statistically significant after correcting for the number of tests performed.

Table 6 includes, for the same causes of death, the observed and expected number of deaths, the SMRs in exposed and control populations, and the relative risks: ratios of the SMRs in the exposed and control population. The total numbers of leukaemia deaths were 58 and 62 in exposed and control communes respectively. None of the tests comparing the SMR of the exposed population to the SMR in the control population were statistically significant.

Tables 7.1 to 7.9 present, for each cause of death, the observed and expected number of deaths, and the SMR, by sex, age, type of installation and distance from installation.

There is no significant increase in the risk of death with a decreasing distance to the nuclear site, except for overall mortality (p=0,002).

3.2 Detailed results

For each cause, two tables present the observed and expected number of deaths and the SMRs both for exposed and for control communes, as well as the ratios of the SMRs in exposed and control communes; the results are presented separately for each installation. In the first table the results are given by distance from installation, and in the second table by age.

These detailed results are given for a purely descriptive purpose, to allow the inspection of mortality data around each site by local health professionals. The results are therefore presented without any statistical test of significance: the multiplicity of tests would lead to problems in interpreting their results.

For each cause of death, heterogeneity between installations was tested. A heterogeneity between installations was observed for overall mortality ($p=10^{-4}$) and for lung cancer mortality (2 deaths around Chinon, p=0,02). For Hodgkin's disease, 8 of the 12 observed deaths occurred in the vicinity of Marcoule, but the test for heterogeneity between installations was not statistically significant (p=0,22).

4. Conclusion

Our study shows no excess leukaemia mortality in the population aged 0-24 residing near French nuclear sites. The power of this study is reasonable: when the reference is the general population, and with an expected number of leukaemias around installations equal to 60, the probability of detecting an increase of 50% is 95% (with a type I error of 5%), and the probability of detecting an increase of 23% is ~ 50% (Breslow 1987). When the reference is a control group of similar size, the probability of detecting an increase of 50% is ~ 80% (Breslow 1987).

Our results confirm Viel and Richardson's study of leukaemia mortality around La Hague (Viel 1990), which used geographical units with populations seven times larger than in our study. The excess leukaemia observed around nuclear sites in the United Kingdom is not observed around French nuclear sites although the same methodology was used as in Forman (1987).

The amount of radioactive effluent discharged might have been higher around Sellafield and Dounreay than around French installations (Viel 1990). The excess leukaemia observed in the United Kingdom could also be attributed to some characteristic common to Sellafield and Dounreay, but not shared by French installations, for instance a rapide increase of population leading to viral infections (Kinlen 1989), or some unknown factor shared by existing and potential nuclear sites in the United Kingdom (Cook-Mozaffari 1989).

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Optimization and management of radiation protection

DEVELOPMENT OF FUNDAMENTAL DATA FOR RADIATION PROTECTION

Contract Bi6-324 - Sector C21

1) *Smith*, ICRP

Summary of project global objectives and achievements

The primary objective in radiological protection is to provide an appropriate standard of protection of man without unduly limiting the beneficial practices giving rise to radiation exposure. To achieve this end, it is necessary to quantify the detriment associated with exposure and to develop a general policy of protection for individuals and exposed populations.

The major achievement during the contractual period was to publish the 1990 Recommendations of the International Commission on Radiological Protection (ICRP). These recommendations were supplemented by the scientific evidence used to estimate the risks associated with exposure to low doses of ionising radiations.

In the new recommendations, the ICRP has maintained and strengthened its 1977 System of Dose Limitation. The basic requirements for those human activities which involve an increase in the overall exposure to ionising radiations, referred to as practices, are that;-

(a) any practice and its system of protection needs to be justified and should produce sufficient benefit to the exposed individual or to society to offset the radiation detriment it causes

(b) the protective system should be optimised in relation to any particular source within a practice to ensure that the dose to individuals, the number of persons exposed and the likelihood of incurring exposures that are not certain to occur (potential exposures) are kept as low as is reasonably achievable, social and economic factors being taken into account. The optimisation process should be constrained by restrictions on the doses to individuals from any source or by the risk to individuals from potential exposures so as to limit the inequity likely to result from the inherent economic and social judgments, and

(c) the combined effect of all the relevant practices on any individual should be suitably limited by a dose limit or to some control of risk in the case of potential exposures. The source-related dose constraint introduced in the optimisation process should ensure that no individual receives a combined dose from several sources that would exceed the recommended dose limit.

The new recommendations address the need to intervene to reduce the dose that would be received unless remedial action is taken. The system of protection recommended is that the proposed intervention should do more good than harm and the form, scale and duration of the intervention should be optimised so that the net benefit of the reduction of dose should be

maximised. Dose limits do not apply in the case of intervention; but it is recognised that there will be some level of projected dose above which, because of serious deterministic effects, intervention will almost always be justified.

It is hoped that these new recommendations will form a basis for the proposed European Community Directive regarding the basic safety standards for the health protection of the general public and workers against the dangers of ionising radiation.

Project 1

Head of project: *Dr. Smith*

Objectives for the reporting period

To adopt and publish recommendations and reports on various aspects of radiation protection, prepared for the Main Commission of ICRP by its four standing Committees on biological effects, derived limits, protection in medicine and application of the recommendations. The Committees are aided by ad hoc Task Groups and Working Parties who critically evaluate available data. The head of the project plays a coordinating role in this process on behalf of the Main Commission.

Progress achieved including publications

The latest epidemiological results from the Japanese Life Span Study indicate with reasonable certainty that the human cancer risks associated with ionising radiations are about three times higher than they were estimated to be in the 1970's. Details of the ICRP estimates of cancer risk, genetic risk and risk to the fetus at low doses of ionising radiation and the methodology behind these estimates are given in a series of ICRP publications. In addition, a report on the biological basis for dose limitation in the skin discusses the cells at risk and their location; the dose response relationships for cancer induction and deterministic effects; and dosimetric considerations with reference to the effects of highly localised irradiation ("hot particles").

Adoption of the new recommendations necessitates a revision of the Commission's currently recommended derived limits. In order to apply immediately the recommended lower dose limits (based upon stochastic effects), interim values of Annual Limits on Intake (ALI) for workers were calculated. These values incorporate the latest radiation and tissue weighting factors, but the metabolic and biokinetic data published in ICRP Publication 30 (Limits for Intakes of Radionuclides by Workers) were used in the calculations. A complete revision of ICRP Publication 30 will require input from Task Groups currently preparing reports on the most appropriate model to represent the deposition and clearance of inhaled radioactive material from the human respiratory tract; and on the age-related anatomical, biochemical and physiological parameters to use to describe the metabolism and excretion of incorporated radionuclides when calculating dose coefficients and ALIs. In the meantime, the interim ALI values will remain valid.

Three other reports prepared during this contractual period are to be considered for adoption by the Main Commission. One report outlines a conceptual framework for protection from

potential exposures which provides a unified set of principles combining radiological protection and nuclear safety. It is anticipated that it will give numerical values for constraints on annual probabilities of sequences of events leading to detrimental health effects. A second report discusses the principles for intervention for protecting the public in a radiological emergency. It will provide guidance on the protective actions necessary to avert exposures via various pathways and on techniques to derive generically optimised intervention levels. A third report on protection against radon in buildings will make recommendations on action levels for intervention, based upon epidemiological data derived from studies on miners and relating Working Level Months and cancer risk.

A report will soon be published as Part 2 of ICRP Publication 56 (Age Dependent Doses to Members of the Public from Intakes of Radionuclides). Doses per unit intake following ingestion are given for isotopes of sulphur, cobalt, nickel, zinc, molybdenum, technetium, silver, tellurium and polonium using the new tissue weighting factors. Dose coefficients following inhalation of these radionuclides are not included, but they will appear in a future publication, together with updated values for inhaled radionuclides published in Part 1, when the report on the Human Respiratory Tract Model for Radiological Protection becomes available.

Work initiated during the contractual period which will continue includes a consideration of other sources of epidemiological data to supplement the results from the Japanese Life Span Study and the appropriateness of risk projection and population transfer models.

With regard to protection against the medical applications of ionising radiations, feasability studies are in progress to consider the optimisation of protection of patients in diagnostic radiology; to provide criteria for the implementation of a radiation protection programme in biomedical research involving exposure of healthy volunteers and patients; and to provide an outline on the hazards of potential exposures of patients due to mechanical or human failures.

Publications

1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Annals of the ICRP 21 (1/3), 1991. Pergamon Press, Oxford.

Annual Limits on Intake of Radionuclides by Workers Based on the 1990 Recommendations. ICRP Publication 61. Annals of the ICRP 21 (4), 1991. Pergamon Press, Oxford.

Risks Associated with Ionising Radiation. Annals of the ICRP 22 (1), 1991. Pergamon Press, Oxford.

The Biological Basis of Dose Limitation in the Skin. ICRP Publication 59. Annals of the ICRP 22 (2), 1991

APPLICATION OF ALARA IN COMPLEX DECISION-MAKING SITUATIONS (NRPB ASSOCIATION)

Contract Bi6-347i - Sector C21

1) *Wrixon*, NRPB - 2) *Lochard*, CEPN - 3) *Meggitt*, SRD AEA Technology

Summary of project global objectives and achievements

One of the fundamental principles underpinning radiological protection is that all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account. Since this was initially stated, considerable work has been undertaken to develop a full understanding of the principle and how it should be applied in practice. Much of the understanding obtained during the previous contract period is reflected in the Report produced by NRPB and CEPN entitled, ALARA - From theory towards practice (CEC EUR 13796 EN, 1991).

The major difficulties identified in the previous contract period lay in the collection of adequate data to undertake full ALARA studies and the availability of tools such as practical guide books and computer packages for implementing ALARA. These tools were identified as also having a role in training.

During the period of this current work, the new ICRP Recommendations were published. The ALARA principle as defined in these recommendations contained new elements: the explicit recognition of potential exposures and the use of dose and risk constraints. Dose constraints, in particular, were seen as a means of limiting the inequity in the distribution of individual doses that is likely to result from the inherent economic and social judgements of the ALARA process. Consequently, some consideration has been given to how dose constraints might be developed and the role that generic ALARA studies might have.

Whilst the optimisation principle is relatively well-established in operational protection, there are more complex situations, such as low probability, long term effects, heterogeneous detriments or where equity questions are involved, for which there is no straightforward way to apply ALARA principles. A second part of the project was therefore aimed at extending the current methodologies to encompass these more complex situations.

In summary the global objectives were:

(a) to develop appropriate software and tools for undertaking optimisation of protection,

(b) to develop appropriate databases on incidence of failures,

(c) to investigate the application of ALARA to decision-making in complex situations and to propose a general methodology to aid decision-making in such situations.

The major achievements were:

(a) the preparation of software codes for cost-effectiveness and cost-benefit analysis,

(b) the preparation of procedural guides for implementing the ALARA principle in the operation and maintenance of facilities,

(c) the evaluation of the use of these procedural guides in the context of training,

(d) the exploration of the possibility of setting up a database on accident and incidents,

(e) the development of a fuller understanding of the concept of dose and risk constraints in the contexts of public, occupational and medical exposures, and how values for dose constraints might be applied,

(f) a thorough review of the various methods of structuring problems and the application of decision making in complex situations,

(g) a critical review of the information on risk aversion.

Project 1

Head of project: *Dr. Wrixon*

Objectives for the reporting period

The project objectives were

(a) to develop further procedural guidance on carrying out optimisation of protection.
(b) to develop the idea of generic optimisation and its interaction with dose constraints.
(c) to study the feasibility of setting up an accident and incident database.

Progress achieved including publications

1. Procedural guidance

A fundamental principle underpinning radiological protection is that all exposures shall be kept as low as reasonably practicable economic and social factors being taken into account; often referred to as Optimisation of radiation protection or as the ALARA principle. Since the principle was first stated NRPB and CEPN have, in previous contracts, undertaken considerable work to act as an input to the understanding of the principle and how it should be applied in practice. The draft report that was prepared under the previous contract reflected this understanding and was written in a format that would allow it to be used as a reference and training manual. Early in the present contract, the draft report was the subject of a CEC Peer Review Group meeting, in Ispra, Italy. With a few minor comments the Group endorsed the work and recommended that the final report be published as a book. Much of the work in the early part of the present contract was devoted to updating and finalising the book, "ALARA - From theory towards Practice" which has now been published[1].

A spin off from this work has been the CEC training course "Optimisation and Radiological Protection in the Design and Operation of Nuclear and Industrial Facilities". Three such courses 19-23 November, 1990, 3-7 June, 1991, and 4-8 November 1991, at Saclay, France have been run and further courses are planned. These courses, jointly sponsored by DG XI and DG XII under separate contracts, were always envisaged as a two way process; the courses building on the experience of this and previous projects, and the project feeding off the ideas evolving from the collective practical experience of the participants. Indeed this has proved to be the case.

Areas of note where developments have taken place are given below. These have been addressed in various papers[2,3,4].

(1) Development of procedural guidance, that consolidates advice on structural approaches and the use of decision aiding techniques. In particular, emphasis

has been placed on pre-job reviews using checklists, which address whether or not there is scope for reduction of tasks, transfer of work from high exposure environments, reduction and better coordination of the workforce, improved working conditions, the use of better adapted tools etc.

(2) The importance of commitment at all levels: that is those charged with regulating, controlling, managing and operating radiological protection in installations, together with the workforce itself.

(3) The full integration of optimisation of protection within overall Work Management. It became clear from the Optimisation training courses that to achieve this objective different organisational structures are required to take account of variations in safety cultures between organisations and between countries.

2. Generic optimisation

During the contract, ICRP brought out its revised recommendations in their Publication 60. This extended the definition of Optimisation to explicitly include potential exposures and put greater emphasis on exposure of individuals. In particular it introduced the concepts of dose constraints and risk constraints to limit the inequity in the distribution of individual doses and risks possibly resulting from the inherent economic and social judgements of the optimisation process. Work has been carried out to develop the understanding and implications of these changes to the Optimisation principle[2,3,4,6,7]. This has addressed the functions and derivation of dose constraints in public, medical and occupational exposure, but with the emphasis on occupational exposure.

Dose constraints are seen as operating differently for the three types of exposure. In public exposure the dose constraint would apply to the average dose to the critical group; in medical exposure it applies to the average dose from a type of examination and acts as an investigation level, whilst for occupational exposure it applies to an individual's dose. In the latter case the constraint has two functions. Firstly it would in normal circumstances eliminate protection options that would give rise to predicted doses above the dose constraint. Secondly, for various reasons the doses actually received may exceed the dose constraint, and in these circumstances it acts as an investigation level.

The process by which dose constraints should be quantified is sometimes referred to as generic optimisation and should include the assessment of levels of individual dose presently received in well managed operations, the identification of any sub groups of workers receiving the higher doses and clarification of the driving forces. The underlying theme of this analysis would be to determine the distribution of individual doses that is "reasonably achievable" in the breadth of circumstances of the sector of interest with a view to setting the dose constraint or investigation level near the upper end of the distribution.

3. Accident and incident database

The concept of risk constraints is less well developed, but it was clear, even before the advent of ICRP Publication 60 that in order to factor potential exposures into

optimisation it would be necessary to have data on the frequency and range of consequences of failures of protection measures. To this end the current availability of data in the UK was reviewed. Findings indicate that the quality and quantity of data varies significantly from one sector of use to another. In many sectors the data is restricted to legally reportable incidents thus excluding failures of equipment and procedures that for various reasons did not actually give rise to significant doses ("near misses") but which could be relevant to optimisation. This part of the project was hampered by the lack of adequate records and the confidentiality of those records that do exist. Work is continuing on developing a voluntary reporting system for an accident and incident database.

Publications

1 Stokell, P J, Croft, J R, Lochard, J, and Lombard, J. ALARA: From Theory towards Practice. CEC Report EUR 13796 EN, CEC Luxembourg, 1991.

2 Lefaure, C, and Croft J R. Elements for designing ALARA programmes for maintenance and routine operations in nuclear facilities. Conference on Occupational radiation Protection, Guernsey 1991, BNES. Thomas Telford Ltd London.

3 Robb, J D, and Croft, J R. Recent perspectives on optimisation of radiological protection. Proceedings of a CEC conference on Implications of the new ICRP Recommendations on Radiation Protection Practices, 26-29 November 1991, Salamanca (to be published).

4 Croft, J R, and Robb, J D. The integration of ALARA into work planning and organisation. NEA Workshop on Work Management in Occupational Dose Control, 4-6 February 1992, Paris (proceedings to be published).

5 Robb, J D, Kendall, G M, and Stokell, P J. Risk of occupational exposure in the United Kingdom. Conference on Occupational Radiation Protection, Guernsey 1991, BNES, Thomas Telford Ltd London.

6 Wrixon, A D, Croft, J R, Hudson, A P, and Robb, J D. Advice on the 1990 Recommendations of the ICRP Concerning Occupational Exposure (in preparation).

7 Shrimpton, P C, Wall, B, Croft, J R, and Webb, G A M. Advice on the 1990 Recommendations of the ICRP concerning Medical Radiology (in preparation).

Project 2

Head of project: *Dr. Lochard*

Objectives for the reporting period

To develop appropriate tools and software for undertaking optimisation of protection in the design and operation of nuclear installations, such as:

1. Development of a decision aiding techniques software

2. Preparation of a generic procedure guide for the implementation of the ALARA principle into radiation programmes for the design, operation and maintenance of nuclear installations

3. Global survey of adequate software and databases needed for each step of an ALARA programme

Progress achieved including publications

1. Decision aiding techniques software

In 1990, an agreement was reached on the methodology and the basic structure of a decision aiding technique software. A specific NRPB/CEPN workshop on this topic was organised in Paris (April 1990) to discuss and design the software. During the following months a report was written describing the functions, algorithms and output (tables, graphs) to be developed in the software (CEPN report No. 174 - June 1990). In order to optimise co-operation between CEPN and NRPB on this topic, a member of the CEPN team spent two months at Chilton, during the first trimester, 1991.

The software has now been developed and is available for external users. It allows cost effectiveness analysis to be performed for occupational exposure reduction options.

2. ALARA procedure guide

2.1 Maintenance and operation

In order to implement ALARA during maintenance and normal operations, CEPN proposed to EDF, at the beginning of 1990, a complete ALARA programme including motivation actions, ad hoc structures and procedures like reviews, check-list. These proposals have been largely adopted and tested during the Steam Generator Replacement that took place at Dampierre 1 (February to May 1990) and led to a significant savings in individual and collective dose. Based on the experience gained during that operation a more generic guide has been developed during the project. A first draft of such a guide was presented during the Saclay ALARA training course in November 1990 (see later). Interactions with representatives of utilities and Authorities from different European countries, including Germany and Sweden, has led to the modification and completion of

this guide to take into account national backgrounds, feed back experiences and radiological protection cultures. Improved drafts of the guide were discussed during subsequent ALARA training courses and were presented at the May 1991 BNES Guernsey meeting. The end of 1991 and the beginning of 1992, were mainly devoted to complete this guide with proposals concerning ALARA and work management (optimisation of mishaps, reworks, working conditions .....). First conclusions were proposed and discussed at the February 1992 NEA workshop, and at the French ALARA courses (March and June 1992 at Saclay). An important survey within nuclear power plants is now ongoing to help in modelling all factors involved.

2.2 Design of installations

In the course of 1990 and 1991, CEPN has been actively involved in a project aimed at optimising the radiological protection of workers within a new fuel fabrication facility under construction in France (the MELOX plant). This project allowed the delineation of the key issues on the implementation of the ALARA principle at the design stage. A generic methodology and specific tools have been developed allowing a first generic reflection about the role of ALARA in design. This methodology and the tools were presented first during the Guernsey meeting and secondly at the last ALARA training courses. It is now obvious that the implementation of ALARA at the design stage, which has only quite recently been studied in any systematic way, requires further work. This will be undertaken during the next period, the purpose being to propose more adequate ways of defining ALARA targets, objectives and procedures adapted to the design phase.

2.3 Decommissioning

In the course of 1990 and 1991, CEPN has been actively involved in a project aimed at optimising the radiological protection for the workers during the BR3 dismantling at MOL (Belgium). This project allowed a start to be made to the development of a more global approach to the application of ALARA to decommissioning. A first generic reflection about the role of ALARA in decommissioning will be presented at an October 1992 SFEN meeting and included in the overview paper concerning ALARA in installations at the next CEC ALARA seminar.

3. Survey of adequate software and database for implementing an ALARA programme

During this 1990-1991 period, a global survey of adequate software and databases needed for each step of an ALARA Programme has been performed. The analysis carried out concerning the existing tools, has pointed out the necessity to develop a tool for optimising "a priori" the individual doses to operators, and a package "dosimeter- software" for tracking the adequate job-related-data. It has also pointed out the need to develop specific quantified tools for analysing the impact of work management options. These analyses were presented during the last CEC Course, and further proposals were discussed at the NEA workshop (Paris 02/92).

4. ALARA training course

On behalf of the DG XI and DG XII of the CEC, three training courses entitled "Optimisation of radiological protection in the design and operation of nuclear and industrial facilities" were organised jointly by NRPB and CEPN in Saclay (France), in close co-operation with the French Institute of Nuclear Sciences and Technologies (INSTN) and the

Training Centre for the French Nuclear Industry (CETIC), 19-23 November 1990, 3-7 June 1991, 4-8 November 1991. During these seminars the new developments achieved within the joint Project were presented and widely discussed with the participants.

The next CEC ALARA training course will be held in November 1992 at Saclay, and the basic changes in ICRP Publication 60 will be integrated into the course material. One matter that will be discussed will be the French position concerning the "α" value which takes account of equity and risk aversion. The methodology, referred to as the 'reasonable-cost' methodology, has recently been adopted by the EDF.

Publications

1 Lochard, J, and Lefaure, C. Proposition d'organisation et procédure ALARA pour la préparation, le suivi et le retour d'expérience des chantiers de maintenance : application au RGV. Janv. 1990. Rapport CEPN No. 166 bis.

2 Schieber, C, Lombard, J, and Lefaure, C. Propositions pour l'élaboration d'un logiciel d'analyses coût-efficacité et coût-bénéfice en vue de l'optimisation de la radioprotection. Juin 1990. Rapport CEPN No. 174.

3 Lefrancois, I, and Crouail, P. Analyse de la préparation et de la réalisation du remplacement des générateurs de vapeur de Dampierre 1, en vue d'établir un rapport de retour d'expérience radioprotection. Mémoire de stage INSTN, Juin 1990.

4 Lochard, J. ALARA programmes in operation : a generic framework. CEC ALARA Course, Saclay, November 1990.

5 Lefaure, C, and Croft, J. Elements for designing ALARA programme for maintenance of nuclear facilities. Proceedings of the International Conference organised by the BNES on Occupational Radiation Protection, Guernsey, 29 April - 3 May 1991.

6 Pages, P, Degrange, J P, Le Bail-Tassel, L, Nimal, J C, Ducroux, R, and Lorenzelli, M. ALARA at the design state of nuclear installations. Proceedings of the International Conference organised by the BNES on Occupational Radiation Protection, Guernsey, 29 April - 3 May 1991.

7 Blain, A, Abela, G, and Schieber, C. ALARA within Training. CEC ALARA Courses Saclay, June and November 1991.

8 Schieber, C. L'utilisation de logiciels et de bases de données pour le contrôle des doses travailleurs. NEA Workshop, Paris 4-6 February 1992, to be published.

9 Coates, R, Lefaure, C, and Schieber, C. The role of work management in occupational dose control. NEA Workshop, Paris 4-6 February 1992, to be published.

10 Crouail, P, and Lefaure, C. Spécificité de l'optimisation de la radioprotection appliquée au démantèlement. Congrès SFEN, Avignon 9 October 1992, to be published.

Project 3

Head of project: *Dr. Meggitt*

Objectives for the reporting period

The general aim was to investigate the application of ALARA to decision-making in complex situations and propose a general methodology to aid decision-making in such situations.

Specific objectives were to:

(a) review the current approaches to decision-making in an ALARA context,

(b) propose a general framework for ALARA decisions and specific decision-aiding techniques,

(c) identify factors relevant to the decision process in various categories of problem (eg routine exposure, probabilistic exposure, exposure in the future), how they interact with each other and the trade-offs involved in reaching a decision,

(d) investigate how these factors and trade-offs can be incorporated into the decision process,

(e) demonstrate the application of the methodology to selected case studies to illustrate its use. The case studies will be representative of the principal areas in which the methodology is likely to be applied.

Progress achieved including publications

Optimisation in radiological protection is a complex process involving trading-off conflicting objectives. A report has been prepared that outlines a general decision-process, including decision-aiding techniques, which can help the practical implementation of ALARA (As Low As Reasonably Achievable). The stages in the decision process are briefly described and methods for structuring the decision, identifying important attributes and determining weighting factors for the attributes are discussed. Multi-criteria outranking analysis (MCOA) and the application of multi-attribute utility analysis (MAUA) to complex problems involving uncertainty are also investigated. The practical application of the techniques to hypothetical problems in radiological protection is demonstrated.

Neither the decision-process nor the analytical techniques are algorithms or machines for making decision. No process or technique can capture all the facets of a decision and the ultimate responsibility for the decision is always with the decision-maker. The decision-process does, however, help the decision-maker understand his problem more fully and which facets of it determine the preferred option. It also helps communicate to others why, and under what circumstances, a particular course of action is preferred.

The contents of the report are given on the attached sheets.

Publications

1 Phillips, F, Allott, R W, and Wilkinson, H L. ALARA in complex situations: The application of decision-making to radiological protection. SRD/ALARA/R001, 1992.

2 Phillips, F, Allott, R W, and Wilkinson, H L. Optimisation of radiological protection in complex situations. In Volume II of the Proceedings of the 8th International Radiation Protection Association, Montreal, 1992.

3 Phillips, F, Wilkinson, H L, and Allott, R W. Decision-making in radiological protection. SRD, AEA Technology, TSSD/A/5, 1991.

REDUCTION OF DOSE IN X-RAY DIAGNOSTICS BY THE CHOICE OF THE OPTIMAL SCREEN-FILM COMBINATION

Contract Bi6-316 - Sector C22

1) *Hoeschen* , PTB

Summary of project global objectives and achievements

Abstract

This report deals with the correlation between the physical image quality of X-ray screen-film systems used in conventional radiology and the visual detectability of diagnostically relevant image details. An important image quality parameter is the Wiener spectrum, which quantitatively describes the image noise properties of screen-film systems. This study investigates the influence of two different Wiener spectra on the visual detectability of lung nodules in chest images: original chest radiographs are digitized, their Wiener spectra modified by means of a digital image processing system, and then reprinted on photographic film. Radiologists evaluate the detectability of the lung nodules in these modified reproductions. The results of these experiments are presented and interpreted in this report. It seems that an increase in noise by a factor of two, which in general corresponds to a more sensitive X-ray screen-film system, has no influence on the detectability of lung nodules.

1. Introduction

In radiology, diagnostic accuracy is essentially determined by the image quality of the X-ray images. It can be intuitively expected that there is a relationship, commonly known as a "psychometric function" [1], between the diagnostic accuracy and the physical image quality of the radiographs. This relationship is know qualitatively, but in general not quantitatively: the better the image quality (e.g. resolution, low noise, contrast), the more accurate the diagnosis. Beyond a certain point, however, further improvement of the physical image quality will not lead to a further improvement of the diagnosis, because the performance of the human visual system is limited. As an improvement of the image quality is generally connected with an increase in the X-ray dose and thus with an undesirable increase in the patient's exposure [2], any improvement of the physical image quality which does not lead to a higher degree of the diagnostic accuracy is pointless. On the contrary: in such a case it would be possible to reduce the patient's exposure without any loss of information for the radiologist.

Knowledge of the quantitative relationship between the physical image quality and the diagnostic accuracy can also indicate how accurate the measurement of the physical image quality parameters must be, for example: it is unneccessary to reduce the measuring uncertainties of these parameters to such an extent that the measurably small differences in image quality can no longer be distinguished by radiologists. This aspect is of particular importance for both the development of measuring methods and the development of standards for the measurement of image quality parameters.

This study investigates how the visual detectability of lung nodules in chest images is influenced by a variation of the noise of conventional X-ray screen-film systems, characterized by its Wiener spectrum [3].

2. Method of investigation

2.1 Principle

To keep as close as possible to radiological practice, original X-ray images of healthy patients are employed in this study: the original radiographs are digitized by a scanner, and the digital images are stored. Lesions simulated by means of a digital image processing system are then inserted into these images. A laser printer is used to reproduce the modified images on photographic film. With this procedure a set of X-ray images is obtained which resemble as far as possible the original radiographs, with the exception of the simulated lesions. By means of the digital image processing system, a further set of images is produced, where to the digital images already modified by the lesions, a digitally generated image noise is added. This second set of images is also printed onto photographic film by the laser printer. These two sets of images differ in their image quality only by their image noise, i.e. by the Wiener spectrum.

Both sets of images are presented to radiologists, and the visual detectability of the simulated lesions is quantitatively evaluated by means of the "receiver operating characteristic" (ROC) method [4, 5]. The differences between the ROC curves resulting for both sets of images are analyzed by appliyng statistical significance tests [6].

2.2 Production of the images

Twelve original chest radiographs, 34.75 cm * 34.75 cm in size, (screen used: Kodak Lanex Medium; film: Kodak T-MAT L; X-ray beam quality: 141 kV, 2 mm Al filter) are digitized by a drum scanner (Hell C299L). The sampling interval on the film is about 45 µm, resulting in a digital image size of 7680 * 7680 pixels. The optical densities on the X-ray film are digitized in the density range from 0 to 2.5 above fog and base and converted linearly to integer values ranging from 0 to 249.

In each image within the region of the lung, 27 regions of interest (ROI) 3.8 cm * 3.8 cm in size are randomly selected and marked by marginal lines. About half of these ROIs are randomly selected to contain exactly one signal simulating pathological lung nodules: these signals are rotationally symmetric, 10 mm in diameter, and have a radial contrast profile like that of an X-ray image of regularly absorbing spheres. The contrast of the signals is near the limit of visibility. Radiologists have not been able to distinguish these simulated lung nodules from true nodules.

In order to produce the images with additional image noise, a two-dimensional noisy image with a certain spectrum is generated by means of a digital image processing system (Kontron IMCO 1000) and then added to the digital lung image. In Fig. 1 two Wiener spectra are shown: the lower curve represents the spectrum of the images without additional noise after they have been printed on photographic film. The upper curve represents the Wiener spectrum of the images with additional noise. For spatial frequencies below 2 line pairs (LP) per mm, this spectrum is about 50% larger. Both spectra contain a noise fraction which is caused by the drum scanner when the images are digitized and reprinted. The difference of the Wiener spectra corresponds to the typical difference of Wiener spectra when X-ray screens of the same type with a speed difference of a factor of about two are used. Any difference in the resolution or modulation transfer function of these screens may be neglected due to the size of the nodules.

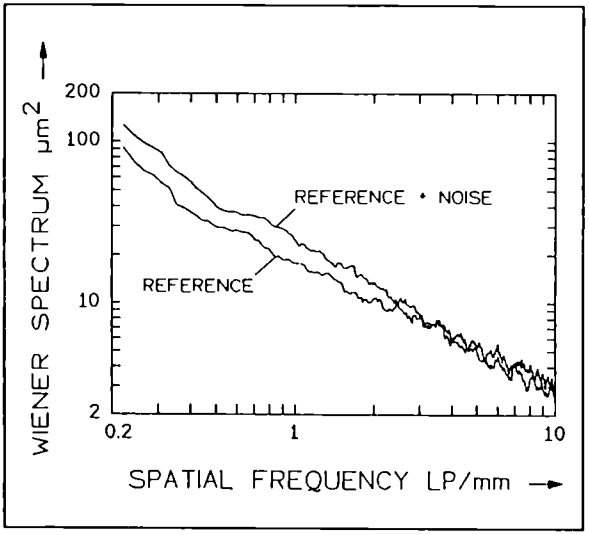

Figure 1: Wiener spectra of the images without additional noise (reference) and of the images with additional noise

The digital images are printed in the original size onto a special laser scanner film (DuPont Cronex MRF 31) by a drum laser printer (Hell C299L). The sampling interval, the image size and the range of optical densities after the processing of the film correspond to the respective values when the images are scanned.

2.3 Evaluation of the images

In a preliminary study on the detectability of low-contrast pattern embedded in a noisy background, the receiver operating characteristic method (ROP) and the nine alternative forced choice method (9-AFC) have been compared with respect of their suitability for the evaluation of the images [7]. Both methods have shown advantages and disadvantages, but for reasons of practicability the ROC method has been preferred for the experiments reported here. Appendix 1 gives a brief outline of the ROC method and its theoretical background.
The lung images with and without additional noise are evaluated in the following way: both sets of images with 7 images and with a total of 189 ROIs each, 94 of which contain lung nodules, are presented to radiologists in random succession. To each ROI the observer must assign a number between 1 and 5 as follows:

1. definitely no lung nodule existing,
2. probably no lung nodule existing,
3. uncertain,
4. lung nodule probably existing,
5. lung nodule definitely existing.

The resulting data are analyzed by the respective computer programs (CORROC2, developed by C.E. Metz, Chicago) [6]. For each observer and for each set of images, a ROC curve is determined by means of the "binormal" model [4,8] which is generally used in this kind of

visual ROC investigation. Thus two ROC curves are obtained for each observer; these curves quantitatively describe the detectability of the lung nodules for the two sets of images.

The ROC curves contain statistical uncertainties, as only a limited number of images can be evaluated. In order to determine whether the two generally different ROC curves do actually differ from each other, statistical significance tests are applied [6]. The outcome of these tests is the probabilities of the detectability of the lung nodules in the two sets of images being different.

3. Results

The two sets of images with and without additional noise have been evaluated by 14 radiologists with at least five years experience and by two graduate radiologists [9]. A typical example of the ROC curves obtained in these experiments is presented in Fig.2, which shows the results of one of the 16 observers. It contains the true positive fraction of detected lung nodules (TPF) versus the false positive fraction (FPF), i..e. the fraction of ROIs where a lung nodule was falsely detected. In Fig. 2 the data points marked by the symbols 'x' and '+' represent the results actually obtained, with the '+' marks referring to the set of images with additional noise. The continuous curves are the ROC curves obtained by a curve fit of these measured data points using the binormal model [1,4]. The dashed curves characterize the statistical uncertainty of the ROC curve for the set of images without additional noise; the two dashed curves comprise the $\pm$ 1σ uncertainty range for this ROC curve. There is a small difference between the two ROC curves: in the images with additional noise the lung nodules could even be detected slightly better than in the images containing no additional noise.

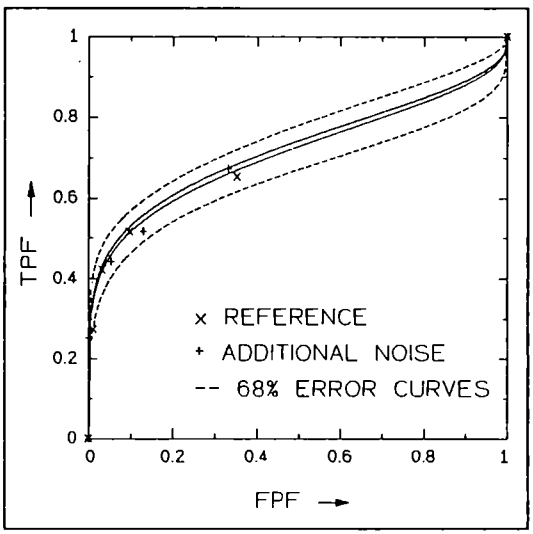

Figure 2: ROC curves obtained for one of the six observers: the (FPF, TPF,) data pairs are marked by simbols ("x": images without additional noise, "+": images with additional noise). The continuous lines are the result of a curve fit with the binormal model; the dashed curves show the 1 uncertainty range for the ROC curve in the case of no additional noise.

However, the $\pm 1\sigma$ uncertainty range clearly shows that this difference is not significant. The significance of the difference between the ROC curves corresponding to the two image sets has been tested by means of a bivariate X^2 -test for the parameters **a** and **b**, taking into account the correlation between the two data sets [6]. At a significance level of $\alpha = 5\%$ this difference is **not significant**.

The ROC curves for the other observers are similar to the curves shown here. The ROC parameters of all observers are shown in table 1. In the case of five of the 16 observers the ROC curves for the images with additional noise were almost identical to the ROC curves for the images without additional noise. For five other observers the ROC curve for the images with additional noise was slightly lower than the ROC curve for the images without additional noise. For six observers it was the reverse. However, in no case was there a significant difference in the detectability of the lung nodules.

Table 1: ROC parameters from CORROC2, * with 7 different lungs, 189 regions of interest and 94 nodules per image set. (See appendix 1 for explanation of the parameters.)

Observer	images without additional noise			images with additional noise		
	a	b	A_z	a	b	A_z
1*	0.75±0.31	0.50±0.18	0.75±0.07	0.84±0.44	0.38±0.22	0.78±0.11
2*	0.61±0.16	0.44±0.10	0.71±0.05	0.65±0.17	0.45±0.11	0.72±0.05
3*	0.55±0.20	0.60±0.13	0.68±0.05	0.77±0.22	0.68±0.15	0.74±0.05
4*	0.94±0.15	0.55±0.09	0.79±0.03	0.88±0.15	0.46±0.08	0.79±0.04
5*	0.74±0.19	0.34±0.10	0.76±0.05	0.74±0.20	0.47±0.13	0.75±0.05
6*	0.83±0.14	0.55±0.08	0.77±0.04	0.95±0.15	0.60±0.09	0.79±0.03
7	0.98±0.42	0.36±0.19	0.82±0.09	1.15±0.36	0.54±0.19	0.85±0.06
8	0.98±0.13	0.55±0.09	0.80±0.03	0.86±0.13	0.62±0.10	0.77±0.03
9	0.79±0.11	0.53±0.07	0.76±0.03	0.85±0.12	0.66±0.09	0.76±0.03
10	1.00±0.12	0.46±0.07	0.82±0.03	1.12±0.13	0.57±0.07	0.84±0.03
11	0.85±0.11	0.51±0.07	0.78±0.03	0.89±0.12	0.66±0.08	0.77±0.03
12	0.84±0.14	0.50±0.11	0.77±0.03	1.15±0.17	0.66±0.15	0.83±0.03
13	0.81±0.23	0.53±0.16	0.76±0.05	0.96±0.25	0.63±0.19	0.79±0.05
14	0.85±0.12	0.63±0.07	0.76±0.03	0.79±0.11	0.58±0.07	0.75±0.03
15	1.11±0.13	0.48±0.07	0.84±0.03	1.11±0.14	0.58±0.09	0.83±0.03
16	1.00±0.12	0.64±0.08	0.80±0.03	0.84±0.12	0.74±0.08	0.75±0.03

4. Conclusions

The investigations have shown that a Wiener spectrum which is about 50% larger does not cause a significant reduction in the detectability of lung nodules in X-ray chest images. As up to now the investigations have been performed with only one kind of signal, generalizing conclusions can only be drawn from these results with caution.

Nevertheless, the results indicate that a least in the case of the diagnostic detection of lung nodules in chest images an X-ray screen-film system with a higher speed can be used without loss in diagnostic accuracy. It can further be concluded that demands on the measuring accuracy for the determination of Wiener spectra may be relatively low.

Acknowledgement

The authors gratefully acknowledge the radiological department of the municipal hospital of Wolfsburg for making the original radiographs available, and all the radiologists that have given their spare time to take part in this ROC study.

Appendix 1. Brief outline of statistical decision theory

Beginning with the early 50s a methodology has been developed for examinations on the detectability of low-contrast signals imbedded in a noisy background: the receiver operating characteristic method (ROC) [1]. Since the early 70s this method has been successfully applied to experiments on the detectability of disease in medical radiographs [4,5,6].

Proceeding from the experimental situation of an observer who has to distinguish between two different kinds of stimuli, denoted as "noise alone" and "signal + noise", it is assumed that the observer bases his decision on a certain decision variable "x". This quantity is influenced by both the physical properties of the stimuli presented, e.g., the optical luminance distribution of an image in a visual detection task, and the psychophysical characteristics of the observer. It is assumed that the occurrence of a value x due to the stimuli with and without signal is described by two probability density distributions p(x | s) and p(x | n), respectively (see figure 3 (a)). Stimuli with quantity x smaller than a certain decision threshold level k are denoted as "noise alone", stimuli with x larger than k as "signal + noise". Integration of p(x | s) and p(x | n) from k to infinity yields the fractions of true positive (TPF) and false positive (FPF) decisions, respectively. That is, a certain (FPF, TPF) pair corresponds to a certain criterion level k: a strict criterion level for the occurrence of a signal results in both a small false positive and a small true positive fraction. A more lenient criterion level results in FPF and TPF near 1.

If the observer uses several criterion levels, he will get several (FPF, TPF) pairs. A plot of TPF versus FPF is called a receiver operating characteristic (ROC) curve (see figure 3(b)). In the most commonly used "binormal model" it is assumed that p(x | s) and p(x | n) can each be described by a Gaussian probability density distribution. The motivation for using this "Gaussian assumption" are the practical advantages for computations and the central limit theorem of statistics. Provided that these conditions are fulfilled, the ROC curve is determined by two parameters: parameter **a** is the distance between the two distributions normalized to the width of the "signal + noise" distribution, and parameter **b** is the ratio of the widths of the "noise alone" and the "signal + noise" distributions.

As an example Fig. 3(b) shows a computed ROC curve resulting from **a**=1 and **b**=1. In the case of **a** = 0 both underlying density distributions have the same mean value, and a distinction between stimuli with and without signal based on quantity x is impossible.

In the (FPF, TPF) plot this case is represented by the main diagonal. If, on the other hand, the overlap of both distributions decreases (parameter **a** increases), the detection task will become easier and the corresponding ROC curves approach the limits FPF=0 and TPF=1 in the (FPF,TPF) plot. The area A_z under a ROC curve is a commonly used quantity for the detectability of the test pattern [4].

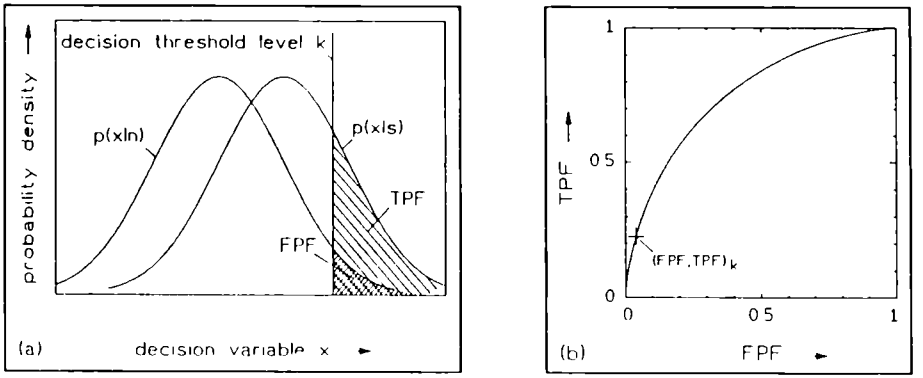

Figure 3: (a) Example of the probability density distributions of decision variable x in the case of "noise alone", p(x | n), and of "signal + noise", p(x | s). For a certain decision criterion level k the fractions of true positive and false positive decisions are denoted by hatched areas.
(b) Fraction of true positive decisions (TPF) versus fraction of false positive decisions (FPF). The ROC curve is computed from the distributions of (a). The point on the curve marked with a cross corresponds to the decision threshold level k in (a).

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REDUCTION OF PATIENT EXPOSURE IN MEDICAL DIAGNOSTIC RADIOLOGY. DOSIMETRY AND RISK (NRPB ASSOCIATION)

Contract Bi6-347g - Sector C22

1) *Wall*, NRPB - 2) *Drexler*, GSF Neuherberg
3) *Kramer*, PTB - 4) *Broerse*, TNO-ITRI

Summary of project global objectives and achievements

Objectives

This contract has involved a number of projects concerned with radiation dosimetry in diagnostic radiology, either for assessing doses and hence radiation risks to patients or for assessing the performance of x-ray imaging equipment. The objectives have been to improve the ease and accuracy with which doses to patients from x-ray examinations can be estimated, to develop methods of risk evaluation and to measure the performance of components of x-ray equipment such as antiscatter grids and automatic exposure control devices that can have a significant impact on patient dose. Some of these endeavours have been concentrated in the areas of computed tomography, mammography and paediatric radiology which are of particular radiological protection interest owing to the relatively high doses involved or the relatively high sensitivity of the organs or the patients exposed.

Achievements

Considerable progress has been achieved in computational dosimetry using Monte Carlo techniques to track the passage of x-ray photons through geometric phantoms representing the patient. Both GSF and NRPB have simulated CT examinations on similar adult phantoms and produced catalogues of data that enable organ doses to be estimated from simple dose measurements on the CT scanner. GSF has simulated exposures typical of Siemens scanners that predominate in Germany whereas NRPB's calculations have covered 27 models of CT scanner from the 5 major manufacturers supplying the UK. Extensive databases enabling organ doses to be calculated for any type of CT examination on a wide range of scanners have been supplied on floppy disc to interested CEC contractors. A common approach to CT dosimetry is now possible throughout Europe yielding the organ doses of interest in radiation protection in a relatively easy manner. With effective doses often exceeding 20 mSv for CT examinations and CT contributing as much as 20% of the collective dose from all diagnostic radiology in the UK, is important that CT doses can be readily and consistently assessed.

Improvements in phantom design continue apace at GSF. Voxel phantoms, based on CT image data from real patients, have been constructed for an infant and a child and an improved method of processing the CT data is being developed during the construction of an adult male voxel phantom. By scaling up or down the size of the voxels in the infant and child phantoms, the influence of patient size on organ doses for a constant exit dose during

typical radiographic exposures has been studied. These results are valuable for assessing the impact of different radiographic techniques and patient size on doses delivered during paediatric radiology and will be reported to the CEC contractors developing quality criteria in this area. NRPB has incorporated a range of mathematical paediatric phantoms in their Monte Carlo programs and the simulation of typical radiographic exposures and comparison with GSF results will take place in the next contract period.

Full dosimetric support was provided by NRPB and GSF to two European-wide trials of the Quality Criteria developed by CEC Study Groups for paediatric and adult radiography respectively. Special postal TLD services were supplied to hospitals taking part in the trials and guidance was developed on reference doses for use in paediatric radiology.

The suspected higher sensitivity of paediatric patients to deleterious health effects from radiation exposure has rarely been quantified and is likely to be affected by the recent revisions in the health effects models used to predict radiation detriment. NRPB has been analysing these new models and has developed a database that enables health detriment from radiation exposures to be evaluated as a function of the age and sex distribution of the exposed population. Preliminary results indicate that for typical x-ray examinations the health detriment per unit dose for paediatric patients will on average be nearly twice that for the general population whereas for geriatric patients it will be less than one fifth.

Although only one organ is irradiated during mammography it is particularly radiosensitive and the low energy of the x-rays used leads to severe attenuation through the breast and considerably complicates the dosimetry. Comparisons of measured and calculated depth-dose distributions in a perspex breast phantom exposed to two types of mammography unit have been made by TNO. The ionisation chamber measurements require a large correction at these low energies for the fact that the chamber displaces phantom material and TNO have made extensive studies to obtain the best method for deriving a displacement correction factor. Measured depth-doses for the same applied potential and half value layer (HVL) differed considerably for the two mammography units. Agreement between measured and calculated depth-doses appeared to depend critically on the spectral data used in the calculations and whether they were matched to measured HVLs or depth-doses, with the latter being the preferred option. The relationship between image quality and dose for various technical conditions has been studied and the relative effectiveness of some technique factors has been seen to vary markedly with breast thickness.

Most modern mammography units incorporate an automatic exposure control (AEC) device to terminate the exposure when a prescribed amount of radiation reaches the image receptor. These should ensure that the same average optical density is produced on the film irrespective of the thickness or density of the imaged breast. However, the radiation detector in the AEC device will not always have the same characteristics as the film-screen combination and equal optical densities may not be achieved under all exposure conditions. PTB have successfully completed an investigation of the performance of the AEC systems in three makes of mammography x-ray equipment. Monte Carlo calculations were used to demonstrate that the

radiation fields transmitted through perspex phantoms closely resembled those transmitted through breast material. The ability of the AEC devices to control optical density of the exposed films was then tested for various tube potentials, phantom thicknesses and diameters, and for four film-screen combinations. Both sets of equipment demonstrated satisfactory control except for phantoms of small diameter, in which case radiation scattered from the unattenuated beam striking the breast support could lead to over or under response of the AEC detector. The manufactures have been informed of these results and a report will be published.

GSF were unable to proceed with a survey of the speed of film-screen combinations commonly used in x-ray diagnosis as the recognised standard methods for doing this are currently being revised by national (German) and international committees. However, it is essential that any revised method recommends the use of radiation qualities that closely match those reaching the film-screen combination after having passed through the patient and an antiscatter grid. GSF has consequently measured such spectra under typical radiographic conditions and found them to be quite different from those used in the existing standard methods for measuring film-screen speed. They have demonstrated that realistic spectra can be simulated by simply filtering the primary x-ray beam with a three-component filter and have reported these valuable results to the revising committees. X-ray spectra have also been calculated within and on the exit surface of water and lung tissue phantoms. They have been published in a catalogue and the exit spectra have been compared with those calculated for some standard dosimetric or imaging phantoms, revealing, once again, the inadequacy of one of the standards.

Project 1

Head of project: *Mr. B.F. Wall*

Objectives for the reporting period

1. Provision of patient dosimetry services and advice for the further development of the CEC "Quality Criteria for Diagnostic Radiographic Images".

2. Development of Monte Carlo programs for calculating organ doses from CT examinations and from conventional paediatric x-ray examinations.

3. Estimation of age and sex specific radiation risks, detriment and QALYs for x-ray patients.

Progress achieved

1. Dosimetry and advice for CEC quality criteria documents

Two European trials of Quality Criteria for Diagnostic Radiographic Images developed by study groups set up within the CEC Radiation Protection Research Programme, took place during the contract period. The first was for paediatric radiography and the second for adult radiography, and for both trials NRPB provided suitable TLDs to measure entrance surface doses from common types of radiograph at up to 30 hospitals in Great Britain, Ireland, The Netherlands and Scandinavia.

In the adult trial, the original radiographs and questionnaires giving examination and equipment details were returned to NRPB with the exposed TLDs. After processing the TLDs, the dose results together with the radiographs and questionnaires were sent on to an expert group in Paris for assessment. Briefly summarising the dose results from NRPB; the mean doses measured at each hospital exceeded the reference dose values quoted in the CEC adult Quality Criteria Document for 17% of the hospitals for chest examinations, 9% of hospitals for lumbar spine examinations and 63% of hospitals for breast examinations.

Similar TLD measurements for other European countries participating in these trials were undertaken by two other contractors to the CEC Radiation Research Programme, one of them (GSF) being a partner in this contract. Experts from the three TLD suppliers also met with representatives of the CEC study group developing the Paediatric Quality Criteria Document to advise them on reference entrance surface doses for paediatric radiography. An appendix on this subject was prepared for the next draft of the Quality Criteria Document for Paediatric Radiography and was published in 1992.

Inter-calibration of the three TLD systems used in the trials of the CEC Quality Criteria had taken place earlier, demonstrating close agreement. During this contract period two further

inter-calibrations were carried out by NRPB with TLD systems being used for patient dosimetry by CEC contractors in the UK (Faulkner) and Holland (Theissen).

In the UK a National Protocol for Patient Dose Measurements in Diagnostic Radiology has been prepared and published in collaboration with the Institute of Physical Sciences in Medicine (IPSM) and the College of Radiographers (CoR). The protocol advocates the same dosimetry techniques and dose criteria as in the CEC Quality Criteria document for adult radiography. It also includes advice on the use of dose-area product meters and provides reference values of dose-area product for a number of types of complete x-ray examination. Doses measured according to the protocol are to be collated nationally by NRPB to provide a continual assessment of patient dose trends in the UK.

2. Monte Carlo organ dose calculations

The main thrust of our efforts in computational dosimetry during the contract period has been the completion and documentation of a series of Monte Carlo calculations for estimating organ doses from CT examinations. In all, 23 series of calculations have been carried out modelling 27 types of CT scanner operating under one or more sets of exposure conditions. In each case, doses to up to 27 organs in a mathematical phantom were calculated for the individual irradiation of 208 contiguous 5 mm thick transverse slabs of the phantom from the top of the legs to the top of the head. Doses from an appropriate selection of slabs can be combined to simulate any type of CT examination of the head or trunk. Since the organ doses are normalised to the free-in-air dose on the axis of the scanner that can be easily measured, the results can be tailored to a particular scanner. A report describing these calculations and providing a sample of sets of normalised organ doses has been published (NRPB-R250, 1991) and the complete dose data for all 23 series of Monte Carlo calculations has been made available on a computer disk to all interested CEC contractors.

The results of these calculations have been used to assess patient doses in a survey of CT practice in the UK that was completed and reported in 1991 (NRPB-R248 and R249). For example, effective dose equivalents were calculated for standard head and body scans carried out according to the manufacturer's recommended procedures to compare the dose-efficiency of different models of scanner. Figure 1 shows that while all models tested deliver similar doses for head scans (2 - 3 mSv) there are large variations in dose for standard body scans (4 - 11 mSv). Even wider variations were observed when local clinical practice was taken into account rather than simply following manufacturer's recommendations. Effective dose equivalents ranging between 2 and 20 mSv and occasionally as high as 30 mSv were seen for some common types of CT examination. In view of these high and variable levels of exposure and the rapidly increasing availability of CT in the UK, a document was published giving formal advice on the protection of the patient in CT with 17 recommendations aimed at ensuring better control of patient doses.

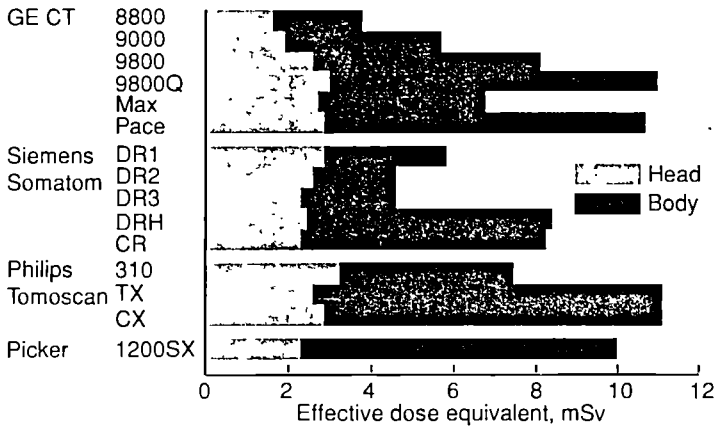

Figure 1 Doses for standard CT head and body scans

Our Monte Carlo programs for calculating organ doses from conventional x-ray examinations have been extended to include all of the organs required to estimate the new ICRP quantity 'effective dose'. A range of paediatric mathematical phantoms representing patients ranging in age from newborn to 15 years has been included in the programs. However, x-ray examinations have not yet been simulated on these phantoms as the appropriate exposure conditions have yet to be determined. This will form part of the work proposed for the next contract period in collaboration with other contractors in the UK and Germany.

3. Radiation risks for patients

The latest information on the health effects of ionising radiation (as discussed in recent reports from UNSCEAR, BEIR and the ICRP) has been analysed in great detail at NRPB and one of the outcomes is a database that enables the health detriment from radiation exposures to be evaluated as a function of the age and sex distribution of the exposed population. Those exposed at a young age are seen to be at considerably greater risk per unit dose than those exposed later in life but, at least for moderately uniform exposures of the body, there is little difference between the two sexes. The relative sensitivity to radiation effects for different age/sex groups depends markedly on how the dose is distributed among the radiosensitive organs so that in diagnostic radiology it varies from one type of x-ray examination to another. A preliminary analysis has shown that for typical medical x-ray exposures the health detriment per unit dose for paediatric patients will be on average about twice that for the general population and for geriatric patients it will be less than one fifth on average. These preliminary findings are discussed in a document giving the NRPB response to the recommendations concerning medical exposures in ICRP Publication 60, to be published shortly. However, further analysis is necessary including a study of radiation detriment expressed in terms of Quality Adjusted Life Years (QALYs) and it is proposed to continue this work in the next contract period.

Project 2

Head of project: *Dr. G. Drexler*

Objectives of the reporting period

1. Survey on the speed of film-screen combinations commonly used in x ray diagnosis.

2. Construction of further realistic (voxel) phantoms for persons of different ages and sizes using CT data.

3. Calculation of organ doses from typical x ray examinations using geometric (MIRD) and voxel phantoms.

4. Calculation of photon spectra inside tissue equivalent phantoms and their dependence on the position inside the phantom.

5. Measurement of entrance surface doses on patients (in support of the CEC initiative to evaluate the impact of the recommendations on "Quality Criteria for Diagnostic Images").

Progress achieved including publications

1. Measurement of x ray spectra behind phantom and anti-scatter grid

Item 1 could not be treated in the planned way since the existing standards for measuring the sensitivity of film screen systems for x ray diagnosis are going to be revised. This could not be foreseen when the project was issued. For this revision it is essential to know the spectral distribution of the radiation impinging from all directions on a point in the plane of the imaging system behind a patient-like phantom and anti-scatter grid; this will enable the use in the standard procedure of a radiation quality most similar to the real one. Because these spectra were unknown up to now, it was decided to determine them experimentally.

Spectra were measured behind a perspex phantom (thickness: 20 cm, field size: 30 cm x 30 cm) and a grid (grid ratio: 8, strips/cm: 40, focus-to-grid distance: 115 cm) for tube voltages of 70 kV, 90 kV and 110 kV by applying a scanning procedure which allows for the detection of beams from all angles up to 52° to the central beam.

It was found that the impact of the grid on the radiation quality has to be considered, that the radiation qualities as used up to now differ widely from the real ones behind patient and grid and that the latter can be simulated by filtered direct x ray beams with regard to spectral distribution. These results were reported to the national and international committees concerned with the revision of standards for determining the sensitivity of film screen systems used in x ray diagnosis.

2. Construction of voxel phantoms

There exists a demand for voxel phantoms derived from CT data of real patients, to validate the numerous results achieved up to now with mathematical (MIRD-type) phantoms and to be able to alter the phantom size by varying the size of the voxels. A technique of phantom segmentation (i.e. processing of patient CT data so as to determine to which organ or tissue every voxel belongs) is under development, offering a high degree of automisation. The scan pictures are processed using the MIPRON image analysis software running on a MIPRON/Kontron computer. As a first step, a voxel phantom of an adult male is under construction whose size resembles that of the ICRP Reference Man. The patient (38 years of age) had a whole body CT scan with 220 contiguous slices of 8 mm thickness. The size of the volume elements (voxels) is ca. 35 mm^3. The final voxel model will consist of more than 200 objects. The segmentation technique being developed will give the possibility of relatively quick segmentation of further phantoms. (CT scans of further patients already exist.)

3.1. Organ doses from Computed Tomographic (CT) examinations

CT is a technique offering a high diagnostic capability but delivers higher doses to the patient compared to conventional radiography. Organ doses were calculated for the CT scanners most commonly used in the FRG for three radiation qualities, using the adult mathematical phantoms ADAM and EVA and a Monte Carlo code. Since CT is poorly standardised with regard to position and length of the scanned body region, the results, which were compiled in a catalogue, are given as mean organ dose conversion factors per CT slice of 1 cm width. The catalogue provides also instructions for evaluating the mean dose to an organ resulting from a particular CT examination, by summing up the contributions to the organ dose from each relevant single slice.

3.2. Influence of patient size on organ doses; scaling factors

In order to evaluate organ doses for a real patient from the calculated doses to a phantom, scaling factors are required to account for the difference in dimensions. With the help of the existing voxel phantoms, a method was developed to obtain organ-specific scaling factors, by varying the size of the patient: the voxel size was changed in one or more dimensions, and the effect of these variations on single organ doses was investigated by Monte Carlo calculations. The 5 most common examinations to babies up to 10 week old and to children at the age of 5-7 years (skull a.p., thorax a.p. and p.a., abdomen a.p. and pelvis a.p.) were considered. It was found that the scaling factors strongly depend on the examination type, beam quality, depth of the organ in the body and the fraction of the organ being directly irradiated.

3.3. Improvements of the mathematical phantoms ADAM and EVA

The new recommendations of the ICRP (ICRP Publication No. 60) concerning new weighting factors relevant to the evaluation of effective dose, introduced a tissue weighting factor for oesophagus, an organ which had not been defined before in ADAM and EVA. This organ was now incorporated, represented by an elliptical cylinder ranging in height from within the neck down to the top of the stomach. The new quantity "effective dose" can

then be estimated from the organ doses to these phantoms whenever it is necessary.

4.1. Calculation of photon spectra inside water (or lung) phantoms

The alteration of several spectra relevant in diagnostic radiology inside cubic or cuboid water phantoms was evaluated using the Monte Carlo code KASTENSPEC. Spectra were calculated at several depths (including the exit surface) and off-axis distances together with their mean photon energy and were compiled in a catalogue.

A cubic phantom of 30x30x30 cm^3 and a cuboid of 40x40x20 cm^3 were chosen as the phantoms most commonly used. The material was water in most cases; in some cases lung tissue was simulated. The incident spectra were typical diagnostic x rays spectra, radiation from radioactive sources and monoenergetic beams (to compose arbitrary spectra).

4.2. Calculation of photon spectra in standard dosimetric or imaging phantoms

In order to investigate whether the phantoms used for quality control accurately simulate an average patient, some of the standard dosimetric/imaging phantoms were simulated, e.g., the DIN (Deutsches Institut für Normung) phantom and the CDRH (Centre for Devices and Radiological Health, USA) phantom. Photon spectra behind these phantoms, as they result after scattering and absorption, were calculated and compared to the relevant spectra of water and lung phantoms (the latter are assumed to simulate the patient). It was found that the DIN standard dosimetric phantom for quality control produces at its exit a considerably harder spectrum due to its copper content, whereas the CDRH calibration phantom simulates the transmission of x rays through a lung phantom accurately, from the spectral point of view.

5. European Community Research Action

Following an EC initiative to evaluate the impact of the EC recommendation on "Quality Criteria for Diagnostic Images", patient doses of 360 average-sized patients resulting from thorax, lumbar spine and breast examinations in Belgium, Denmark and Germany were determined. For this purpose, 36 hospitals and practices were provided by mail with suitable TL-dosemeters to measure entrance surface doses as occurring under routine conditions. The results were transmitted to an expert group to evaluate the quality of the above examinations in the frame of a European Community Research action. Anticipating the detailed findings of this group, it can be already stated that there are large differences between the various countries; furthermore, 26% of all the above examinations lead to entrance doses higher than those recommended in the "Quality Criteria for Diagnostic Images".

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Veit, R., Zankl, M.: "Influence of patient size on organ doses in diagnostic radiology", Radiat. Prot. Dosim. (in press)

Zankl, M., Panzer, W., Drexler, G.: "The calculation of organ doses from computed tomography examinations", Radiat. Prot. Dosim. (in press)

Schneider, K., Kohn, M.M., Bakowski, C., Stein, E., Freidhof, C., Horwitz, A.E., Padovani, R., Wall, B., Panzer, W., Fendel, H.: "Impact of radiographic imaging criteria on dose and image quality in infants in an EC-wide survey", CEC Workshop: Test Phantoms and Optimisation in Diagnostic Radiology and Nuclear Medicine, Würzburg, 17-19 June (1992)

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Project 3

Head of project: *Dr. Kramer*

Objectives for the reporting period

1. Investigation of the properties of the radiation fields behind phantoms of various thicknesses for a number of tube voltages and field diameters by means of Monte Carlo calculations.

2. Investigation of the response of a representative selection of film - screen combinations as a function of tube voltage, phantom thickness and field diameter.

3. Investigation of the radiological properties of automatic exposure control systems produced by three manufacturers with respect to the influence quantities tube voltage, phantom thickness, lateral phantom extension and dynamic range.

4. Evaluation of recommendations for improving the automatic exposure control systems examined with the objective of reducing the number of non- acceptable radiographs and of extending the rated range of the automatic exposure control systems examined.

Progress achieved including publications

1. Properties of the radiation field behind phantoms

Monte Carlo (MC) calculations were carried out to give a quantitative description of the radiation field behind various phantoms. The conditions simulated were chosen so as to match realistic conditions as closely as possible. In the absence of photon fluence spectra for molybdenum-target X-ray tubes in the literature such spectra were obtained experimentally. This was accomplished by means of the following steps. Pulse height spectra were determined with a high-purity Ge-detector for energies from 5 keV upwards. With the help of a response matrix calculated for this detector the pulse height spectra were converted into photon fluence spectra.

The MC-calculations used the spectra obtained for tube voltages of 25, 30 and 35 kV. Phantom materials were breast tissue substitute material (H: 11.1%, C: 51.0%, N:1.5%, O:31.1% from D.R. White *et al.*, BJR 60 (1987) 907) and poly-methyl-metacrylate (PMMA, Perspex) in the thickness range from 2.5 to 6 cm. Circular phantoms with diameters between 10 and 25 cm were used. In the following a brief overview of the results at 6 cm behind the exit surface of the phantom, i.e. approximately in the image recording plane, is given.

For a given mass per area the PMMA and breast substitute material have closely matching properties in view of relative dose contributions of direct and scattered radiation. Depending on phantom thickness, diameter and tube voltage the ratio of the two components, respectively, was between 4:1 and 1:1. In all, there was the tendency that beam hardening was slightly stronger in the breast substitute material than in PMMA. Expressed as mean energy of the photon fluence spectra behind the two phantoms the differences were, however, always smaller than 0.5 keV and are therefore likely to cause only marginal differences under practical circumstances.

Under a few selected conditions the MC-calculations were verified by experimental measurements. When comparing dose rates in front and behind a phantom these verifications

produced - at face value - disapointing results. The differences between calculation and experiment were significantly larger than the statistical uncertainties of the MC-calculations, which were of the order of one percent. Responsible for these differences were seemingly very small errors in the spectrometry. Photons in the lower energy part of the spectrum yield the important contribution to the air kerma in front of the phantom. Due to their strong absorption in the phantom they give, however, hardly any contribution to the dose behind the phantom. Deliberately introduced small modifications of the spectra, which altered the mean energy by less than one per cent could be shown to cause variations comparable in magnitude to the discrepancies mentioned above. Satisfying agreement between experiment and calculation was found, if the ratio of dose contributions from direct to scattered radiation was considered. The conclusion is drawn that for other parameters than the transmission coefficient there is good agreement between calculation and experiment.

2. Sensitivities of film-screen combinations

Such measurements were attempted; however, they could not be concluded successfully due to instabilities in the film precessing.

3. Properties of automatic exposure control systems

The automatic exposure control (AEC) systems of three currently commercially available X-ray mammography units were examined. The machines investigated were Mammo diagnost UC (Philips), Mammomat 2 (Siemens) and Senographe 500 TS (General Electric). As a result of the MC calculations, which showed that perspex represents an acceptable phantom material for mammography, the investigation used semicircular perspex phantoms of diameters 10, 18 and 25.5 cm in the thickness range between 2 and 8 cm. Four film-screen combinations were used: Agfa, Mammoray MR-II and MR-Detail; Du Pont, Micro Vision and Cronex ortho micro; Fuji, Mi-MA and HR Mammo fine; Kodak, Ortho-MA and MIN-R. For the systematic investigation of the properties of the three AEC systems some 2300 radiographs were taken and about 11000 optical densities were measured.

The table shows results for the Senographe for a phantom diameter of 18 cm. The sensitivity of the AEC was adjusted such that an optical density of 1.5 above fog and base was obtained under the chosen reference condition of 28 kV and 4 cm perspex. For the Kodal film-screen combination the table gives the adjustment in terms of dose necessary in order to obtain a constant optical density of 1.5 above fog and base. In everyday operation the sensitivity of the AEC can only be varied in discrete steps of a finite width by means of the so-called exposure correction switch. Depending on its position, p, and for a given combination of tube voltage and phantom thickness this switch allows the dose, D, per radiograph to be varied according to

$$D = D_0 s^p, \quad p=[-3,-2,-1,0,1,2,3,]$$

where D_0 is the dose for p=0, s is the step width which is typically s=1.2. If optimum use is made of this switch, deviations in optical density from the desired value are restricted to values corresponding to plus or minus half a step width.

Table - Factor by which the mAs product has to be multiplied for securing optical density 1.5 above base and fog

phant.-thickn. (cm)	22 kV	25kV	28kV	30kV	32kV	35kV
2.0	1.061	-	-	-	-	-
2.5	1.016	1.009	0.965	0.984	-	-
3.0	1.153	1.021	0.970	0.969	0.876	1.033
3.5	-	1.044	-	-	-	-
4.0	-	1.078	1.000	1.056	0.947	1.150
5.0	-	-	1.074	1.125	1.211	1.257
5.5	-	-	-	1.192	-	-
6.0	-	-	-	-	1.353	1.427
7.0	-	-	-	-	1.580	1.612

For the data of the table figure 1 shows the conditions under which the position of the exposure correction switch should be altered in order to restrict deviations from the desired optical density to plus or minus half a step at most. The loci of optimum transitions are represented as curved lines of constant optical density. The figure within each region gives the optimum setting of the correction switch for that region. Due to the finite power of the generator the upper left corner of the diagram bordered by the straight ascending line is not accessible. This representation of the data allows firstly a very rapid assessment of the quality of the AEC. Secondly the information is presented in a form which makes it easily usable in everyday operation.

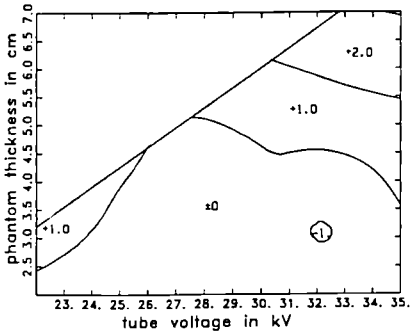

Figure 1

For the various combinations of X-ray machines, phantom diameter, position of the detector of the AEC and film-screen combinations a total of 23 such diagrams were prepared. For all mammography sets differences between the various film-screen combinations investigated were relatively small amounting to one step at most for high values of tube voltage and phantom thickness. The position of the detector of the AEC had also a relatively small effect, which, by and large, also increased with increasing tube voltage and phantom thickness.

Most pronounced effects were found upon variation of the phantom diameter. While the differences between 18 and 25.5 cm diameter were not too relevant, very important differences occured for the transition from 18 to 10 cm. The deviations were, as shown in the two diagrams of figure 2, so large that useless radiographs could only be avoided by making ample and proficient use of the correction switch. For all three machines it could be shown that the unattenuated beam impinging on the patient support cassette and other materials produces considerable amounts of scattered radiation.

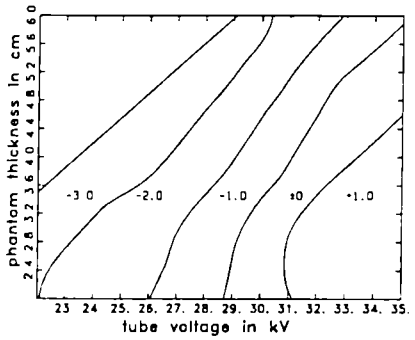

Figure 2 a

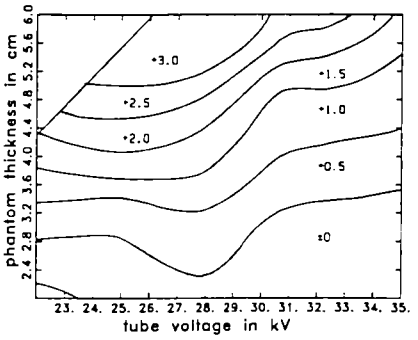

Figure 2b

4. Recommendations to the manufacturers

As figures 2 a) and b) clearly demonstrate the scattered radiation can, depending on the design of the machine, either lead to an over-or to an under-exposure of the radiograph. This can be explained by a greater response of either the film-screen combination or the detector of the AEC to scattered radiation than to the direct radiation. The fact that deviations to either side can be realized in different constructions strongly suggests that a 'neutral' construction should be feasible, which shows good properties for all phantom diameters.

Publications

Kramer, H.M., "Wie gut funktioniert die Belichtungsautomatik an Mammographieanlagen?", *Medizinische Physik*, Ed. K. Jordan, Hannover 1991, p. 176.

A publication of the results is underway.

Project 4

Heads of project: *Dr. J. Zoetelief, Prof. Dr. J.J. Broerse*

Objectives for the reporting period

The dosimetric aspects of the project include absolute dosimetry, monitoring of dose to the breast during actual mammogaphy and dose specification. The technical aspects concern studies on determination of physical image quality as well as optimization of technical conditions (e.g., film/screen combinations, film processing, use of antiscatter grids, tube voltage and automatic exposure control units) to achieve maximum image quality at minimum absorbed dose. Quality control is essential to maintain optimum conditions.

With regard to absolute dosimetry, the aims were investigation of displacement correction factors of ionization chambers in-phantom for various phantom materials, a comparison between results from dose measurements in phantoms using ionization chambers and calculated depth-dose distributions and monitoring of patient dose during actual mammography.

For optimization of mammography, the objectives were determination of image quality with the aid of a contrast-detail phantom and measurement of absorbed dose required to obtain an optical density of 1.0 for various technical conditions.

Improvement of the quality control protocol in collaboration with the Comprehensive Cancer Centre Rotterdam.

Progress achieved including publications

1. Displacement correction factors of ionization chambers in-phantom for mammography

For photons employed in mammography, experimental displacement correction factors obtained by linear extrapolation to zero cavity radius differ considerably from unity. Non-linear extrapolation to zero cavity radius for mammography radiation qualities would lead to different displacement correction factors and their associated errors. Some of the experimental data at different cavity radii suggest a non-linear dependence of the reading on cavity size. There is, however, a lack of extrapolation models.

Absorbed dose calculation in different geometries might provide models of extrapolation to zero cavity radius as well as insight into the dependence of displacement correction factors on cavity size, cavity shape, wall material of the chamber, phantom material and depth in-phantom. Therefore, transport calculations for photons were made with the Monte Carlo Neutron Photon (MCNP) code (Briesmeister, 1986) employing spectrum data from Panzer et al. (1978) for 28 kV X-rays and phantoms of various materials.

The results of calculations for different cavity shapes and phantom and chamber wall materials are presented elsewhere (Zoetelief et al., 1990). Main conclusions drawn from these studies are that extrapolation to zero cavity radius should be made with an exponential instead of a linear function. Displacement correction factors, k_d, are dependent on the shape and size of the cavity and on phantom material. The influence of the wall material of the chamber is related to differences in attenuation between wall material and phantom material. The best estimate of k_d for 0.6 cm^3 thimble type graphite NE2571 ionization chambers based on experiments and calculations is 0.79 ± 0.04 for measurements in PMMA phantoms. The dependence of k_d on depth in-phantom requires further investigation.

2. Comparisons of measured and calculated depth-dose distributions in-phantom

For two types of mammography units, i.e., a Philips Mammodiagnost U and a Soredex Mamex dcS operated at tube voltages of 25, 28, 30 and 31 kV, absorbed dose has been measured with a 0.6 cm^3 NE2571 type ionization chamber at various depths inside a 6 cm thick polymethylmethacrylate (PMMA) phantom. The entrance absorbed doses were derived from air kerma measurements free-in-air. Measured depth dose distributions normalized to the entrance dose show considerable differences for the two types of units when operated at the same tube voltage (Jansen et al., 1992) despite the fact that the measured half value layers (HVL) were nearly the same.

Depth dose calculations in the same irradiation geometry as used for the measurements were made with the MCNP code employing photon spectra for mammography X-ray qualities at tube voltages of 25, 28, 30 and 31 kV according to various authors. In addition, HVL values are calculated for the various spectra and compared to values quoted by the authors. There is generally a significant difference between the quoted and calculated HVL values (Jansen et al., 1992).

A comparison of measured and calculated depth-dose data shows best agreement for measurements at the Philips mammography unit and calculations employing spectral data of Birch et al. (1978) whereas the results of measurements at the Soredex unit are in good agreement with calculations for spectra of Panzer et al.(1978) at 28 and 31 kV. This could not have been anticipated on the basis of measured HVL values. A possible explanation might be that the first HVL refers to attenuation by a factor of two whereas in a 6 cm thick phantom the attenuation is roughly a factor of 100.

It is concluded that the choice of a photon energy spectrum to be used for dose calculations, should not be based on measurements of HVL, but on penetration characteristics obtained from measurements in homogeneous (PMMA) phantoms.

3. Studies on monitoring of absorbed dose to the breast during actual mammography

Experimental data obtained previously on entrance absorbed dose during exposure of breasts and PMMA phantoms of various thicknesses has been analyzed further e.g. in terms of average glandular tissue absorbed dose and average breast dose (see Table).

Table 1: Entrance, central, exit and average absorbed dose values for compressed breast for two tube voltages employing the automatic exposure control unit for the Mamex dc Mag. The values are based on entrance doses determined through measurement of the energy fluence and by using erffective attenuation coefficients derived on the assumption that exit doses for compressed breasts and PMMA phantoms are equal for the same entrance dose and tube voltage.

Tube voltage	*thickness of compressed breasts*	*SSD*	D_{en}	D_c	D_{ex}	$\overline{D}_g$	$\overline{D}_b$
(kV)	*(mm)*	*(mm)*	*(mGy)*	*(mGy)*	*(mGy)*	*(mGy)*	*(mGy)*
26	30	570	1.38	0.227	0.049	0.308	0.336
	40	560	2.02	0.266	0.046	0.406	0.438
	50	550	2.71	0.294	0.043	0.501	0.536
27	50	550	4.22	0.461	0.067	0.783	0.837
	60	540	6.46	0.540	0.060	1.06	1.14
	70	530	8.82	0.570	0.049	1.30	1.40

The average absorbed dose $\overline{D}_g$ for actual mammography is for a 30 mm thick breast on the average about 50 per cent higher than, for a 50 mm thick breast about equal to, and for a 70 mm thick breast about 35 per cent lower than that estimated from PMMA phantoms of comparable thickness at the same exit dose.

Combination of the values of $\overline{D}_g$ from the table normalized to an exit dose of 50 μGy with the distribution of compressed breast thicknesses would result in a mean value of $\overline{D}_g$ of about 0.6 mGy. This is close to the values of $\overline{D}_g$ for the 50 mm thick PMMA phantom corrected to an exit dose of 50 μGy. Variations in $\overline{D}_g$ with compressed breast thickness are approximately a factor of four, whereas variations for the same breast thickness are about a factor of two at maximum.

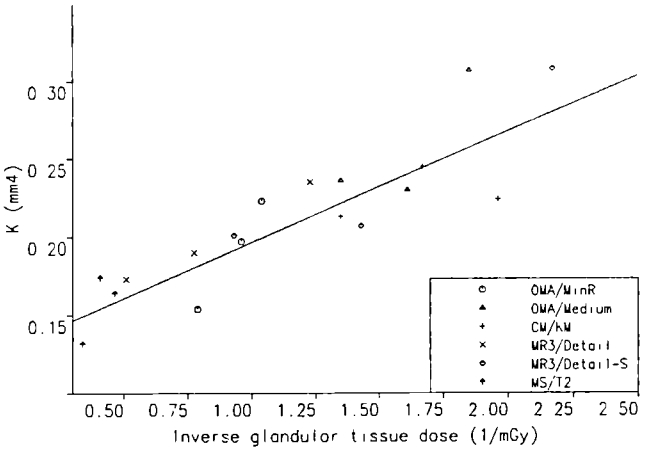

Figure: Image quality parameter K as a function of inverse average glandular tissue absorbed dose for various film-screen combinations. The values refer to a 4.55 cm thick PMMA phantom, 28 kV tube voltage, presence of a grid and various film processing conditions, i.e., developer temperatures and process periods of 35.6 °C and 330 s, 36.0 °C and 180 s and 38.0 °C and 90 s. For each film-screen combination, the highest, intermediate and lowest dose correspond to the shortest, intermediate and longest process periods investigated, respectively.

4. Determination of image quality in relation to absorbed dose for various technical conditions

Image quality was assessed with the aid of a contrast-detail phantom and absorbed dose was measured using an ionization chamber system. Image quality and absorbed dose were determined for different film-screen combinations, tube voltages, film processing conditions and phantom thicknesses and in presence or absence of a grid. Radiographs of the phantoms were made at an optical density as close as possible to 1.0 and examined by two observers. On the basis of the just visible test spots three image quality parameters were derived, including K, i.e. the film average of the square of the product of the just visible diameter and depth.

A lower value of K indicates a better image quality. An example of the results is shown in the figure. More detailed results can be found elsewhere (Zoetelief et al., 1992). The main conclusions are that among the three image quality parameters used, K is the most sensitive one. In general, image quality improves and absorbed dose increases when the tube voltage is reduced, a grid is present and the film process time is reduced. For different film-screen combinations the absorbed dose and image quality are considerably different. For a 1 cm thick phantom decreasing the tube voltage is more effective than the use of a grid for improving image quality. For a 4.55 cm thick PMMA phantom the use of a grid is more effective to improve image quality than is decreasing the tube voltage. It is important to use phantom thicknesses relevant for patients for optimizing image quality and absorbed dose.

5. Quality control

A computer program was developed to improve the evaluation of quality control for mammography. It provides analysis of check source measurements, kVp measurements, depth dose measurements in-phantom, X-ray output and average absorbed dose as a function of phantom thickness.

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QUALITY CRITERIA, TOLERANCES, LIMITING VALUES, DOSIMETRY AND OPTIMIZATION IN A NUMBER OF FLUOROSCOPIC, DIGITAL FLUOROSCOPIC, DSA AND DIGITAL RADIOLOGICAL SYSTEMS

Contract Bi7-014 - Sector C22

1) *Malone* - FDVH/St. James's Hospital/TCD
2) *Boddy/Faulkner* - Regional Radiation Physics-Newcastle
3) *Busch* - Univ. Heidelberg Klinikum Mannheim

Summary of project global objectives and achievements

This contract has initiated, in the '90-'92 period, a concentrated range of work on a broad front aimed at bridging the gap which has opened up between major advances in Digital X-Ray Imaging Technology on the one hand, and the lack of corresponding developments in Quality Assurance, Patient and Staff Dosimetry, and the Optimization Process on the other. The areas of work in which progress has been achieved are clear from the following technical reports submitted by each partner in the Co-Ordination Group. These are more limited than was originally hoped to achieve, due to the inevitable limitation in the resources allocated to the project. However it is hoped to continue the work started within the framework of a new contract, which will extend to 1994. In addition the summary of Objectives/Achievements and Final Report for continued contract Bi6-343 are included with the report for this co-ordination group.

(a) **Bi7-014:** This Co-Ordination Group was established to research Radiation Protection, Quality Assurance, and Optimization problems with Fluoroscopic, Digital and the new Radiological Technologies. It involves three partners, who have developed, in association with the appropriate Commission Officials, a very effective co-ordination methodology to foster the scientific work of the Group and related activities. In total eleven project meetings were held by the participants in the Group, many on the side of other scientific/related meetings. These meetings have been effective in stimulating each of the participants to undertake an approach to the work that would not be possible for individual or smaller groups working in isolation. As a result the output from the project, which includes its possible continuation into the next programme, is considerably greater than would be the case if the sum of the work that might otherwise be contributed by each participant individually was taken. The promotion, development, and bringing to fruition of this type of collaborative venture is particularly sensitive to the contribution from Officials of the Commission, who can do much to enhance such an approach.

The technical work of the Group has concentrated on a number of areas. These principally include: the automatic controls and settings that are part and parcel of almost all digital systems; patient and staff dosimetry; indices of Image Quality, criteria for write-off of equipment and the comparative efficacy of different types of new technology for different types of clinical examination.

With regard to the automated systems involved in almost all aspects of the function of Digital X-Ray Imaging Technology, a number of major findings are now clear. The first, the scope and range of the activities under the control of automated systems is extending all the time. Originally, such systems were limited to exposure control and closely related activities. It is now clear that they operate at multiple levels in most digital systems,

including, where relevant, the selection of post processing algorithms and the final printing of the image. It is equally clear that the criteria for setting up these systems have not been subject to peer review, and need much further study to bring them within the network of the Radiation Protection Optimization Process. Not only are the systems not optimized, but the basis for their operation is not widely known or clearly understood in many cases by those using them. However, within the framework of this project a good start has been made on describing the phenomenology of the operation of these devices, and of identifying the weak links that ultimately can compromise the operation of extremely sophisticated devices.

The Group paid special attention to ensuring standardisation and dosimetry through participation in two international collaborations during the project, and by establishing a special set of definitions of the conditions of measurement to be used by each of the participants in the Group. The patient dosimetry work involved is extremely complex and varied, and much of the effort of the Group has concentrated on attempting to identify the most important set of studies to be selected and performed. This is because of the almost open ended range of work that remains to be done as the range of new possibilities available with new technology extends.

Indices of Image Quality involving objective and subjective measures have been subject to intensive investigation and review within the project. In conclusion the Group feels that for many (but not all) purposes one or two objective indices of Image Quality may provide very useful information. Examples of such indices are noise, signal-to-noise ratio, and resolution. In addition there are circumstances where semi-quantitative evaluations of Image Quality are also extremely valuable. To allow for these situations a set of quantitative contrast detail test objects have been developed, with an associated/ underlying development of the required theoretical framework.

With patient studies a set of intercomparisons has been performed in respect of the effectiveness of different digital technologies for different types of examination such as chest, abdomen, bone etc. In many cases, it has been possible to reach conclusions, some of which are published in the references cited. For example, it is reasonably clear that with the present generation of large image intensifiers, chest imaging is not well performed. On the other hand, it is relatively well performed with the present generation of photostimulable phosphors. This and a range of other conclusions are useful while the use of the present range of technology is being consolidated. However, it is also necessary to have a clear perspective of the potential for further enhancement and improvement of each of these technologies, which in turn has the potential to change these conclusions and lead to the need to have them upgraded.

The work of the group on the criteria on which Image Intensifier/TV Systems are written off in practice, led to considerable discussion and to the presentation of a paper based on a series of case reports in this area, at an IPSM meeting in the U.K. This paper produced an unusually intense reaction, which was echoed in the conclusions of the second session of the Workshop on Radiation Protection and Quality Assurance and Digital Radiology held in Mannheim (see below). The reaction, and the associated discussion it prompted have consolidated the view within the project of the need for further considerable development in this area. This meeting was very successful, and highlighted the need for further meetings in the more widely applied areas of Digital Imaging Technology, such as Digital Cardiac Imaging, DSA, etc. It was also clear to the group that there is a need for teaching meetings

as well as for expert meetings.

The Group was associated with a major Workshop on Radiation Protection and Quality Assurance in Digital Radiology held in Mannheim from the 7th to the 9th May 1992. The workshop drew a wide range of experts from many countries who contributed to developing a consensus on various aspects of Radiation Protection, Quality Assurance, and Optimization of Clinical Application in these areas. The conclusions reached include:

- the fact that the weakest link in the imaging system with most Digital Radiological Systems is the hard copy device. This view had long been advocated within this project and highlights the need for explicit study of the Quality Assurance and Optimization of the these devices.

- Numerous incidents were cited of machines set up by suppliers which provide unacceptable images. These incidents were most frequently cited by those who had purchased the equipment. In some cases, also, settings that worked at one site did not work at another. Examples of situations in which patient dose was much larger than necessary were cited. In many of these cases user training might improve the situation, but in addition there is an evident clear need for both standardisation and optimization of automated devices, at all levels in this new technology. This applies from the acquisition of the image to its final presentation by the laser imager, and includes for example post processing algorithms and the exposure selection/control mechanisms.

- With respect to patient dose assessment the results presented were confused. Part of this confusion resulted from a lack of use of well developed dosimetry units and standards of methodology. The present phase of this work clearly requires a statement of the air kerma at the input to the image receptor and a statement of patient doses based on an instrument such as a diamentor. The quantity most usefully derived from a diamentor reading might not be the commonly used dosimetry units, but could be something such as integral absorbed energy. There is also a clear case with respect to digital technology for development of Guideline Doses as recommended in ICRP 60.

- With respect to Quality Assurance a standardised approach to indices of Image Quality is absolutely essential. This will be assisted by carefully attending to the different levels of Quality Assurance that must be implemented in practice. These include:

  Regular Constancy Checks,
  Acceptance/Write-Off/Rigorous QA Assessment,
  External Audit.

Each of these levels requires different indices of Image Quality, and much of the apparent conflict between indices of Image Quality results from fuzzy thinking about the appropriate one to apply to each level. Acceptance/write-off and rigorous work at this level should be undertaken by the Hospital's own Physics Service if such is available. If not it should preferably be undertaken by an agency independent of the supplier company. The external audit of the effectiveness of Image Quality/Patient Dose should be undertaken within the framework of a study such as the Image Quality study presently undertaken by the European Commission for conventional radiological projections.

- It was felt that the Commission should establish a Group to lead on the development/ protocols equipment write-off and training.

Throughout the project a significant effort has been devoted to attempting to use standardised approaches, and where possible to availing of expertise in other Groups working on related topics within the Radiation Protection Programme. This for example, was the case with respect to AEC work, and with respect to dosimetry protocols.

Project 1

Head of project: *Dr. Malone*

Objectives for the reporting period

Year 1:

(a) Study of the operation of AEC/AGC systems with a view to establishing the basis for their operation; (b) Establishment of standard dosimetry methods and cross calibration with partners; (c) Initiation of Dosimetry and Optimization Studies; (d) Retrospective identification and critique of basis for writing-off a number of Fluoroscopy Rooms.

Year 2:

(a) Continuation of characterization of AEC/AGC and Factor Selection Systems in Digital Units; (b) Development of Criteria for Optimization of Image Quality viz a viz exposures selected by automatic systems; (c) Standardization of definition and methods of assessment of Signal-to-Noise Ratio (SNR); (d) Participation in various aspects of staff and patient dosimetry; (e) Further evolution of criteria for acceptance/rejection of equipment.

Progress achieved including publications

1. Context of Work and Distribution of QA and Optimization Effort

Work in this area was initially supported within the Radiation Protection Programme during the 1985-89 period. The initial contract was tentative, in that the place of digital technology was only beginning to emerge, and the approach to be taken to Quality Assurance (QA) for it was unclear. For example, (a) an approach based on the type of approach used in Nuclear Medicine, which had used Digital Technology for over 20 years might prove suitable; or (b) an approach based on the indices used within the telecommunications industry for Electronic Imaging Systems might be an alternative; or (c) a simple extension of the approach used in Conventional Diagnostic Radiology might be suitable.

It was felt that sufficient work was in progress under heading (c), and hence an approach based on ideas from (a) and (b) was devised which, in short, attempted to evaluate uniformity (based on Nuclear Medicine) and SNR (based on Electronic Imaging Technology) as suitable quality control measurements. Arising from this study a much clearer picture of the nature and impact of digital technology had emerged and was carried forward into the 1990 91 programme, which has just finished. By this time it was clear that Digital X-Ray Imaging Technology including Computated Radiography, DSA, Digital Fluoroscopy, and other technologies would have a major impact. Hence a need to develop a rational and comprehensive QA approach to them was clear. A Co-Ordination Group capable of undertaking this work was established, and its work developed on a number of fronts. Measurements of noise and Signal-to-Noise Ratio (SNR) were brought forward from 1985-89 programme, as providing a useful tool for the assessment of Digital Systems, as well as

providing a limited but frequently effective marker for Image Quality. This and numerous other end points, such as resolution, MTF, noise power spectrum etc. have provided the basis for initial studies within the 1991 programme on QA and Optimization of Digital Systems. Part of this study necessitated a critical review of the impact of Digital Systems in Radiological practice. For example it was found that typically most of the QA effort is employed on the 84% of common examinations that use only 20% (by cost) of the equipment. In practice it was found that little QA was employed on the most expensive 70% of equipment supplied in acute general hospitals, and that there is much need to develop QA Criteria for this large fraction. Furthermore, a single set of examinations (those of the GI Tract) using this fraction of the equipment contribute over one quarter of the population dose from medical radiation. In addition it is clear from studies in Japan, the USA, and the more developed parts of Europe, that computed radiography which is not included in the above statistics is gradually gaining a foothold throughout the community, while little effort is been devoted to the QA of such systems. While the effort employed in QA of digital systems has been relatively small, practically no optimization studies of any consequence have been undertaken.

2. Studies of Automated Control Systems

A major output of the 1990-91 programme has been the explicit recognition of the extent to which the intervention of an operator is being replaced by automated control systems at all levels in Digital X-Ray Systems, and the newer aspects of Medical Imaging. Traditionally this form of automated intervention was confined to automatic exposure control (AEC), and automatic gain control (AGC) devices in Image Intensifier-TV/Film Screen Systems. Now however the scope and range of these devices has greatly increased, while the knowledge of their basis for operation and user familiarity with this knowledge has not increased in parallel. The contribution of this study has been to identify, in part at least, the range of such systems which are now common, as well as characterising the basis for performance of such systems using objective measurements, in a limited number of cases. Automated devices now contribute to the production of the image in radiology in the following ways: (a) AEC; (b) AGC in TV; (c) Automated adjustment of light reaching the image receptor (iris control); (d) pre-programmed exposure values for individual examinations; (e) automated selection of density values in film formatting/laser imaging devices; (f) automated post-processing of images; (g) automated pre-selection of the sequence of exposures to be taken and their timing; (h) automated control of the synchronisation of imaging sequences and contrast pump injections etc.

This range of automated systems greatly reduces the scope for the intervention of an operator, and in some centres has gradually eroded the competence of the operator in contributing to the final Image Quality. Manufacturers have generally been reticent about the basis for operation of these system, and as far as has been determined they have only been optimized with respect to engineering design based on a relatively straight forward user specification. In most cases it appears that radiation protection, dose reduction, and optimization criteria has not played a dominant part in the design of such systems.

With respect to the kind of AEC that is now used with respect to II-TV Systems, the following range of devices has been found in one user department:

(a) AEC based on output of light from the II; (b) automatic adjustment of exposure based on output from TV Camera; (c) AEC device based on 100mm camera, or cine camera;
(d) Automatic Exposure Selection based on serial changer for large films in front of II;
(e) pre-programmed Exposure Selections for several of the above options.

In each case the basis for operation of the AEC Selection System was different from the others, and in most cases the sensitive area within the image to which the AEC responded was different from the others. In most cases the user was not aware of the basis for the operation of the control, that the control was different for each system, or that the sensitive area employed might be different using different imaging methods. In many cases several of these imaging methods are used side by side within seconds of each other in practice.
The performance of each of the above Automatic Exposure Selection Devices has been examined for a number of examples of each case. The indices used to assess the performance of the device have included: input exposure to the imaging transducer; SNR; image resolution; and film density. As a result of the studies the Group now has increasing confidence in selecting the appropriate indicator to describe the performance of an AEC Device. From these studies it is clear that the performance of these systems are not simple, that their design criteria needs to be publicly known, discussed and evaluated so that the devices may be optimized. This is important as they are gradually becoming the main determinant of patient dose in radiological investigations.

3. Automated Devices and Optimization

A number of simple optimization studies were undertaken in which physical parameters were examined to see at what point they no longer improved as the dose was increased. In the case of the parameters examined, SNR and resolution, values were found with relatively low resolution digital images at which there was no point in further increasing the dose, as it would no longer improve Image Quality. However, these simple physical considerations, while useful, leave the additional question of whether the maximum resolution that can be provided by the physical system is in practice required to provide an effective clinical examination. In addition during the conduct of these investigations it was found that the measurements of noise, and the specifications of the image at the point at which it is accessed is not sufficiently reliable to provide the basis for physical experiments on optimization. In view of this, it was necessary to undertake studies on the accessing and down loading of digital data from the appropriate point in the Imaging Devices. This has proved to be a major difficulty, although we have had some success with it.

In reviewing optimization studies, it has become clear that it is an area in which there are major benefits to be derived from the application of expert system technology. The Group undertook studies with a view to defining the range and type of such systems that it would be valuable to explore and implement.

4. Dosimetry

During the 1991 programme our Group participated in two major diagnostic radiology dosimetry intercomparison studies (refs. 1,10). The first was an intercomparison of the dose meters commonly used in Diagnostic Radiology, the second an intercomparison of the diamentor systems to be used in this study in three countries. In both cases the results proved useful. In addition our Group contributed to the consolidation of the standardised approach to dosimetry to be adopted within the framework of the Digital Radiology and new technology projects.

5. Equipment Write-Off

At the end of the 1985-89 study, it became clear that the problem of writing-off fluoroscopic and digital equipment would be a major one, in view of the economic implications of such actions. Likewise during the 1991 programme it has become clear that the question of acceptance testing of equipment in this category is also a major one which has, to date, not been adequately addressed. A careful history has been kept and case reports compiled, of a series of individual incidents in which equipment of high value in this category must be written off. In most cases a full range of the recommended performance tests are undertaken. In addition the actual reason given for writing off the equipment in the formal report to the management of the institution involved has been assessed. In most of these cases patient dose, poor resolution, noisy images, and equipment unsuitable for effective economic repair, are commonly occuring themes in write-off reports. This area continues to remain difficult because the objective criteria required for equipment write-off in the patient directive have not been established on a community wide basis. It is also clear from a review of the available write-off reports that the scientific basis for such criteria remains to be firmly established as a set of objective limitations on performance indicators. The strength of the reaction to a presentation in this area at an IPSM meeting on Patient Dose and Image Quality confirmed the need for such criteria. The absence of any criteria against which the acceptance of computed radiography equipment could be judged was one of the surprising results of the Mannheim meeting.

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Project 2

Heads of project: *Prof. Boddy , Dr. Faulkner*

Objectives for the reporting period

Year 1:

(a) Investigate the use of automatic exposure control (AEC) and automatic brightness control (ABC) systems in fluoroscopy and digital imaging; (b) Design and develop quantitative techniques for image quality assessment; (c) Commence patient dosimetry studies on selected examinations and treatments involving fluoroscopy and digital imaging. Study staff doses and protection in fluoroscopy and digital imaging.

Year 2

(a) Further investigation of the use of AEC and ABC systems for particular examinations; (b) Extend patient and staff dosimetry measurements; (c) Commence performance evaluation of fluoroscopy and digital imaging systems using quantitative test objects; (d) Review the application and usefulness of available test objects in fluoroscopy and digital imaging; (e) Start development of automated quantitative quality assurance measurements in fluoroscopy and digital imaging.

Progress achieved including publications

1. Automatic exposure control (AEC) and automatic brightness control (ABC) systems

A theoretical model has been developed to predict the energy deposition in the input phosphor of an X-Ray Image Intensifier (II) and a photostimulable storage phosphor system. The energy deposited and the dose at the phosphor are calculated, together with the air-kerma reading of an ionisation chamber placed at the image receptor input surface. Allowance for the energy response of the ionisation chamber may be selected if desired. The model has been used to make a series of theoretical predictions for a range of tube potentials and phosphor mass thickness.

A reference point for the AEC is the dose-rate at the II input surface. A survey of input dose-rates has been performed. Results indicate that AEC systems operate under a wide range of dose-rates and hence image quality. This clearly indicates the need for the assessment of AEC performance and the development of standardised set-up and measurement protocols. There is clearly substantial scope for patient dose reduction in this area.

2. Identification of appropriate image quality parameters

Although contrast detail test objects are available for image intensifiers and digital imaging systems, these are entirely unsuitable for optimisation studies. In order to optimise an II or digital imaging system, it is vital to be able to vary the tube potential and technique factors over a wide range. This has necessitated the development of a dedicated set of optimisation

test objects for II and digital imaging systems, a key feature of which is that the radiation contrasts may be calculated for any beam quality. The accuracy of the contrast prediction has been experimentally verified by a radiographic method. These test objects have been successfully used to assess the performance of a digital subtraction angiography system.

Complementing the development of a set of optimisation test objects has been a theoretical investigation into a model which will predict the imaging behaviour of any imaging system, given certain limited information about its performance. In particular, details of the resolution and noise are required. It is anticipated that this model will form the basis of an optimisation prediction programme for any imaging system.

A study into appropriate image quality parameters for the performance characterisation of II and digital imaging systems has been initiated. The view that this should include quantitative measurements of image noise and resolution and subjective indices (e.g. contrast-detail detectability and receiver operation characteristic analysis) was supported by the conclusions of the recent expert meeting in Mannheim.

Some of the problems associated with the use of contrast detail test objects on II systems and the interpretation of the results obtained have been studied. In particular, the effect of visual bias on the contrast detail performance has been demonstrated. This has resulted in a modified measurement protocol for II's in which the input dose-rate and the relation between the magnification of the displayed image and viewing distance is held constant.

3. Dosimetric and optimisation studies

It is important to measure dose levels and assess radiation risks in fluoroscopy and associated digital imaging techniques. A vital part of establishing norms for radiation doses is the development of standardised patient dose measurement protocols. Unfortunately, no such standard protocols exist for fluoroscopy and digital imaging, thereby making transEuropean comparisons difficult. This is a major problem identified at the recent expert meeting in Mannheim. This Group has been active, both in collaboration with its partners in this project and on a national scale, via the Institute of Physical Sciences in Medicine, in the promotion of common dosimetry protocols.

The use of large area ionisation chambers linked to an electrometer is particularly suited to patient dose measurements in fluoroscopy in which the technique factors, field size and projection direction change throughout the examination. International studies into doses in fluoroscopy and associated digital imaging techniques are being undertaken, using in the main, dose-area product meters, complemented by direct patient dose measurement using thermoluminescent dosemeters (TLD). The dose-area product meters have been calibrated against a dosemeter with a calibration traceable to a national standards laboratory and the TLD in an independent performance test.

In view of the limited published data, a survey has been performed to determine typical dose levels for children of different age groups undergoing a number of common radiological and fluoroscopic examinations. (Chapple et al, 1992).

The implication of magnified fields of view on patient doses in fluoroscopy under automatic exposure control has been studied on a number of II's. It was discovered contrary to popular belief that a change in field size will result in a comparable or lower dose-area product rate.

4. Assessment and reduction of staff doses

Interventional radiological examinations in general, involve long screening times, often resulting in high doses to staff and patients. In certain circumstances, individuals with a high interventional radiology workload may receive a dose which necessitates them becoming classified radiation workers. The development of accurate personnel monitoring arrangements for these individuals is required. It is also important to be able to measure and predict the scattered dose to individuals performing interventional radiology examinations.

A simplified method of assessing scattered doses to individuals working in diagnostic radiology has been developed. A series of experiments were performed in which the air-kerma-area product and the scattered radiation dose in the vicinity of a patient couch were simultaneously measured for a range of tube potentials and x-ray field sizes. Further measurements were performed to discover the effect of focus/skin distance (FSD) on scattered radiation distributions. It was deduced from the results of this investigation that the scattered radiation at a given position correlates with the air-kerma-area product measured at the tube housing, irrespective of tube potential and field size. It is possible to predict scattered radiation levels from a baseline measurement and a knowledge of the air-kerma-area product to within an accuracy of 20%.

A number of studies into dose levels to individuals performing fluoroscopy procedures have indicated that it is the radiation dose to the lens of the eye which may be a critical factor in the determination of whether the person becomes a classified radiation worker. In addition, there are many other situations in which it is important to consider extra eye protection in fluoroscopy.

With the change in tissue weighting factors proposed by ICRP, there are a number of organs in the head and neck which make a significant contribution to the effective dose of workers in radiology who wear a lead apron. The effect of various protective devices worn to shield organs in the head and neck has been studied.

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Project 3

Head of project: *Dr. Busch*

Objectives for the reporting period

Year 1:

Digital Image Intensifier (II) Radiography: (a) Study of image capabilities in comparison to conventional film/screen radiography (spatial resolution, contrast, dose); (b) Optimization of exposure parameters for imaging of the gastrointestinal tract by phantom, specimen and patient studies; (c) Constancy tests for digital image intensifier radiography (single exposure);

Digital II radiography and storage phosphor radiography: (a) Comparison of different digital and analog imaging methods for the chest by phantom and patient studies.

Year 2:

Digital II radiography: (a) Patient/staff dosimetry for different kinds of examinations with comparison to conventional film/screen radiography; (b) Optimization of parameters of low dose examinations (e.g. paediatrics, pelvimetry); (c) Constancy tests (including DSA).

Storage Phosphor Radiography: Comparison of different digital and analog imaging methods of the chest including newest film/screen combination (KODAK: InSide-System).

Progress achieved including publications

To a growing extent radiological image information is recorded, stored and processed as digital data. For the large field of projection radiography today new digital image recording methods are available (digital image intensifier radiography, storage phosphor radiography). Advantages and disadvantages of these methods, especially the opportunity to lower the dose, has been evaluated within this project. Digital image intensifier radiography has been used in the Clinic in Mannheim for DSA examinations and digital projection radiography instead of conventional film/screen radiography. Measurements have shown that compared with 100mm technique and film/screen radiography, digital radiography has poorer spatial resolution, but improved contrast resolution. The most common use of digital radiography was for examinations of the gastrointestinal tract. Using the demonstration of the mucosal fine relief pattern as a criterion of image quality, digital image intensifier radiography was able to achieve this satisfactorily. Comparison with film/screen radiography showed no loss of diagnostic information. Advantages of image intensifier radiography are reduced radiation dose, the possibility of post processing, storage and transfer of digital data.

Due to a wide dynamic range it is possible to vary the dose of digital image intensifier radiography for each type of examination according to the required image quality. To define the possible decrease of dose compared to film-screen radiography (speed 200) the dependence of spatial resolution and contrast detectability upon dose was evaluated. Acquisition

parameters were fixed for different types of examinations and tested by imaging anthropomorphic phantoms as well as patients images. Our results demonstrate that the dose can be reduced by 60% for double contrast examinations and 85% for mono-contrast studies. Although digital image intensifier radiography is less suited for chest and skeletal imaging, a 14 cm image intensifier can be used for imaging small lesions. If poor image quality is accepted (e.g. pelvimetry, sometimes in paediatrics), a maximum reduction of 95% is possible.

Luminescence radiography is a new digital imaging modality, which can be used instead of conventional film radiography for many kinds of examinations. Imaging capabilities of luminescence radiography were compared with film/screen radiography by test images and examinations especially in intensive care radiology. The results demonstrate, that luminescence radiography is an advantageous imaging method for intensive care radiology, which guarantees a constant high image quality, lowers the dose and gives new opportunities for post-processing, storage and transfer of digital images.

In recent years new analogue and digital techniques have become available for chest imaging. A study within this project compares conventional film/screen, asymmetric film/screen (InSight), equalisation (Amber), storage phosphor and digital image intensifier techniques by phantom exposures and patient examinations. The quality of chest images of 43 patients was classified by seven observers in four different hospitals. According to the results of phantom measurements and previous study, digital image intensifier radiography was excluded from the patient examinations because of its low image quality. The Amber system had the best image quality. Images of the storage phosphor system were of good quality in both mediastinal and peripheral fields of the chest.

For a high level of performance, quality assurance procedures for digital radiography are as important as for conventional film/screen radiography. Yet no standardized procedures have been established for routine use for digital projection radiography and digital subtraction angiography (DSA). In Mannheim test phantoms have been used for evaluation of performance characteristics and for quality assurance measurements of digital projection radiography and digital subtraction angiography for 2 years. Different methods have been developed for digital image intensifier radiography, but this can be transferred to digital storage radiography as well. For 12 months two phantoms for the DSA-mode of digital image intensifier radiography have been employed. These phantoms were built with regard to the DIN-Norm 6868 part 8. For the "single shot" mode of digital image intensifier a standard test-phantom (PTW-Norm) was used. With this phantom spatial resolution, contrast detectability and dynamic range could be measured. Primary goal of our test phantom measurements was the development of effective test procedures for performance characteristics and quality control, which are easy to handle with limited additional equipment, not time consuming and representative for clinical imaging. The experience of one year demonstrated, that by the evaluation of these phantom images a constant high performance level can be achieved.

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THE EFFECTIVE DOSE EQUIVALENT DUE TO X-RAY DIAGNOSTIC EXAMINATIONS AND THE IMPACT OF QUALITY CONTROL ON MEDICAL EXPOSURE

Contract Bi6-343 - Sector C22

1) *Schmidt,* Klinikum der Stadt Nürnberg

Summary of project global objectives and achievements

The consequences of the newest radiological techniques with regard to the radiation exposure of patients and staff are being determined in this project.

The interventional procedures in radiology increase considerably with high ratios of expansion. The exposure of the patient, well as that of the radiologist is relativly high.
A general documentation of all interventional procedures was started in Germany. Besides the type of intervention, inquiries of different parameters were made, which influence radiation exposure, like time of fluoroscopy, number of images, configuration of the X-ray unit and the standard datas of the X-ray unit.
More than 60% of all interventions are angioplasties. About 50% of these examinations were performed with digital systems (DSA). With these interim datas, the risk resulting from the radiation during the interventions can be evaluated (ICRP60). Of course, this risk depends on the individual dose of the procedure and on the age of the patient. In comparison to the surgical risk the radiation risk seems to be in the order of one or two factors lower. The benefit of the patient, who is treated with this method, is without doubt much higher than the expectation to survive without therapy.
Corresponding with the relative high exposure of the patient and the complexity of the interventions, the radiation exposure per examination, which the staff has to endure is high. With ring dosimeters (TLD), the exposure of the hand of examiners and the assistant personnel was determined. The equivalent dose of the hand of examiners lies in the range of 0.05 to 0.3 mSv per intervention. The exposure of the assistent staff is nearly a factor of 10 lower. However an excess of the dose limit is only expected with more than 1500 examinations per year.
The exposure of the radiologist, measured by means of a radiation survey meter on the chest, can come to 5 mSv per year. The exposure of the assistant for interventions is relativly high in comparison to other X-ray diagnostic examinations, especially in the course of exposures of the head (eye and thyroid), as has been demonstrated by measurements of cooperating groups. Last but not least, in consequence of the strong increased ratio and the progressive claims of the radiologists to the image quality (dose), this field of radiological diagnostic deserves increase of attention in the future.

In addition to the project Bi-F-137-D of the CEC, the suitability of digital storage phosphor foils for mammography was investigated. The analysis of physical parameters of image quality such as resolution and exposure, and the ROC-analysis of conventional and digital mammograms showed, that at the present time neither in image quality nor in dose reduction with the use of digital storage phosphor foil no advantage can be seen.

Project 1

Head of project: *Prof. Schmidt*

Objectives for the reporting period

- To start a central German documentation on interventional radiology
- To analyze the frequencies of interventions
- To analyze the frequencies of localizations and methods
- To determine mean values of fluoroscopic time and number of images
- To estimate the mean exposure of patients due to interventions
- To compare the risk of exposure due to interventions with the surgical risk
- To measure the equivalent dose of body and fingers of staff in interventional radiology
- To analyze dependencies of staff exposure
- To compare conventional and digital mammography

Progress achieved

1. Interventional radiology

The rapidly increasing number of interventional procedures in radiology and the radiation exposure of patient and staff, which is linked with it, was the reason to start an extensive German documentation on the interventions performed in the years 1990 and 1991. The inquiry was conducted in the Klinikum Nürnberg. 35 of more than 100 institutions, who are participating at the study, reported more than 6000 interventions in the year 1990. 60% of all interventions are angioplasties (Figure 1).

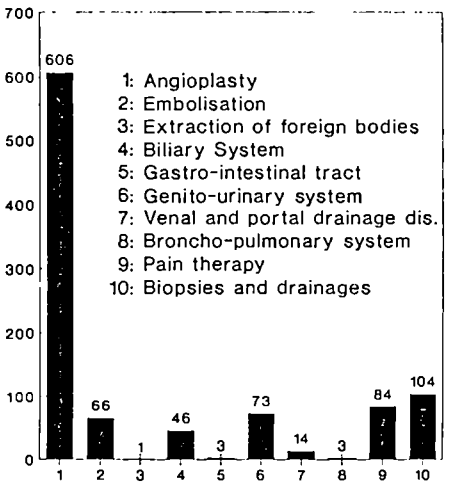


Figure 1 - Frequency of interventions per 1000 total interventions in Germany. (10.000 interventions at 35 institut.)

2. Patient dose

The localization of the intervention is crucial for the estimation of the radiation exposure of the patient. Approximately 40% of all angioplasties are performed at the body (Figure 2). Additionally relating to different medical questions, special dose-relevant data were collected, such as: type of the X-ray unit, kind of the imaging system, time of fluoroscopy and number of images per intervention. All over Germany, half of all interventions are performed by using DSA (Figure 2).

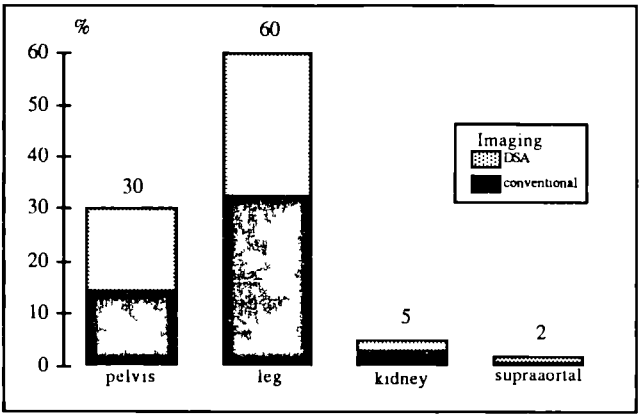


Figure 2 - Frequency of localizations of Angioplasties, Germany 1991.

The mean values of fluoroscopic time and number of images per intervention, respectively Angioplasty, is shown in Table 1.

Table 1 - Mean values of time of fluoroscopy and number of images

	all interventions	angioplasties
time of fluoroscopy (s)	630	680
number of images	10,5	12,5

Hence is has to be calculated, that angioplasties cause the highest exposure by the way of comparison. In addition, so-called standard data from the protocol of the acceptance tests were taken as example. Out of this, a statistical weighted mean dose at the image receptor could be evaluated. The dose per image is in the range of 1 µGy (0.1 µGy to 10 µGy). The dose rate depends to a high extent on the type of the X-ray unit and has a mean value of about 1 µGy/s with a similar range. Considering the radiation quality, the attenuation factor of the equipement, the mean depth of organ and the distribution of localizations, one could roughly estimate a mean effective dose for patients of 2 mSv per intervention.

The individual radiation risk, depending on the kind of intervention and the age of the patient, is in the range of 10^{-3} percent to 1 percent. The alternative method to radiological interventions is the operation.
Surgery and anaesthetization are connected with a lethal risk too. In Table 2 the orders of the risks can be compared.

Table 2 - Lethal risk of interventional radiology, surgery and not treated disease (within 5 years)

	risk per 1000
intervention	0.1
surgery	10
no theraphy	100-1000

Because of the till now incomplete registration of the participating institutes interventions' and the unknown relation of a bewildered population, the collective exposure is currently very roughly estimated.

The contribution of interventions to the collective dose due to medical irradiation may be approximated with 1%, assuming one angiographic examination or two inteventions per year and per 1000 inhabitants (spot-check Nürnberg).

This rough examination and the registered increase of interventional procedures (at the hospital) forces attention to the exposure of these examinations.

3. Staff dose

It's impossible to establish a direct proportionality between radiation exposure of patients and staff, as other investigations have shown too. Nevertheless a high exposure of staff have to be expected in radiological interventions. One reason is the examiners short distant to the patient, while applicating contrast media. The most important factors, which the exposure of the examiner influence, are to some extent entirely unrelated. A selection of these factors is in Table 3.

Table 3 - Factors, which influence the radiation exposure of the examiner

- position of examiner
- sensitivity of the imaging system
- radiation quality
- overhead or undercouch tube
- fluoroscopy time and number of images
- experience of the examiner
- kind of intervention
- patient parameters (obesity)
- protective devices

Some dependences were investigated in cooperation with five Bavarian hospitals. TLD-measurements have shown, that the dose at fingers, thyroid and eye does not correlate very

well with exposure parameters. Not even an unambiguous dependence with the mean time of fluoroscopy could be determined.

The relative position of examiner and patient is obviously of prime importance. Typical dose values of examiners and assistant are shown in Table 4.

Table 4 - Fluoroscopy time, number of images, equivalent doses on fingers, relative frequency of interventions (mean values per examination)

X-ray unit	1	2	3	4
tube position	overhead	overhead	undercouch	undercouch
fluoroscopy	DSA	conventional	DSA	conventional
images	image intens.	direct radiogr.	100mm	image intens.
time of fluoroscopy	400 s	400 s	600 s	320 s
no. of images	5.7	6.5	21.5	13
frequ.of interventions	0.04	0.35	0.96	0.12
equivalent on fingers:				
examiner/mSv	0.25	0.26	0.07	0.29
assistant/mSv	0.03	0.03	0.04	0.02

The comprehensive results of the staff radiation exposure of inteventions are:

- the highest exposure of examiners is measured at the forehead,
- the exposure of the assistant is at a factor of 10 lower than the examiners,
- the mean dose of staff is lower by using undercouch tubes,
- of prime importance is the position of the examiner and the complexity of the intervention (complications),
- the exposure of hands per intervention is usually not higher - even lower - than in angiography,
- the mean equivalent dose of the hands is 0.25 mSv per intervention,
- an excess of dose limits is normally not to expect,
- additional radiation protection is recommended.

Digital Radiography

One of the digital methods in radiology is the usage of storage phosphor foils. On account of its large dynamic range, this method gives the possibility to reduce the patient's exposure. In this connection the project No. Bi-F-137-D was continued, to investigate the suitability of storage phosphor foils for mammography. For this reason, physical parameters and now ROC-analyses of conventional and digital mammograms were compared. The advantages and disadvantages of storage phosphor foils in mammography are listed in Table 5.

Table 5 - Advantages and disadvantages of storage phosphor foils.

Advantages	Disadvantages
- high object latitude - good blackening of image irrespective of exposure - good presentation of subcutan regions	- less distinct recognition of microcalzifications - black haloes around bigger microcalzifications - brightenings in the honeycomb-structured graphs of fatty tissue - underexposed images have an intensified noise - a resolution of maximal 5 lp/mm can only be achieved with doses higher than for conventional film screen systems

For the present time digital images are not suitable for mammography. Microcalzifications cannot be detected as reliably as with conventional film screen systems.

QUALITY ASSURANCE AND REDUCTION OF PATIENT EXPOSURE

Contract Bi7-019 - Sector C22

1) *Fagnani*, CAATS - INSERM - 2) *Moores*, Integr. Radiological Services Ltd
3) *Alm Carlsson*, Univ. Linköping - 4) *Dance*, The Royal Marsden Hospital
5) *Flioni-Vyza*, Greek Anti-Cancer Institute - 6) *Rimondi*, Univ. Ferrara

Summary of project global objectives and achievements

The coordinated project was characterised by fruitful exchanges among laboratories already involved in the previous CEC radiation protection programme, and, on the other hand, by the establishment of positive collaborations with laboratories which recently joined the project.

Two main observations have emerged from the work carried out during the two years' duration of the project:

1) All the laboratories involved in the project have made considerable efforts in order to respect and achieve their own project objectives ;

2) The participating laboratories constitute an homogeneous group and represent a coherent example of European cooperation.

Despite the preliminary difficulties encountered at the begining of the project, differing according to the specific country concerned (availability of radiological and computer equipment, institutional and governmental approval, compatibility of computers, etc), the coordinated programme's final objectives -- practical implementation of QA in diagnostic radiology and design of ES for QA -- have been fully achieved by all the participating laboratories.

In particular significant progress was made by those laboratories involved in the theoretical aspects of computing codes, mathematical simulations, and the design of physical phantoms for mammography (Project n°3, n°4, n°7).
On the other hand, the laboratories concerned by the practical implementation of QA have produced very interesting results and achieved tangible improvements in terms of patient dose reduction and promotion of the CEC quality criteria document (Project n°1, n°2, n°5, n°6, contract Bi6-214, contract Bi6-211, contract Bi6-136).
For the first time in diagnostic radiology, an Expert System for Quality Assurance prototype for mammography was designed through an effective collaboration established among the particpating laboratories.

Project 1

Head of project: *Dr. Fagnani*

Objectives for the reporting period

The main objectives of the contract were :

- to establish and to evaluate for the first time in France a comprehensive Quality Assurance protocol in the framework of a pilot campaign of breast cancer screening ;

- to contribute to risk analysis for medical exposure using the QALY methodology ;

- to collaborate in the design of an Expert System prototype for Quality Assurance in mammography.

Progress achieved including publications

Part 1 : Screening for breast screening campaign

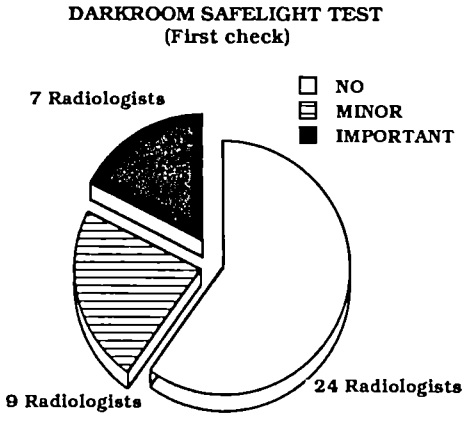
In France there are ten mammography screening campaigns officially recognized by the National Social Security System as "Pilot Experiences" devoted to the early detection of breast cancer. All these campaigns are organized on a regional scale and involve private practitioners almost exclusively.

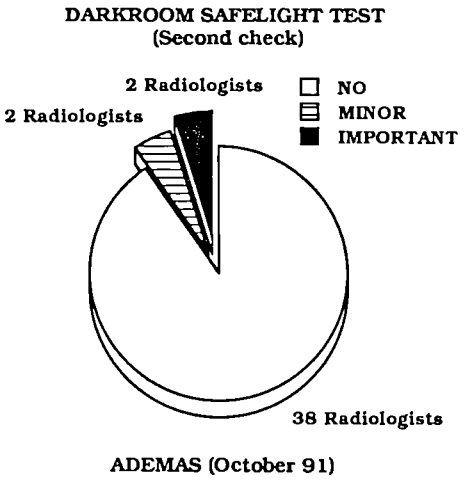
Among these regional experiences, **only one** is at present concerned with Quality Assurance : the Bas-Rhin, campaign called "ADEMAS". This campaign includes 46 screening centres spread over a triangle of 300 Km in the eastern part of France, next to the German border. This campaign started in June 1989 without either previous technical evaluation nor precise technical requirements concerning the radiological equipment involved.

In such a context, characterised by a total absence of information or training in QA and QC, and considering the total lack of QC equipment in the 46 centres (phantoms, measuring instruments, test-tools), a QC protocol specific to this screening campaign and local technical conditions was defined in early 1990. The elements included in this protocol were chosen in order to identify the "status quo" of local radiological equipment and technical practices. The protocol addressed the four aspects of the mammography chain, including :

- production of the image (X-ray generator, focal spot size) ;
- image recording (X-ray film, cassettes, screens) ;
- image processing (processor, dark room conditions) ;
- image visualisation (viewing boxes).

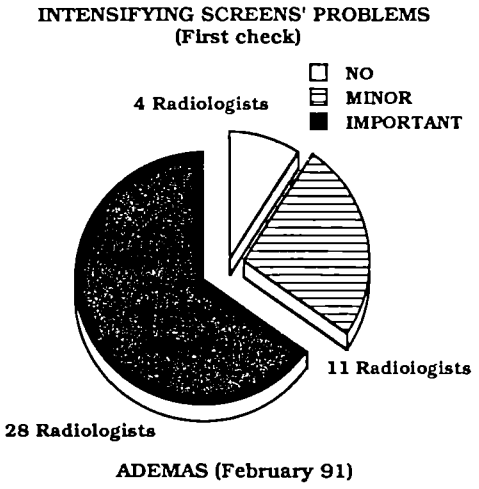
According to the frequencies of the tests included in the designed QC protocol, three visits to each radiological center were performed respectively in February 1991, October 1991 and April 1992 in order to evaluate trends in dosimetry and image quality.
Obtained results clearly demonstrated the absolute necessity for a well-established quality control program within the context of such a screening campaign and for strict compliance with its technical requirements.
Significant improvements were made in all steps in all mammography imaging chains through the effective implementation of quality control measurements and collaboration with the involved paramedical staff.
In order to illustrate observed trends, a comparison of some relevant indicators of quality of equipment used in such a screening campaign between the first and the second round of Quality Control measurements is given below.





In 16 out of 40 radiological centres (40% of the total number), darkroom safelight problems were found in February 1991 while, after the implementation of the appropriate proposed corrective actions, in only 10% of them, those problems were still present in October 1991.
A further reduction of these problems was observed after the third check in April 1992 when only 5% of all radiological screening centers still had minor problems.
Concerning intensifying screens, the following two pie charts clearly illustrate the positive evolution that has occurred between the two consecutive Quality Control checks.

Again, a very significant and tangible improvement in the image quality and dose was obtained through the practical implementation of the appropriate technical corrective actions.



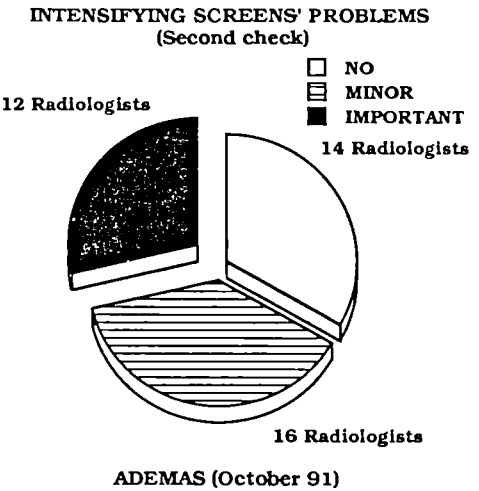


Image quality performances were measured by using Leeds TORMAX test phantom according to the most common technical parameters used in each screening centre (kVp, mAs, grid, film-screen combination ...)

The overall findings of the first control (February 1991) enabled us to identify a very poor quality of image expressed in terms of high contrast limiting resolution power : minimum value of 5.6 lp/mm, maximum value of 8.9 lp/mm, mean value of 7.4 lp/mm.

The second control, carried out after having taken into account technical advice and equipment modifications (focal spot corrections, revision of the automatic exposure control systems, purchase of new cassettes, cleaning of intensifying screens, etc...) revealed a substantial improvement of the same limiting resolution power : minimum value of 8,9 lp/mm, maximum value of 14,3 lp/mm, mean value of 12 lp/mm.

As far as dosimetry is concerned, entrance surface dose measurements for a 5 cm tick perspex phantom were performed in each radiological centre by using TLDs specifically calibrated for mammography.

As one might have expected, a very large range of doses (normalized to a breast thickness of 4,5 cm) was found for all centres at the first control : average entrance dose value of 16 mGy with a minimum value of 4.5 mGy and a maximum value of 34 mGy.

In accordance to the actual efforts performed at the level of each component of the mammography imaging chain, the second and third controls confirmed the efficacy of such a Quality Control initiative and enabled us to estimate a corresponding dose reduction of 30% in October 1991 (average dose value of 11,8 mGy) and further 15% in April 1992 (average dose value of 10,1 mGy)..

In a more general way, problems were identified at different levels of the entire

mammography chain : kVp consistency, dark-room safelight, film-screen contact, developer temperature, film-screen sensitivity, focal spot size, etc.
In conclusion, this evaluation permitted us : to set up a management framework to facilitate higher quality screening; to identify technical corrective actions; to stimulate and improve multidisciplinary team work, and to disseminate information to all those who are responsible for training and educational initiatives.

Part 2 : Risk analysis for medical exposure

The expression of the detriment associated with exposure to low doses of ionizing radation has most often been expressed as life-long risk estimates of extra-mortality or extra incidence of cancer. Such extrapolations do not permit evaluation, in terms of cost effectiveness or comparability, of efforts to reduce this risk by quality-control measures, early screening programmes, or targetting of the at-risk population. In particular, the detriment is usually expressed as man-Sieverts or cancers, units which do not permit comparison with other risk-reducing actions in the planning of health services or allocation of financial resources. We have tried, therefore, to explore the possibility of applying the QALY (quality adjusted life years) methodology of cost-utility analysis to the domaine of diagnostic radiology.

An extensive bibliographic review has shown that QALY methodology is almost exclusively applied to the evaluation of therapeutic interventions, and particularly in the case of chronic diseases. To date, we have identified only one application of QALYs to diagnostic radiology, that of B.Wall and J. Russel, published in the Journal of Radiological Protection. He qualified the cost-utility advantage of various radiation protection devices in the reduction of patient dose. His cost-utility results compare favorably with various therapeutic interventions and could be used to make investment decisions.

Nevertheless, important theoretical questions remain concerning the QALY methodology in general, and the appropriateness of an application to diagnostic radiology. This methodology is based upon psycho-statistical research in the general "healthy" population, producing a value matrix of health states. Application of the methodology requires the comparison of at least two real health states for the patients in question, usually before and after a specific treatment, or a comparison between two groups of patients treated with different interventions. Secondly, the transferability of the value matrix to non-British cultures is hotly debated and various efforts (EuroQol, for example) are underway to create internationally valid matrices. Furthermore, few validation efforts exist concerning the generalisation of Quality-of-life results from a specific study to subsequent modelling efforts elsewhere. This is particularly important for work on diagnostic radiology, because such models would integrate the Quality-of-life results of cancer patients from previous work in the evaluation of years-of-life-gained from avoided cancers. Finally, such calculations do not express the preferences of patients for different diagnostic alternatives (including non participation) which have varying levels of added risk.

This preliminary work leads us therefore to conclude that application of the existing QALY methodology is premature and controversial. While such an application is essential in systems, such as in Britain, where financial decisions are already being made using this technique, it remains theoretical elsewhere. This reality gives us additional time to explore and resolve the methodological issues which remain. It is probable that application of this methodology to interventional radiology would be more feasible and justifiable at the present

Part 3 : Expert system for QA in mammography.

The work carried out in this field was mainly oriented towards the collection and the interpretation of relevant data which could be used by a Knowledge Based System (KBS) as an imput to make hypotheses on equipment malfunctions which might have an influence on observed image quality variations.
Data collected through the ongoing survey of radiological equipment used within the context of the Bas-Rhin breast cancer screening initiative (about 600 Leeds phantom images corresponding to a large variety of equipment, kVp settings, filtrations, film-screen combinations...), together with the daily sensitometry results obtained in a Parisian X-ray hospital department (4 months of follow-up), were, therefore, made available to the other European laboratories involved in the design of an Expert System (ES) for Quality Assurance prototype in mammography.
A fairly comprehensive database was created, and a first attempt was made to identify the influence of both kVp reproducibility, accuracy, and x-ray processors' parameter variations on image quality through data analysis.
Such an analysis enabled us to better understand how to correlate QC test results with the corrective actions to be taken in order to correct abnormal situations.

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Project 2

Head of project: *Dr. Moores*

Objectives for the reporting period

1 To implement routine quality control data analysis techniques and assess the relevance and importance of quality control measurements in predicting objective image quality, as measured from test phantom images and the x-ray exposure requirements.

2 To develop a localised model for assessment of risk in mammography and relate quality control programmes employed in ongoing European breast screening programmes to radiation protection requirements.

Progress achieved including publications

1. Progress achieved

1.1 The development of a data base analysis regime for results of measurements undertaken as part of quality control programmes underpins the effectiveness of any attempts to implement management strategies including expert systems which utilise these data. The predictive efficacy linking "cause" and "effect" must be generated by the experience gained in interpreting previous results. Consequently a great deal of effort must be expended initially in developing a "pure data" set which is unencumbered by unforeseen factors and whose results can be directly related to any changes in radiographic conditions.

The previous report to this project outlined the effect that possible inter-observer variations can have on measurements of limiting resolution undertaken from radiographs of bar pattern images. If these variations are much greater than variations produced by changes in the radiographic conditions then the validity of such a quality control measurement would be in doubt.

Further work on this fundamental aspect of quality control strategies has been pursued during the intervening period. In particular factors which can affect the threshold contrast-detail size measurements, which form such an important basis of quality control measurements employing test phantoms, have been investigated. Attempts have also been made to relate these results to other aspects of imaging performance.

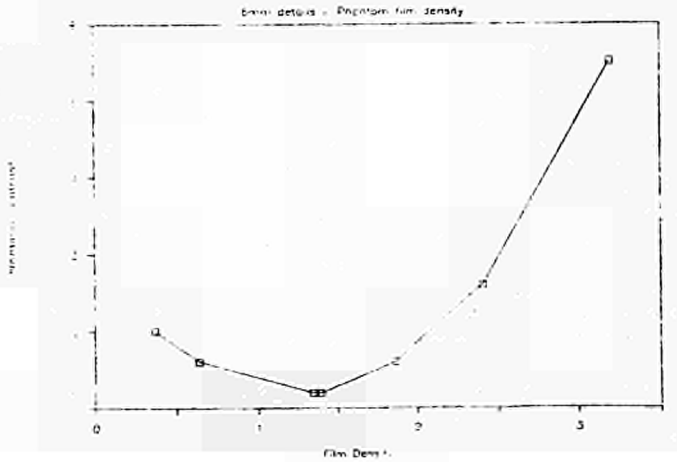

Figure 1 shows the variation of threshold contrast for a 6 mm diameter detail size as a function of film density. The results clearly demonstrate a film density effect on this type of measurement and the sensitivity to such changes is dependent upon the relative magnitude of the discrete contrast values present in the test phantom employed. The magnitude and variation with film density depended not only upon the imaging system itself but also the size of the detail concerned. These results leads one to ask the question as to whether or not threshold contrast-detail measurements need to be supported by some other more fundamental quality control measurements. One such type of measurement which takes into account film density effects, concerns the application of perceptibility curve analysis to imaging systems.

The perceptibility curve corresponds to the just discernable or threshold density difference for each density in the image. Preliminary work has been undertaken on developing a simple test phantom which permits threshold density difference values to be measured as a function of density. Initial results have been encouraging but a great deal of further effort is required.

1.2 A comprehensive review of the scientific literature covering the field of risk-benefits in breast screening programmes employing mammography has been performed. Virtually all studies suffer from two main limitations:-

(i) They nearly all employ average breast sizes and compositions in the assessment of dose to the breast and, therefore, risk.

(ii) Assessment of doses received during examinations do not tend to employ measurements during actual examinations.

Within the framework of operational radiation protection, the application of hypothetical doses to standard sized patients has

limited impact. The European scientific experience over the part decade has clearly highlighted that the implementation of radiological practices is extremely varied and gives rise to wide ranges of patient doses at the operational level. Therefore, a study of doses received by women attending for breast screening was undertaken within the Mersey Region. This was undertaken on over 8,000 women attending 7 breast screening units. The mAs and kV value employed in an examination was recorded for a random selection of women. From known calibration factors for each x-ray unit, obtained during twice yearly quality control measurements, the entrance surface dose was calculated for each women. Knowing the half-value-layer (HVL) of the beam and the kV employed, enabled the absorbed dose to breast tissue to be calculated using previously published conversion factors.

These results, which are not yet available for dissemination, together with the literature study clearly highlight the following:-

1. That existing quality control initiatives in mammographic breast screening programme which employ standard phantoms to assess breast dose do not appear to fulfill Article 41 - 44 of the Euratom Directive 80/836 in respect of the application of operational protection to reference groups.

2. Mechanisms by which dose and risk to all members of a screened population including those with larger/denser breasts by means of phantoms have not yet been clarified given the variations in sensitivity with beam energy of different phantom materials as compared to actual breast tissues.

3. The use of molybdenum target x-ray tubes appears unsuitable for all breast sizes and compositions and, therefore, dose reduction and optimization principle cannot at present be universally applied for all women participating in breast cancer screening programmes when only molybdenum target x-ray tubes are employed.

4. The recent Report 60 of the International Commission of Radiation Protection indicates that the multiplicative risk model rather than the additive model applies to cancer risk from ionising radiations. This implies that cancer statistics for individual countries needs to be incorporated into radiation risk models including those applicable to mammography.

Publications

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Scientific Basis for Standardisation in Radiology (1991). B.M. Moores. In Medical Radiation Protection Practice within the E.E.C. Edited by M. Fitzgerald and J.M. Courades. British Institute of Radiology, London.

A new phantom for mammography (1991) B.M. Moores. Letter to the Editor. British Journal of Radiology. VOL 64, p 639 London.

Radiation protection aspects associated with well women breast cancer screening programmes. (In press) B.M. Moores and E.T. Henshaw. British Journal of Radiology. London.

Project 3

Head of project: *Prof. G. Alm Carlsson*

Objectives for the reporting period

The main objective was to generate results with the computer program developed during the first period. Examinations representing a broad variety of scattering conditions (chest, skeleton, paediatric radiology) should be simulated and the choice of anti-scatter grid and X-ray spectrum optimized for each diagnostic task, the latter including specification of contrasting test detail and image receptor. The mean absorbed dose in the phantom is used as risk parameter in the optimization.The program should be expanded to allow derivation of effective dose in order to test the validity of the results obtained using the mean absorbed dose as risk indicator. Experiments should be performed to check the validity of the computational model. Strategies to expand the computer code to include simulation of crossed grids and inhomogeneous phantoms should be developed.

Progress achieved including publications

1. Introduction and organisational details

The primary aim of this project is to use a Monte Carlo model to optimize the selection of anti-scatter grids in diagnostic radiology. The methodology for this work has been set out in close collaboration between the Department of Radiation Physics, Linköping University (Sweden) and the Department of Medical Physics, Royal Marsden Hospital, London (U.K.). The implementation and running of the computer code have largely been made by a Ph.D. student from Linköping under the supervision of the project leaders at both departments. The student has spent three months in London each year to facilitate integration of the codes developed separately by the two departments in the past. As the project requires powerful computational facilities, the computers at both departments have been used to run the code. Staff from both departments have spent time together planning the computer calculations, analyzing the results and preparing joint scientific papers [1-9] which will provide complete description of the work. Strategies to extend the computer code to include simulation of crossed grids and inhomogeneous phantoms have been developed, but have been regarded as secondary aims. The main emphasis has been on the work with homogeneous phantoms and linear grids to allow derivation of results for a large variety of grids and test situations. Careful validation of the code was accomplished by comparison with measurements reported in the literature [1]. Instead of performing new experiments of our own, we found it more efficient to use the time available to generate results from the code. Since the two groups in Linköping and London have worked closely together, the report of this project must be read in conjunction with that for project 4.

2. Method

2.1 Monte Carlo model

Monte Carlo methods are used to model the imaging chain, including X-ray spectrum, phantom, anti-scatter grid and image receptor. A detailed description of the methods, with a complete validation of the code is given in [1]. The special feature of the code is the use of the collision density estimator to compute physical quantities, such as contrast and signal-to-noise ratio, SNR, at points in the image plane with high precision. Analytical and Monte Carlo methods are combined to derive the transmission of primary and scattered photons through the anti-scatter grid, including the generation of secondary photons within the grid itself. Monte Carlo methods are also used to simulate the energy absorption properties of the image receptor. The code allows easy variation of input parameters, such as X-ray spectrum, composition and size of the phantom and contrasting detail, size and position of radiation field, anti-scatter grid, air-gap and image receptor.

2.2 Grid performance parameters

The grids have been evaluated for screen-film and digital radiography. In the former, image quality is quantified in terms of image contrast and in digital radiography in terms of the SNR. The change in image quality when a grid (or an air-gap) is introduced for scatter rejection is expressed by means of the contrast- and SNR improvement factors, CIF and SIF. The dose penalty paid in screen-film radiography to maintain film optical density is expressed by means of the dose increase factor DIF.

2.3 Strategy for grid comparison and optimization

2.3.1 Grid cover and interspace material

The influence of replacing aluminium in grid covers and interspaces with fibre materials on values of CIF, SIF and DIF was investigated for a number of grids with fixed geometry. The cover and interspace materials were changed from aluminium to fibre and the tube potential was varied between 50-150 kV. In order to select a well designed grid for the case study project below, 44 commercially available grids were compared in three different situations (table 1).

2.3.2 Optimization of grid ratio and tube potential - case studies for screen-film radiology

From the above study, superior and inferior grid designs could be identified but it was not possible to give advice on the optimal choice of grid for a particular examination. To enable such an optimization, a novel approach was used. The goal was to find the combination of tube potential and grid design (ratio, strip width, strip density) which yields the lowest mean absorbed dose in the phantom for a desired contrast. To allow for a wide range of scatter conditions it was important to investigate a large number of cases (table 1). To limit the calculations, this investigation was performed for only one type of a well designed grid (36 lines/cm, 36 µm lead strip width) at a range of grid ratios [4]. In some cases, grid performance was compared to that of an air-gap.

2.3.3 Global optimization of grid design for screen-film and digital radiography

To treat the complete problem of optimizing the combination of grid design and tube potential, the grid parameters were varied outside the range of values available in commercial grids. In these optimizations, the same strategy of comparing doses at equal image quality (contrast or SNR) as in the above case studies was used. The number of examinations had to be limited (table 1) to make possible an investigation in which the strip width, strip density and grid ratio could all be varied.

Table 1. Summary of study areas .

Study area	*Examinations Investigated*	*No. of cases*	*No. of expts.*	*Ref.*
Cover and interspace materials	Als1, Ach1, Ppe1	150	300	3
Screen-film Case studies	Als3, Ach3, Asfr3, Asff3, Pch3, Ppe3	60	360	4
Screen-film Optimization	Als3, Ppe1	300	1800	5
Digital studies	Aki3, Asff3, Als3	30	240	6

A: Adult, P:Paediatric
1: AP or PA view, 2: Lateral view, 3: Lateral and AP or PA views
ch: chest, ls: lumbar spine, pe: pelvis, sfr: small field radiography, sff: small field fluoroscopy, ki: kidney

2.4 Examination parameters

Homogeneous blocks of soft tissue were used to represent the patient. Thin details of bone, iodine and soft tissue were used as contrasting details. The focus-film distance, field size and position were selected to represent different radiological examinations of adults and children. The wide range of conditions investigated are shown in table 1. Each case in the table corresponds to a single projection and grid. Each computer run at a fixed tube potential is counted as a single experiment. The CPU time was 6 months on a Vax Station 3100.

3. Results and discussion

3.1 Grid cover and interspace material

Figure 1 shows results from the survey of commercially available grids for a paediatric examination at 70 kV. The main reason for the differences in DIF is the materials used for covers and interspaces, the lower doses being obtained with grids using fibre materials for these components. The dose reduction is larger at lower tube potentials and at higher grid ratios, thus dose reductions between 20-40% are possible. Up to 10% higher values of CIF, mainly due to a smaller reduction of the primary contrast in the low atomic number interspaces, can be found with fibre grids. Grids of different construction can, however, give similar and good performance as indicated by the overlap of the leftmost curves in figure 1.

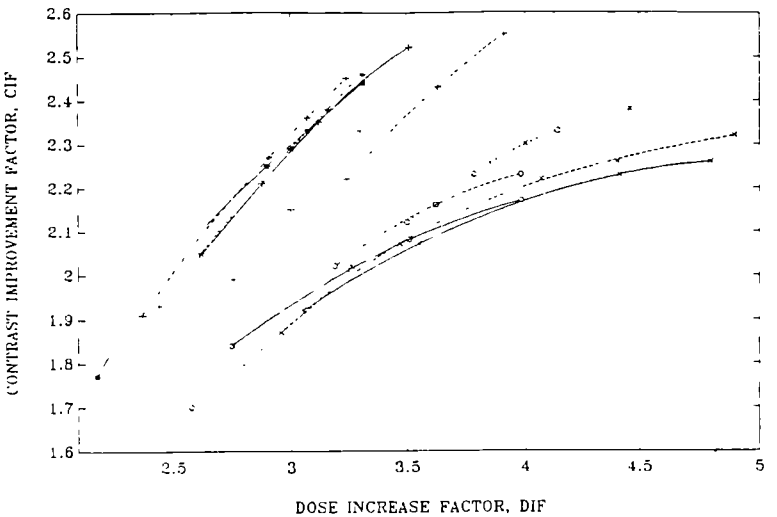

Figure 1. Contrast improvement factor CIF as function of dose increase factor DIF for a paediatric examination (AP-view) at 70 kV. The grid ratio increases in going from the left to the right along the curves. Legends: SMIT Röntgen grids; *——*: 24 strips/cm, +——+: 28 strips/cm, +-·-+: 36 strips/cm, +- -+: 40 strips/cm, *- -*: 44 strips/cm and +·····+: 60 strips/cm. LYSHOLM grids; o——o: 30 strips/cm, o- -o: 40 strips/cm and o·····o: 70 strips/cm. MITAYA grids; x——x: 34 strips/cm, x- -x: 40 strips/cm and x·····x: 60 strips/cm.

3.2 Optimization of grid ratio and tube potential for screen-film radiography

In examinations which generate large amounts of scatter, the use of high grid ratios at high tube potentials yields lower mean absorbed dose than low grid ratios at low tube potentials. High grid ratios may be preferable, because shorter exposure times can be used but careful alignment of the grid in the beam is necessary to avoid de-centering problems. With less

scatter, grids with low ratio can be used provided the tube potential is varied accordingly to achieve the desired contrast level. Here, a 20 cm air-gap can be advantageous with respect to patient mean absorbed dose but must be used in combinations with lower tube potentials and higher tube charges compared to an optimal grid.

3.3 Global optimization of grid design for screen-film imaging and digital radiology

Examples of optimal grid designs in screen-film radiology are given in table 2 for the three examinations in table 1.

Table 2. The grids are defined by strip density, grid ratio and lead strip width and have cotton fibre grid interspaces and carbon fibre covers. They are used at the contrast equivalent tube potential TP_{eq}. The scatter-to-primary ratio in the centre of the image without grid are (from the left) 2.0, 4.4 and 5.9, respectively.

Strip density (cm^{-1})	Grid ratio	Lead strip (μm)	TP_{eq} (kV)	Grid ratio	Lead strip (μm)	TP_{eq} (kV)	Grid ratio	Lead strip (μm)	TP_{eq} (kV)
	Paediatric AP-view			Adult Lumbar Spine AP			Adult Lumbar Spine lat.		
25	9	30	69	12	30	84	18	50	128
40	12	20	69	18	20	84	25	30	127
70	15	10	66	25	10	79	25	30	112

In examinations with large amounts of scatter, grid ratios ≥ 18 are optimal. Such high grid ratios are not used today. It may be worth noting that calculations have been performed assuming an ideal geometry set up. In practice, problem with alignment of grid in the beam may preclude use of very high grid ratios.

In digital radiography, optimal grid design will be the same as in the screen-film case. Optimal tube potentials, however, are considerably lower.

4. Summary, conclusions and recommendations for further work

These are given for the combined work from the two Institutions in the following report (Project 4).

Publications

1. SANDBORG M., DANCE D.R., PERSLIDEN J. and ALM CARLSSON G. 1992. A Monte Carlo program for optimizing image quality and patient absorbed dose in diagnostic radiology. To be submitted to Comp. Prog. Biomed.
2. ALM CARLSSON G. DANCE D.R., PERSLIDEN J. and SANDBORG M. 1991. Monte Carlo modelling of the physics of image formation in X-ray diagnostics. Invited paper, World Congress on Medical Physics and Bioengineering, Kyoto. Med. & Biol. Eng. & Computing. 29, Suppl., Part1,13.
3. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Selection of anti-scatter grids for different imaging tasks: the advantage of low atomic number cover and interspace materials. Submitted to Br. J. Radiol.
4. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Monte Carlo study of of grid performance in diagnostic radiology: factors which affect the selection of tube potential and grid ratio. Submitted to Br. J. Radiol.
5. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Monte Carlo study of grid performance in diagnostic radiology: task dependent optimization for screen-film imaging. To be submitted to Br. J. Radiol.
6. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Monte Carlo study of grid performance in diagnostic radiology: task dependent optimization for digital radiology. To be submitted to Med. Phys.

7. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Optimization of anti-scatter grids: a collection of method and results. Linköping University report series, Report ULi-RAD-R-72, ISSN 0348-7679.
8. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Monte Carlo study of the design and performance of anti-scatter grids. Presented at Radiology&Oncology '92, Birmingham.
9. SANDBORG M., ALM CARLSSON G., PERSLIDEN J. and DANCE D.R. 1992. Comparison of different materials for test phantoms in diagnostic radiology. Presented at the Workshop "Test phantoms and optimisation in diagnostic radiology and nuclear medicine" Würzburg June 15-17 1992. Submitted to Radiat. Prot. Dosim.

Project 4

Head of project: *Dr. D.R. Dance*

Objectives for the reporting period

The principal objective for the reporting period was to advise on the use of the computer program to study the performance of anti-scatter grids and to optimise the choice of grid and X-ray spectrum. The conditions studied should be representative of a wide range of examinations for adult and paediatric radiology including situations with both large and small scattering volumes. The optimisation should be made in terms of the contrast (conventional screen-film systems) and the signal-to-noise ratio (digital systems) in the image, using the mean absorbed dose to the phantom as a cost function. As a second objective, preliminary studies should be made of the extension of the program for the study of crossed anti-scatter grids, and the influence of tissue inhomogeneities on the magnitude of the scattered radiation. As a third objective, the results of the program should be tested against experimental measurements.

Progress achieved including publications

1. Introduction and organisational details

This project has been concerned with the development and use of a computer program to study and optimise the performance of anti-scatter grids in diagnostic radiology. The work has been made jointly with the Department of Radiation Physics, University of Linköping. Much of the code has been developed by a student in Linköping, but the theoretical background for the computer algorithms adopted, the design of the model, the planning of the computer experiments, and the interpretation of the results have been shared between the two Departments. To facilitate this collaboration, both project leaders have made annual visits to the other Institution, and the Swedish student has worked in London for a three month period each year. Because of the joint nature of the project, this report should be read in conjunction with that from project 3, which also presents the combined work of the two Departments.

The use of the computer program has been extremely productive[1-9]. It was decided therefore to concentrate mainly on the first objective of the project, rather than secondary objectives, because of the importance of the results from this work to the present, practical situation of reducing scatter by the use of grids of conventional design. This work required the combined computing resources from both Institutions because of the large number of different situations and grid designs which were studied. It was, however, possible to make a preliminary study of the methodology which could be used for the second objective, and this is discussed below. No experimental study was needed for the third objective of testing the computer program, as it was possible to do this using the wide range of experimental results already available in the literature. Full details are given in [1].

2. Method

2.1 The Monte Carlo computer program

The computer program used to model the patient and anti-scatter grid is described in detail in Sandborg et al [1]. Particular features are the use of the collision density estimator to calculate imaging quantities at any point in the image plane, and the use of analytic methods and analogue Monte Carlo to treat the transmission and scattering of photons by the grid. The program can also be used to study scatter rejection using air-gap techniques.

The patient is simulated as a rectangular block of tissue and the size and composition of this block and of the size of the incident radiation field are easily varied. Contrast and

signal-to-noise-ratio (SNR) are calculated for a test detail whose size and composition can also be changed and the mean absorbed dose to the phantom is used as a measure of risk. (This was justified by comparison with the use of effective dose as a risk measure [4]).

An extensive database of X-ray spectra and image receptors has been established together with details of anti-scatter grids which are commercially available, so that the program can be used to investigate a wide range of imaging configurations for screen-film and digital radiology.

2.2 Grid parameters

Anti-scatter grids can be specified in terms of the number of lead strips per cm (line density), the thickness and height of the lead strips and the thickness of the interspace material. It is usual to quote the ratio of the height of the lead strips to the thickness of the interspace material (grid ratio). It is also necessary to specify the composition of the interspace material, and the thickness and composition of the top and bottom grid covers.

2.3 Grid comparison and optimisation strategies

The performance of anti-scatter grids is usually assessed by comparing the contrast improvement factors (CIF), SNR improvement factors (SIF) and dose increase factors (DIF) associated with their use. We have followed this approach for the first stage of our work [3], which was concerned with the choice of materials used for the grid interspace and covers.

This conventional approach, however, cannot provide advice as to which grid design to use in a particular imaging situation: image quality depends upon the choice of grid and tube potential, and the combination of both aspects is not addressed. We have therefore developed a new optimisation strategy based on fixing a measure of image quality and finding the combination of anti-scatter grid and tube potential which can achieve this level at the minimum possible dose to the patient [4-6]. For screen-film imaging, the contrast of a small test detail is used as the measure of image quality whereas for digital radiology, the SNR is used. In the former case, the mean dose to the patient block is estimated for fixed energy absorbed in the screen whereas in the digital case, it is estimated for fixed SNR.

2.4 Grid comparison and optimisation studies

The applications of the Monte Carlo program reported here can be divided into four main study areas and 14 radiographic projections as shown in table 1. The objectives of these

Table 1. Summary of study areas.

Study area	*Examinations Investigated*	*No. of cases*	*No. of expts.*	*Ref.*
Cover and interspace materials	Als1, Ach1, Ppe1	150	300	3
Screen-film Case studies	Als3, Ach3, Asfr3, Asff3, Pch3, Ppe3	60	360	4
Screen-film Optimization	Als3, Ppe1	300	1800	5
Digital studies	Aki3, Asff3, Als3	30	240	6

A: Adult, P: Paediatric
1: AP or PA view, 2: Lateral view, 3: Lateral and AP or PA views
ch: chest, ls: lumbar spine, pe: pelvis, sfr: small field radiography, sff: small field fluoroscopy, ki: kidney

study areas are discussed with the results . Each case in the table corresponds to a single projection and grid design, and each computer run at a fixed tube potential is counted as a single experiment. The references cited give complete descriptions of the methodology, and of the results and conclusions obtained. The use of air gaps was also investigated for the screen-film case studies.

The total CPU time neded to complete these study areas was six months on a VAXstation 3100. This huge CPU burden, together with the time required to analyse the results of the large number of experiments, precluded extension of the program for some of the secondary objectives of the project, although detailed strategies for these were developed .

2.5 Extensions to the program

A study has been made of the amendments required to incorporate crossed grids into the program, and a strategy developed which involves duplication of the analytic calculation of the transmission through a single grid together with generation of scatter within two single grids placed in contact and with the grid lines running at right angles.

The computer program has been developed in a modular and well structured fashion, and because of this it has also proved to be straightforward to design a strategy for the addition of a simple inhomogeneity within the model.

3. Results and discussion

3.1 Cover and interspace material study

The advantage of using low atomic number materials instead of aluminium for the construction of the grid interspace and covers is well known. However, little data is available to quantify this advantage in terms of image quality (contrast and SNR) and dose saving for different radiographic projections, tube potentials and grid designs. Such data are essential to provide proper scientific justification for the introduction of dose saving (low atomic number) grid designs. The objective of this study was therefore to quantify this advantage for both screen-film radiology (comparison of CIF and DIF values) and digital radiology (comparison of SIF values). The comparison was made in two ways. Firstly, grids of fixed geometry but constructed with low atomic number interspace (cotton fibre) and covers (carbon fibre) or with aluminium interspace and covers were compared for five grid ratios and four tube potentials in the range 50 -150 kV. Secondly, 44 commercially available grids were compared for three different imaging situations representative of low, medium and high scattering volumes, and both adult and paediatric examinations (table 1). These comparisons were made at two values of the tube potential. Full details are given in [3]. The dose reduction found varies with the irradiation conditions, and is generally larger at lower tube potentials, higher grid ratios and lower strip densities. A typical reduction in absorbed dose is 30% (adult lumbar spine AP view, 70 kV, grid with 36 lines/cm and ratio 12)

3.2 Screen-films case studies

The cover and interspace study showed that there is a wide range of "dose saving" grids which are "well designed" and have good performance. The objective of the screen-film case studies was to determine which grids and tube potentials would work best in various imaging situations using the optimisation procedures discussed above. To limit the number of cases run, the study was made for a set of commercially available "dose saving" grids with 36 lines/cm and a lead strip thickness of 36 micron. Grid ratios in the range 6-14 were considered for 12 examinations covering the range of scattering volumes encountered in practice (table 1). Full details are given in [4], which contains recommendations for the various imaging situations, taking due account of the tube charge (mAs) required to maintain the optical density on the film and the alignment and focus-grid de-centring problems associated with the use of higher grid ratios. In situations with a large amount of scatter, the use of a high grid ratio and tube potential is recommended, but for situations with less scatter, it is also possible to use a lower grid ratio and tube potential. In some circumstances the use of an air gap for scatter reduction can be considered.

3.3 Screen-film optimisation

The screen-film case studies were made with grids of fixed line density and strip thickness and it was of considerable interest to allow these parameters to vary as well (including values outside those presently available commercially), to find the optimal grid design which would provide the desired image quality at the lowest possible dose. Such an optimisation requires a large number of cases to be considered, and has only been made for three representative imaging situations (table 1). A full description of the results is given in [5]. For the paediatric optimisation, it was found that the best grid designs had lead strips which were thinner (10-20 micron) than those generally in use, and this was most important at higher grid ratios. For the medium scattering volume, adult lumbar spine AP view, the best grids correspond to what is available today (grid ratio of 12 or more, 30-50 micron lead strips). However, with more scattered radiation (adult lumbar spine lateral view), the use of a higher grid ratio and thicker lead strips is favoured.

3.4 Digital studies

The main objective of the digital studies was to establish the choice of grid and tube potential based on a range of "well designed" grids. In addition, the performance of grids with aluminium interspace and cover was considered, so that the optimum tube potential could also be studied for this case. Six projections were considered at a wider range of tube potentials than for the screen-film study, but for a limited range of grids. The results [5] suggest that the optimum choice of grid design is the same as for the screen-film study. However, the optimum tube potential is lower, and is similar for grids constructed with fibre and aluminium materials.

4. Summary and conclusions

The Monte Carlo computer program developed by the Royal Marsden Hospital and the Univeristy of Linköping has proved to be an extremely powerful tool for the study and optimisation of the performance of anti-scatter grids. Using a new optimisation technique it has been possible to compare commercially available grids and to optimise grid design for a wide range of imaging situations. Recommendations have been made for the choice of grid in each situation. In some cases these corespond well with present "good practice" whereas in others, some modifications in the design or choice of grids are suggested. In certain situations, the use of an air gap for scatter rejection should be considered.

5. Recommendations for future work

The present computer model is limited by the facts that it takes no account of tissue inhomogeneities, the contrast transfer properties and unsharpness of the image receptor, and receptor generated noise. In many imaging situations, it is important to take these aspects into account and it would therefore be of much interest to extend the model to incorporate these effects.

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1. SANDBORG M., DANCE D.R., PERSLIDEN J. and ALM CARLSSON G. 1992. A Monte Carlo program for optimizing image quality and patient absorbed dose in diagnostic radiology. To be submitted to Comp. Prog. Biomed.
2. ALM CARLSSON G., DANCE D.R., PERSLIDEN J. and SANDBORG M. 1991 Monte Carlo modelling of the physics of image formation in X-ray diagnostics. Invited paper, World Congress on Medical Physics and Bioengineering, Kyoto. Med. & Biol. Eng. & Comput. 29, Suppl. Part 1, 13
3. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Selection of anti-scatter grids for different imaging tasks: the advantage of low atomic number cover and interspace materials. Submitted to Br. J. Radiol.
4. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Monte Carlo study of of grid performance in diagnostic radiology: factors which affect the selection of tube potential and grid ratio. Submitted to Br. J. Radiol.

5. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Monte Carlo study of grid performance in diagnostic radiology: task dependent optimization for screen-film imaging. To be submitted to Br. J. Radiol.
6. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Monte Carlo study of grid performance in diagnostic radiology: task dependent optimization for digital radiology To be submitted to Med. Phys.
7. SANDBORG M., DANCE D.R., ALM CARLSSON G. and PERSLIDEN J. 1992. Optimization of anti-scatter grids: a collection of methods and results. Linköping University report series, Report ULI-RAD-R-72, ISSN 0348-7679.
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Project 5

Head of project: *Dr. Flioni-Vyza*

Objectives for the reporting period

The necessity for undertaking this project was stimulated by the fact that quality control checks in x-ray units have not yet been carried out in a national level.

The aim was to evaluate the existing situation in mammography in Greece, with special reference to patient dose and image quality, by collecting general information and taking the necessary measurements. The measured parameters depend on equipment performance and technique used.

The analysis of the collected data should identify the existing problems and give the opportunity of potential recommendations for remedial immediate or future actions. The work was carried out only in mammographic units installed in Public Hospitals and in the mobile screening units of the Hellenic Society of Oncology.

Progress achieved including publications

1. Methodology

The steps, for carrying out the project, were planned in the following way:

a) A protocol was established which contained the general and technical information to be collected and the necessary measurements to be carried out.

b) The units which were installed in Public Hospitals throughout Greece were localized either by contacting the hospitals, or machine representatives and film companies. Twenty nine units were thus located.

c) An official letter was sent to each hospital in order to inform them about the CEC program in progress and ask for permission to check their mammographic installation.

d) The participating Hospitals were visited each time by a team of two medical physicists and the actual, on the spot, work required 3 to 4 hours for each unit

e) On the spot advice was given and correcting measures were suggested where it was thought to be necessary.

The measurements were carried out following the recommendations outlined in reference No 1, unless otherwise stated.

2. Results and discussion

The results of compilation concerning general and technical information, are summarized in Table I.

Table I - General and Technical Information

1.	Site:	Athens (12), Thessaloniki (5). Others (9), Mobile Screening Units (3)
2.	Manufacturer:	Siemens (21), GE-CGR (6) Toshiba (1), Picker (1)
3.	Target Material:	Mo(25), W (1), Mo ? (3)
4.	Filter:	Mo (24), Al (1), Mo-Rh-Al (1), Mo ? (3)
5.	Focal Spot:	0.1/0.3 (3), 0.15/0.4 (7), 0.3 (2), 0.4 (7), 0.5/1.0 (1), 0.6 (9)
6.	Grid:	Y (10), N (19)
7.	Grid removable:	Y (4), N (6)
8.	Magnification:	Y (9), N (20)
9.	SID (cm):	35 (2), 45 (12), 55 (1), 60 (12), 65 (1), 70 (1)
10.	AEC:	Y (26), N (3)
11.	kV range:	25-35 (14), 28,30,35 (15)
12.	Compression Cone:	manual (23), auto (6)
13.	Film-Screen Combin:	Kodak-Kodak (7), Agfa-Agfa (6), Agfa-Kodak (12), Others (4)
14.	Dedicated processor:	Y (10), N (19)
15.	Processing time (min):	1.5 - 2 (27), 4 (2)
16.	Workload (pat/week):	mean: 80, range: 5-250
17.	Quality Control:	Y (9), N (20)

From the above table it is seen that 60% of the units are located in the two major cities. The rest of the country is covered by the 40% which includes the screening mobile units. It is also observed that all units are equipped with tubes having focal spot sizes less than or equal to 0.6 mm as suggested by the CEC (Ref. No2). The SID for all units installed after 1985, (50% of the total , Figure 1) is equal to at least 60cm, in accordance with the above Document. However, with reference to the processing units, only one third of them were dedicated systems as required by the same Document.

The distribution of the Half Value Thicknesses of the different units are shown in Figure 2 and ensure that all units have a total filtration of at least 0.5mm of Al equivalent as recommended by CEC.

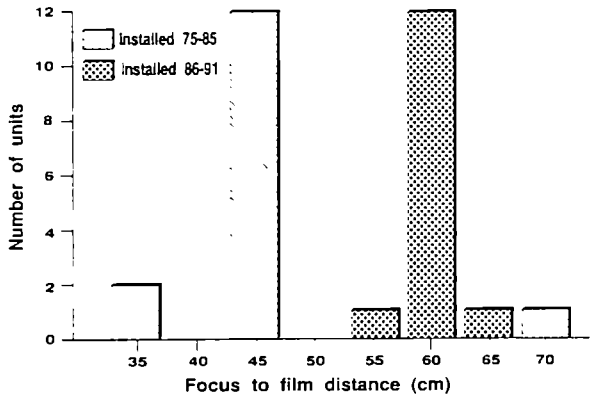

Figure 1. Distribution of focus to film distances used routinely

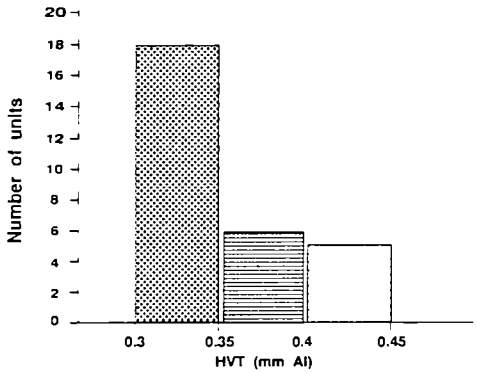

Figure 2. Distribution of HVTs at 30 kV. Corresponding total filtration values range from 0.5 to 0.75 mm Al

The nominal kilovoltage used in the various centers, for a breast of compressed thickness of 4.5 cm, is shown in Figure 3. Preference of the radiologists at 28 kV is obvious. Figure 4 shows the corresponding distribution of the actual kV as measured with a digital kVp-Meter, which indicates that in most centers (75%) a medium sized breast is radiographed using 27-30kV. Three cases should be mentioned here:

a) the use of 60 kV panel indication, which corresponded to 31 kV (but the users were not aware of it);

b) the use of 25 kV panel indication corresponding to an estimated value of 21 kV which was giving rise to excessive entrance dose;

c) the use of 28 kV panel indication which corresponded to 37 kV.

The differences between the nominal kV and measured values in the various centers (expressed in percentage) are shown in Figure 5. It indicates that only 34% of the units are found to be within a difference of ± 5% for all three panel settings of 28, 30 and 35 kV.

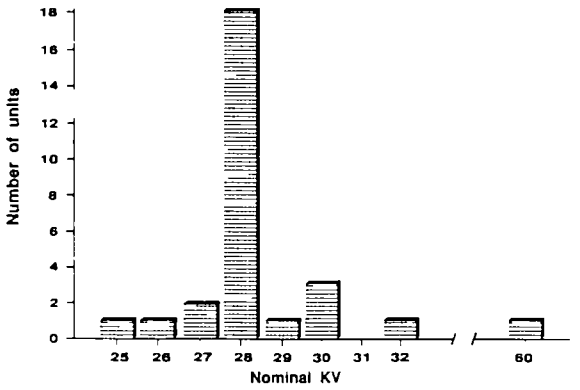

Figure 3. Distribution of nominal tube voltage values used routinely for a medium sized breast. One more unit not yet in routine use.

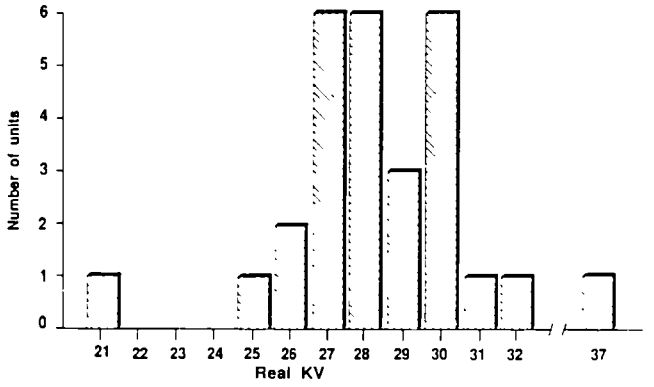

Figure 4. Distribution of measured tube voltage values corresponding to the nominal values used for a medium sized breast.

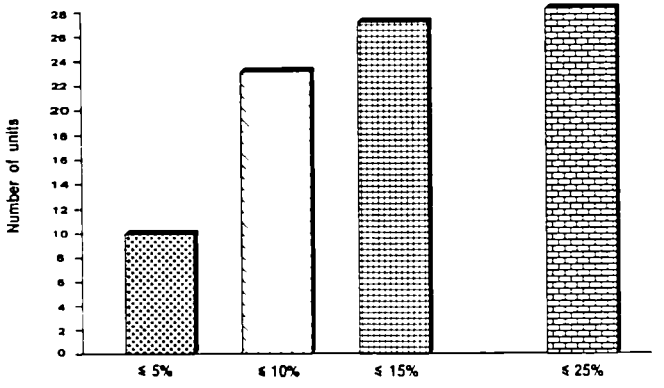

Figure 5. Tube voltage differences between nominal and measured values at 28,30,35 kV. In one more unit the differences were of the order of 100%.

Out of the 29 units tested, 26 were equipped with an Automatic Exposure Control device (AEC). Of those, 19 were functioning so that measurements could be made, whereas the remaining 7 could not be measured at ail. Fifteen out of the nineteen functioning units were using the AEC routinely (Figure 6). Both the kV and thickness compensation was within ± 20% of the mean OD in only 7 of the systems used, and only in 2 of them it was within the recommended limits of ±10%. Among those 4 units not using the AEC routinely , 3 were compesating to ± 20% and 1 to ±10% (Figure 7). More detailed analysis of the AEC information shows that kV compensation is more easily achieved than thickness compensation (Figure 8). For the 7 units which could not be measured see Figure 9. As a result of the above findings, most of the users were advised to have their AEC system properly recalibrated and use it in routine work.

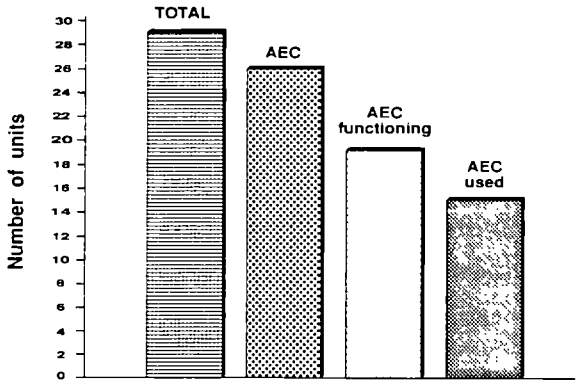

Figure 6. Information concerning the AEC device

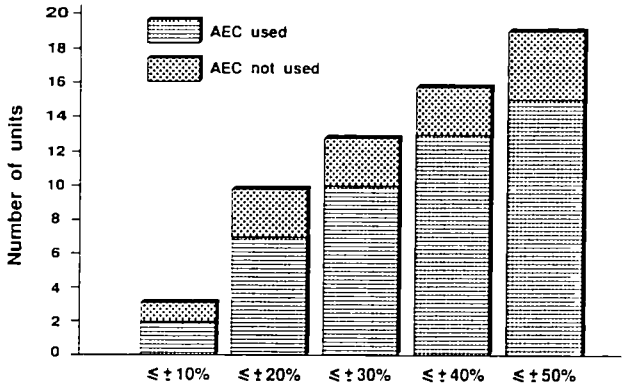

Figure 7. AEC performance level for both kV and thickness change compensation

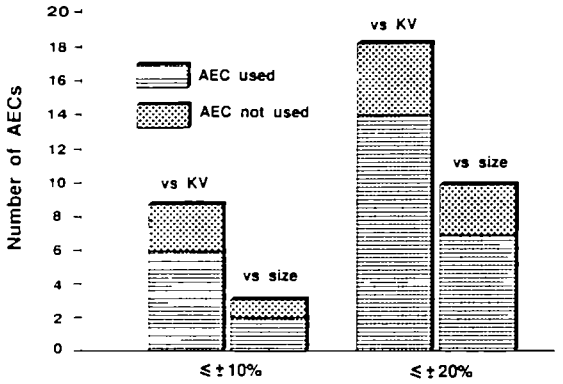

Figure 8. AEC performance level for kV and thickness compensation separately

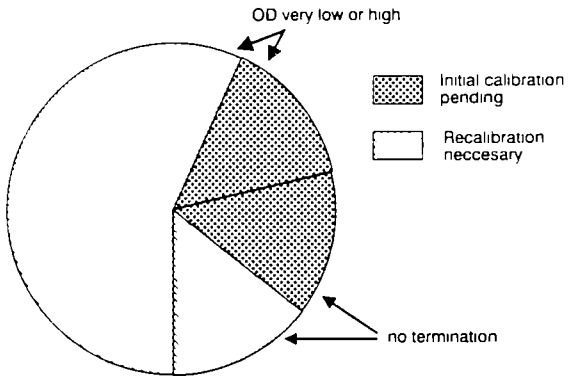

Figure 9. Information concerning non evaluated AECs

To estimate the reference Optical Density above base plus fog, a 4 cm perspex phantom was radiographed using the technique suggested by the user. The results are shown in Figure 10. It is indicated that in 54% of the centers the densities obtained may be outside the recommended range of 0.8 - 1.2 units of OD which results in degradation of image quality.

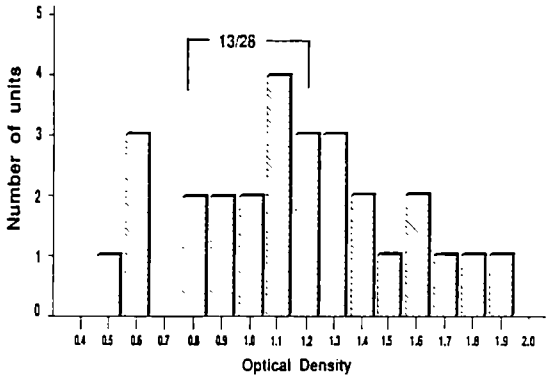

Figure 10. Optical densities obtained at various centers with a 4cm perspex phantom using the technique suggested by the user.

Skin entrance doses were measured in the various centers using the exposure conditions suggested by the user for radiographing a 4.5cm thick compressed breast. A flat ionisation chamber, a 4 cm perspex phantom and a loaded cassette in place were used for the measurements.

The results are shown in Figure 11. The four cases with entrance surface dose above the upper limit of 10 mGy [3] shall now be commented. The extreme case of 25 mGy with no-grid technique, was due to a combination of the following reasons: very low actual kilovoltage of about 21 kV (panel indication: 25 kV), very small SID (31 cm) and very high OD (2.15). After consultation with the radiologist it was decided to increase the panel indication to 30 kV (28 kV measured), decrease the mAs and use the longer cone in all patients (37 cm). This resulted in 5 fold reduction of dose, down to about 5 mGy. The second case of approximately 15 mGy was again a no-grid technique and it was due to the fact that the films were placed in the cassette with the emulsion not facing the screen. This procedure was followed by the users as the lowest mAs of the unit, either in automatic or manual mode, would, otherwise, produce excessive blackening of the films. The machine representatives were contacted so that a solution to rectify the situation could be found. The third and fourth cases, using grid technique-are attribued to a slower film screen combination.

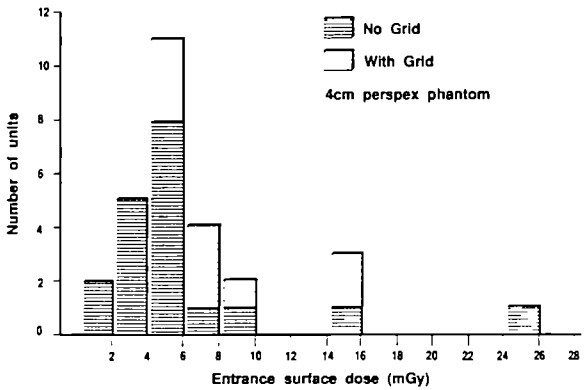

Figure 11. Distribution of measured entrance surface doses using a 4cm thick perspex phantom and exposure conditions suggested by the user.

The mean entrance doses, with and without grid, calculated from our measurements are 8.5 and 5.2 mGy respectively (per projection). The corresponding mean glandular doses have a mean value of 1.7 and 0.9 mGy (with and without grid respectively), which are whithin the upper limits of 3.0 and 1.5 mGy specified in ref. 1.

An indication of the quality of the images produced routinely was obtained by radiographing the Leeds TOR [MAX] test object using the exposure conditions suggested by each user. It was found that 53% of the units comply with the limit of resolution of 14 lp/mm. [3], while 43% have a resolution ranging from 10-12 lp/mm. One unit (films placed upside down) had a very low value of 5.6 lp/mm. Small, high contrast details, 0.25 mm in diameter, (simulating microcalcifications) were visible in all cases at a contrast level of 37% but only in 50% of the cases they were visible at contrast levels in the range 11-20%.

A rough estimation of the conditions in the darkrooms is depicted from Figure 12. It is seen that 3 out of 27 processors, give a base plus fog level larger than the acceptable 0.2 units of Optical Density. In the same Figure, the density difference between an unexposed film and a film exposed for one minute with the safelight on and full illumination of adjacent rooms, is shown. In 7 out of 27 darkrooms the density differences obtained are in excess of 0.05, which is taken as the maximum acceptable value, and it was due to either cracked filters of the safelights (2 cases) or light leakage from the adjacent areas (5 cases). In two of the latter cases the users were aware of the problem and films were handled with lights in the adjacent rooms switched off.

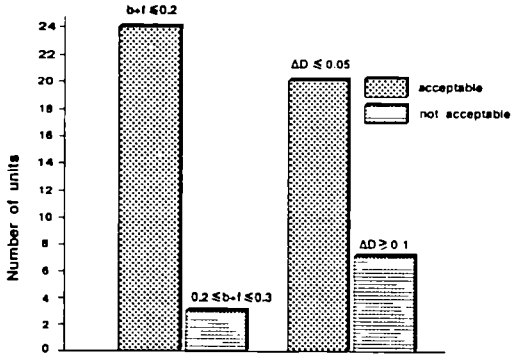

Figure 12. Base + fog and density difference between unexposed films and films exposed for 1 min in the darkroom.

Viewing boxes were visually assessed and it was found that in 13 installations, the light intensity uniformity was good, in 9 was average and in 3 was unacceptable.

Some additional information is presented in Table II.

Table II

Timer Reproducibility:	26 2 1	units better than 5% units between 5% and 10% unit 25%
AEC Reproducibility:	15 3 1	units better than 5% units between 5% and 10% unit above 20%
kV Reproducibility:	22 7	units better than 2% units between 2 and 5%
Field Uniformity:	25 4	units within ± 10% units up to ± 12%
Screen - film contact and light tightness of cassettes:	Approximately 98% of the cassettes tested were found with no problem	

3. Conclusions

Our survey included 29 mammographic units representing 90% of the total number of units installed in Public Hospitals. The remaining 10% were installed after the completion of our measurements.

The conclusions which follow are based on the results presented and on references 1,2,3.

With reference to the technical specifications 50% of the units have an SID of not more than 45 cm and a minimum kV setting of 28 kV which do not comply with CEC criteria.
Approximately half of the users do not use the AEC system in their routine work and only 10% of the systems function at acceptable levels (10% for kilovoltage and thickness compensation). This implies that more frequent calibration is required and that the radiologists and radiographers should be more clearly informed of the usefulness of AEC in routine work.

A large percentage (approximately half of the users) obtain optical densities of the films outside the recommended range. Resolution under routine conditions is also below the limit of 14 lp/mm for about 50% of the units.

Although in a small number of centers the skin entrance dose was in excess of 10 mGy, the mean values were well inside the acceptable upper limit. The same applies to the average mean glandular doses. Our evaluation, however, indicates that skin entrance doses of not more than 7 mGy [2] could be achievable in all cases.

A final conclusion which emerges from the experience accumulated through this project is that the existing situation in mammography in our country can be improved by:

a. Application of a quality control program on a periodic basis;

b. Better training of the relevant personnel in correct usage of equipment and proper techniques;

c. Better awareness of servicing staff on the fulfilment of the limiting values concerning equipment performance.

Publications

Panayiotakis G., Giakoumakis E., Flioni-Vyza A., Xenofos S. and Proimos B., *Quality Control in Mammographic units in Greece*, 6th Conference of Medical and Biological Engineering, Capri, Italy 1992.

Xenofos, S., Panayiotakis, G., Giakoumakis, E., Flioni-Vyza, A., *Quality Control of mammographic Equipment in Greece*, 7th International Congress on Senology, Rhodes, Greece 1992.

Flioni-Vyza, A., Xenofos, S., Giakoumakis, E., Panayiotakis, G., Proimos, B., *A protocol of Quality Control of mammographic units*, 1st Panhellenic Congress on Radiation Protection, Athens, 24-26 of October 1990.

Flioni-Vyza, A., Xenofos, S., Giakoumakis, E., Panayiotakis, G., Proimos, B., *Quality Control of mammographic units in Greece*, 8th Panhellenic Congress in Radiology, Athens, 10-13 of September 1990 (to be published in Hellenic Roentgenology).

References

[1] Fitzgerald M., Dance D.R., Fisher K., Lawinski and Ramsdale M.L.: *Commissioning and Routine Testing of Mammographic X-ray Systems*, Report No 59 IPSM 1989.

[2] CEC Draft Document, *Quality Criteria for Diagnostic Radiographic Images*, June 1990.

[3] European Protocol for the Quality Control of the Technical Aspects of Mammography Screening, March 1992.

[4] American Association of Physicists in Medicine: *Equipment requirements and Quality Control for Mammography*, NewYork, AAPM, Report 29, 1990.

[5] BIR Report 18, *Technical and Physical Parameters for Quality Assurance in Medical Diagnostic Radiology*, London.

[6] BIR Report 20, *The optimization programme for mammography in Italy. In Optimization of Image Quality and Patient Exposure in Diagnostic Radiology*, London, 1989.

[7] Carvalho, A.F., Rocha, M.P., Alves, J.G., Carreiro, J.V., Galvao, J.P., *Radiation Doses in Mammography*, CEC Workshop on Statistics of Human Exposure to Ionising Radiation, Oxford, April 1990.

Project 6

Head of project: *Prof. Rimondi*

Objectives for the reporting period

Project of an electronic instrument for measuring, in real time and in a single shot, wave form, kVp, ripple, HVL, exposure time and exposure. The device consists of a four solid state detector probe, an acquisition electronics and a portable computer. The device is useful for quality control for various reasons:

a) the measurement is not invasive;
b) many parameters are evaluated in a single shot;
c) computer assisted measurement allow a data base for the mammography centers.

Progress achieved including publications

A system composed of a radiation probe and the digitizing electronics with a portable personal computer governed by software developed ad hoc, was designed and tested. The system allow the indirect evaluation of the X-ray characteristics of a Mo anode Mo filtered mammography unit in the range 20-40 kVp.

In a single shot of the tube the system give the possibility to measure in real time: high voltage wave form, ripple , kVp, HVL, exposure time and exposure (C/kg). The measurement accuracy are: 2.5% for wave form and kVp, ± 0.01 mm Al for HVL, ± 0.001 s for exposure time and ± 7% for the exposure.

Moreover the computer assisted measurements allow to built a data base for mammography units and the system is very useful for quality control in mammography.

System for indirect measurements in real time of the X-ray beam characteristics of a Mo/Mo mammography unit

1. Materials and methods

The system is composed of : a radiation probe (consisting of four photodiodes), a digitizing electronics for signal conditioning, and a portable personal computer. Two photodiodes (Hamamatsu S1723-06, sensible surface=100mm2) are dedicated to the measurements of high voltage waveform and kVp; the measure theory is described in details in a previous paper of the Authors (1). The two photodiodes are covered by different filters: 2.20mm Al and 0.15mm Mo respectively, the filter thicknesses are chosen so that the transmitted photon fluences have, in practice, the same value when photons have an energy E less than the Mo K-edge (E_k); while, for $E>E_k$, the transmitted fluences are very different, i.e. the Mo transmission is negligible.

In this condition the ratio between the two photodiode signals is, in practice, proportional to the voltage applied to the X-ray tube (in the range 20-40kV) and is independent of the fluence rate. Moreover photodiodes have a fast enough response to follow transients and their outputs are linear inside a large interval of exposure rate. The photodiode outputs in current are converted into voltage, then amplified and sent in two channels of a multiple sample&hold circuit. Finally the signals, opportunely multiplexed, are sent to a 12 bit A/D converter with a sampling rate of 10kHz. The A/D converter is interfaced to a portable personal computer.

The other two photodiodes (Siemens BPW34, sensible surface=7.34mm2) measure the exposure values over and under a 0.5mm Al filter respectively. The detector outputs are sent into the other two channels of the same sample&hold circuit and digitized as previously described.

In this manner the system, composed of the probe, the digiting electronics and governed by a software developed ad-hoc, can measure in real time and in a single shot of the X-ray beam the kV waveform (visualized on the computer display) and still more: kVp, HVL, exposure time and exposure value.

Figure 1 is an hard-copy of the computer display showing the measurement results.

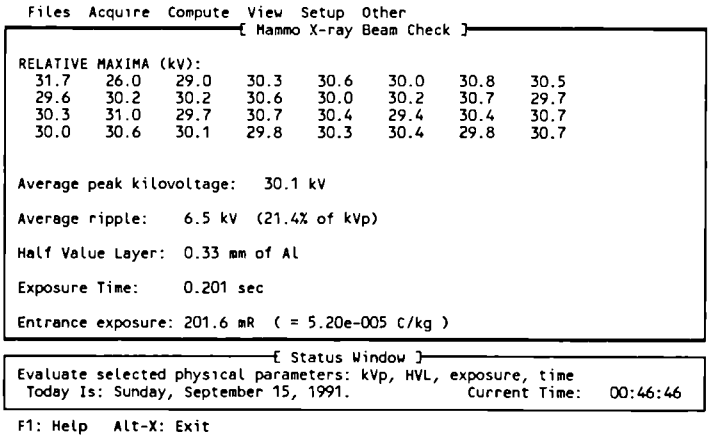

Figure 1. Hard copy of the computer display after a measurement

2. Calibration results

The instrument calibration in voltage was performed by comparison between the radiation probe outputs and the values obtained by means of an invasive high voltage divider (Comet Voltix 150) and a digitizing oscilloscope. The probe was exposed to the beam of an X-ray tube (1mm Be window, 30μm Mo added filter) fed by a special generator giving a constant voltage. The output ratio of the first two photodiodes was evaluated as a function of the high voltage,

performed for voltages in the range 20-40kV, the differences are within ±2.5% in all the range. The waveform of the case presented in Fig.1 appears on the computer monitor as shown in Fig.2. Obviously, in the case of an one-phase unit the computer gives only the part of the waveform greater than 20kV.

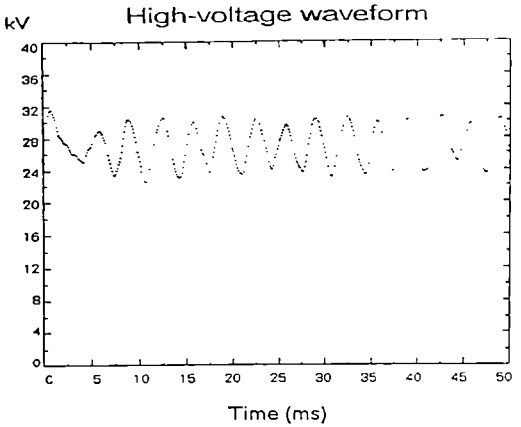

Figure 2. Software reconstructed wave form for a 3 phase mammography unit.

The calibration for HVL measurement was performed exposing the radiation probe to six beams with known HVL and evaluating the ratio of the outputs (of the second couple of photodiodes) integrated over the exposure time. The HVL thicknesses employed for calibration ranged from 0.24 to 0.40mm Al, typical interval for film-screen mammography. A comparison between HVL values determined by the instrument and by the conventional method is presented in Fig.3. With regard to the exposure time value, obviously it is derived from the waveform evaluation performed over all the exposure interval.

Finally, output of the unfiltered photodiode signal (integrated over time) is a function of the exposure value, its calibration was performed by means of a low energy ionisation chamber associated with an electrometer (MDH Radcal) calibrated in the mammography range. In exposure measurements the probe accuracy is affected essentially by the photodiode energy dependence, which was evaluated by means of X-ray beams with various HVL values, see Fig.4. In practice, the mammography HVL values range from 0.27 to 0.35mm Al, in this interval the systematic error is lower than ±5% because we calibrated the probe with a beam having an HVL=0.32mm Al.

3. Conclusion

The Authors believe that the instrument can be very useful for quality control in film-screen mammography.

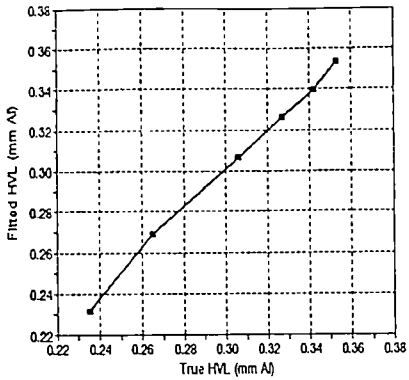

Figure 3. Calibration curve used by software for HVL measurements

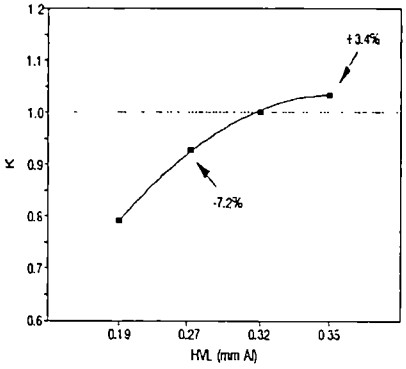

Figure 4. Energy dependence of the solid state detectors used in the probe for exposure measurement.

Publications

M.Gambaccini, O.Rimondi, M.Marziani, P.L.Indovina "RADIATION PROBE FOR INDIRECT EVALUATION OF THE HIGH- VOLTAGE WAVEFORM OF A MO ANODE MAMMOGRAPHY UNIT", Medical Physics, 16, 94-97,1989

E.Burattini, M.Gambaccini, P.L.Indovina, M.Marziani, O.Rimondi "S/N RATIO EVALUATION IN SYNCHROTRON RADIATION RADIOGRAPHY", Physica Medica, VI, 1990

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M.Gambaccini, M.Marziani , O.Rimondi "UNO STRUMENTO PER LA CARATTERIZZAZIONE DI FASCI X MAMMOGRAFICI" Atti del Congresso Naziole AIRP, Ferrara 16-18 Settembre 1991

M. Gambaccini, M. Marziani, M. Cristaudo,L. DeGuglielmo,E. " A PERFOMANCE DEVICE FOR QUALITY CONTROL IN MAMMOGRAPHY" Radiat. Prot. Dosim. in press.

THE PRINCIPLES AND THE PRACTICABILITY OF QUALITY CONTROL AND QUALITY ASSURANCE IN PAEDIATRIC RADIOLOGY

Contract Bi6-211 - Sector C22

1) *Schneider*, Univ. München Kinderklinik

Summary of project global objectives and achievements

Optimization, quality control, and quality assurance of radiological imaging studies of newborns, infants, and children are quite different from those in adults. They are, however, mandatory in terms of radiation protection of the public because paediatric patients represent the most sensitive part of the general population.

Therefore, the project had the objective to screen and assess problems related to radiation protection in paediatric radiology. This included a survey of entrance surface dose (ESD) for seven frequent X-ray examinations in infants, variation in radiographic technique and its influence on image quality. For this purpose we were able to measure the ESD for paediatric patients in a large number of hospitals and offices in Germany and in 10 other European-Community countries. The ESD values, whether measured with a digital analyzing device and a test-phantom, which was performed only in Germany, or with thermoluminescent dosemeters, which was undertaken in 11 EC-countries, showed similar results: a wide variation of the dose with minimum to maximum values in the mean range of 1:50. Furthermore, an analysis of the radiographs of the phantom study showed a relatively high proportion of poor images reflecting deficiencies of the technical system (e.g. malalignment of light/x-ray field and inexact perpendicularity) which lead to unnecessary patient exposure, especially in paediatric patients.

Special paediatric quality criteria for radiographic technique and image quality were developed and compiled in a Working Document of the Commission of the European Communities. An inverse relationship was found between the fulfillment of radiographic technique as defined in this Document and the measured dose for all 7 examinations. In addition, an analysis of the original films of this study proved that this fulfillment did not negatively affect image quality. As a result of these surveys, dose recommendations were elaborated and included in an appendix to the Working Document. This Document will be the base for quality assurance programmes in paediatric radiology in private offices and hospitals in Europe, and can be adapted to new developments, e.g. digital radiography and fluoroscopy.

Project 1

Head of project: *Dr. Schneider*

Objectives for the reporting period

The national comprehensive phantom study surveying radiographic techniques, entrance surface dose and image quality in Germany was continued and completed. After the survey in the old federal countries of radiology departments headed by paediatric radiologists, additional departments of children's clinics, general hospitals and in private offices under the control of general radiologists, paediatricians and other medical specialists had to be investigated. The reason for this extension was to obtain a realistic and more informative overview of the dose variation in paediatric patients in Germany. In 1992 the study was extended to children's hospitals of the new federal countries of Germany.

For these studies, seven frequent x-ray examinations for a 10 months old infant (skull, spine, abdomen, chest using immobile and mobile generators, in addition, chest of the 1000 g premature baby, and pelvis in the 4 months old infant) were chosen. Radiographic technique and equipment were surveyed per questionnaire and their performance measured using a teflon phantom representing a 10 months old infant and a dose measurement device (DAVID; Quart co.). In addition, test-plate (Wellhöfer Kernphysik, ET 807-1) exposures were performed with the individual settings in all departments and offices to check the performance of the equipment and film-developing system.

In an EC-wide survey, direct on-patient measurements of the ESD in 89 clinics in 11 EC-countries were performed using $CaFl_2$-TLDs. Questionnaires were mailed together with the TLDs to obtain data on radiographic technique settings and equipment information. The same seven x-ray examinations and age groups surveyed in the national study were investigated in this study. Dose measurements were made at the Unita' Sanitaria Locale (Udine, Italy), the National Radiological Protection Board (Chilton, UK) and the GSF-Forschungszentrum für Umwelt und Gesundheit, GmbH (Neuherberg, FRG). The original x-ray films were collected and subsequently rated for image quality by a group of paediatric radiologists. Because chest examinations are the most frequent examinations in infants, a repeat survey for only the types of chest examinations of the first survey was made at the end of 1990 and in the beginning of 1991. 76 radiology departments of 11 EC-countries participated in this second survey.

A Working Document — "Quality Criteria for Diagnostic Radiographic Images in Paediatrics" — was developed by an expert group of paediatric radiologists, members of the so-called Lake Starnberg Group, "The Advisory Board of The European Society of Paediatric Radiology". This Document based on the similarly named adult Working Document but was specifically adapted to paediatric patients. The applicability of the definitions for good image quality was tested on the radiographs of the first TLD-survey. In addition, the first draft of the Document was sent internationally to numerous paediatric radiologists and chief

radiographers for review and criticism. The Document underwent several revisions based on the experience with the TLD-study and the feedback from the scientific community. A final version of the Document was completed in 1992. The questionnaire data and the image quality of the original radiographs of the TLD-survey were analyzed and evaluated based on the criteria described in this Working Document.

Progress achieved including publications

A total of 119 radiology departments and 57 private offices in Germany were investigated using the above-mentioned teflon phantom, representing a 10 months old infant. The clinics and offices participating in this study were nearly equally distributed from the North to the South of Germany. A detailed analysis of the results of this survey is now completed. There was no significant difference concerning the use of the different types of generators with the exception of mobile generators. At the time of the survey the departments in the new German countries had, in general, old equipment, mostly 6-pulse generators.

A wide range of the ESD was found for all seven x-ray examinations. The maximum to minimum ratios of the dose varied widely; very high ratios were found, for example for the pelvis (185:1) in departments of paediatric radiologists; on the other hand, low ratios for the skull examination (8:1) in private offices of general radiologists. The mean dose was lowest, but the ratios were highest in departments controlled by paediatric radiologists. These unexpected high ratios can easily be explained: most departments controlled by paediatric radiologists have very low ESDs, but there are still some departments which continue to use a radiographic technique with a high ESD; this widens the range and consequently affects the ratio.

A comparison of the types of radiology departments/offices for their mean dose values for the seven x-ray examinations of the infants are graphed in Fig.1. In general, the lowest mean ESD's were found in departments headed by paediatric radiologists (former West Germany) with the exception of bedside chest x-rays of the premature baby and the 10 months old infant. Similar low values were seen in departments of paediatric radiologist (former East Germany) with the exception of skull and spine films. Some striking differences in ESD between radiologists and paediatricians in hospitals were measured. High mean dose values were detected in private offices with highest doses for the abdomen.

There were eminent differences in radiographic technique between paediatric radiologists, general radiologists and paediatricians. The most important factors responsible for the increase of ESD of the chest ap examination with immobile equipment were the unnecessary use of grids, automatic exposure and the use of film-screen combinations with low speed (<200). About 80% of the non-paediatric radiologists used such a poor technique which may explain the two- to five-fold increase in dose. Chest x-rays performed with mobile equipment in the 10 months and 1000 g premature baby had nearly the same mean dose in all 3 types of radiology departments. However, there was one extreme outlier among the general radiologists in a hospital who had doses of 12,660 and 7,248 μGy, respectively, and was excluded from the graph to avoid distortion of the general trend.

These results for the chest examinations were presented at the annual meeting of the German speaking Society of Paediatric Radiology in 1991 in Cologne. These unnecessary variations clearly stress the need for optimization measures even in paediatric radiology departments.

Concerning the equipment, nearly 40% of the departments in Germany used old-fashioned equipment with a generator age of over 15 years. This was evident for the 1&2 pulse generators; these are not appropriate for use with newborns and older infants because of the inherent long exposure times (> 100 msec). The analysis of the generator dose rate curves clearly revealed deviations, for example, long pre-peak phases in old 6- & 12-pulse generators. Another important finding was the fact that in 10% of the departments the measured peak voltage deviated at least 20% below the KV-settings (maximal deviation was 45%). In additional 30% of departments and offices had deviations between 10-20% were found. These deviations were clearly linked to old generator types (6-, 12-pulse generators). Such large deviations in the kV are very important for paediatric radiology because low kV will increase the dose to the patient. This is specially important because only about half of the departments use additional filtration, but of those who employed additional filtration, very few, with the exception of the paediatric radiologists, used an effective additional filtration of > 1.0 mm Al equivalent. The alarming results of this national phantom study were a motivation for many radiology departments to subsequently initiate quality assurance measures and to replace their old equipment.

In order to investigate some aspects of performance of the tube, light/x-ray field alignment properties and film processing, an analysis of the test plates was made in the national study. These results were presented at the "Workshop on Test Phantoms and Optimisation in Diagnostic Medicine and Nuclear Medicine" (Würzburg 1992). The most important finding was malalignment of the x-ray/light field. In a considerable number of cases the x-ray field was too narrow or, more important, too large. Optical density in the optimal range, i.e. 0.8 - 1.2 over fog, was found in only a few cases. Perpendicularity of the beam was exact in only 5% of the chest and 10% of the skull films; the perpendicularity in nearly 20% of chest films were notably tilted. These results clearly show that regular control of the imaging system is needed.

The results of this national study has been extensively discussed in three doctoral dissertations; an additional five dissertations dealing with different aspects of this study are in progress or under revision.

Some results of EC-wide TLD-survey were presented at the "Seminar on Dosimetry in Diagnostic Radiology" in Luxembourg in 1991. The equipment and the radiographic technique were analyzed and correlated with the measured dose. Dose values (ESD) of the seven x-ray examinations with mean, median, minimum and maximum values are presented in Tab.1. The mean variation is about 1:50 and was highest (1:76) for pelvis. The results of this study formed the basis for paediatric dose recommendations given in the Working Document of the CEC (Appendix I). However, the expert group consisting of paediatric radiologists and medical physicists stressed the fact that these recommendations apply only for infants and further data are needed for older children.

We found a significant inverse relationship between fulfillment of criteria for good radiographic technique and the ESD in all 7 examinations. Furthermore, we were also able to

show that adherence to the guidelines mentioned in the CEC-Document does not negatively affect image quality (an example for the chest x-ray is given in Fig.2). These results were presented at the 29th Congress of the European Society of Paediatric Radiology in Budapest 1992. Individual dose profiles were sent to all participating institutions as a help for them to improve their image quality and/or reduce the dose to the patients. Orientation on the dose recommendations of the Working Document can allow the individual radiology departments in the EC countries to improve their radiographic technique and function as a basis for quality assurance measures.

Table 2 - Entrance surface dose: Basic statistics

	Entrance surface dose (μGy)					N
	min.	max.	mean	median	ratio	total
Abdomen AP, 10 months	77	3210	650.5	440.0	1: 42	45
Skull AP/PA, "	152	4514	1252.7	926.0	1: 30	57
Chest AP/PA, "	21	979	131.3	74.0	1: 47	69
Spine LAT, "	107	4351	1128.0	875.0	1: 41	31
Pelvis AP, 4 months	18	1369	401.1	274.5	1: 76	50
Chest AP, newborn, mobile	11	386	67.8	43.5	1: 35	64
Chest AP, 10 mon., mobile	34	718	128.5	90.0	1: 21	37

In general, because of the wide dose distribution, usage of old equipment and deficits in appropriate radiographic technique, there is a great need of quality assurance programmes in the EC-countries and other European states. The results of our survey not only demonstrated the general usefulness and the capability of the "Quality Criteria", but also indicated that ongoing research is needed to further test the value of the image quality criteria in all paediatric age groups and in other x-ray examinations. These studies are in progress.

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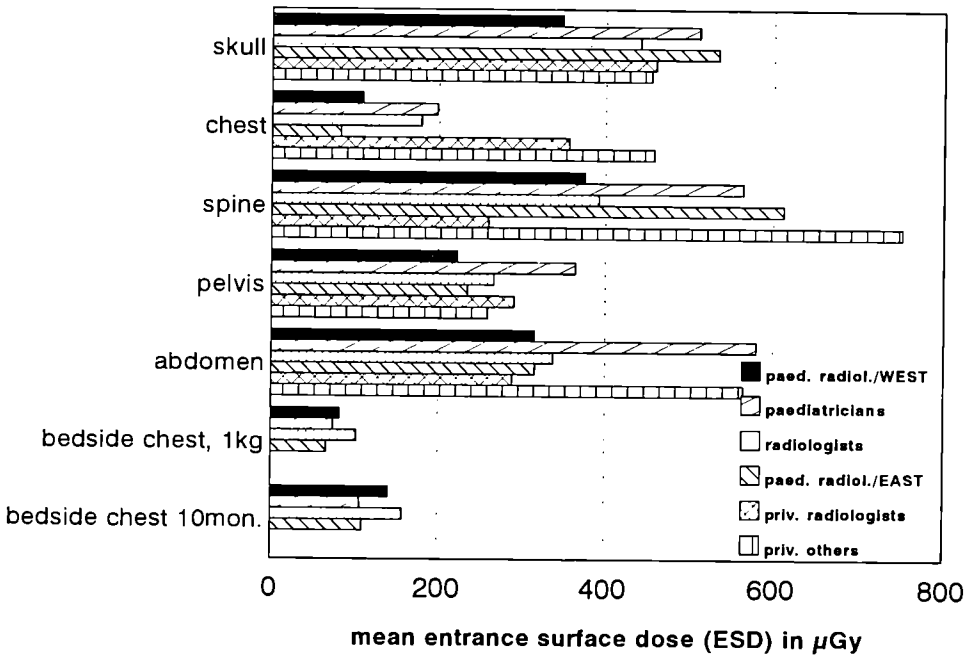

Figure 1 - Comparison of ESD by type of radiology department

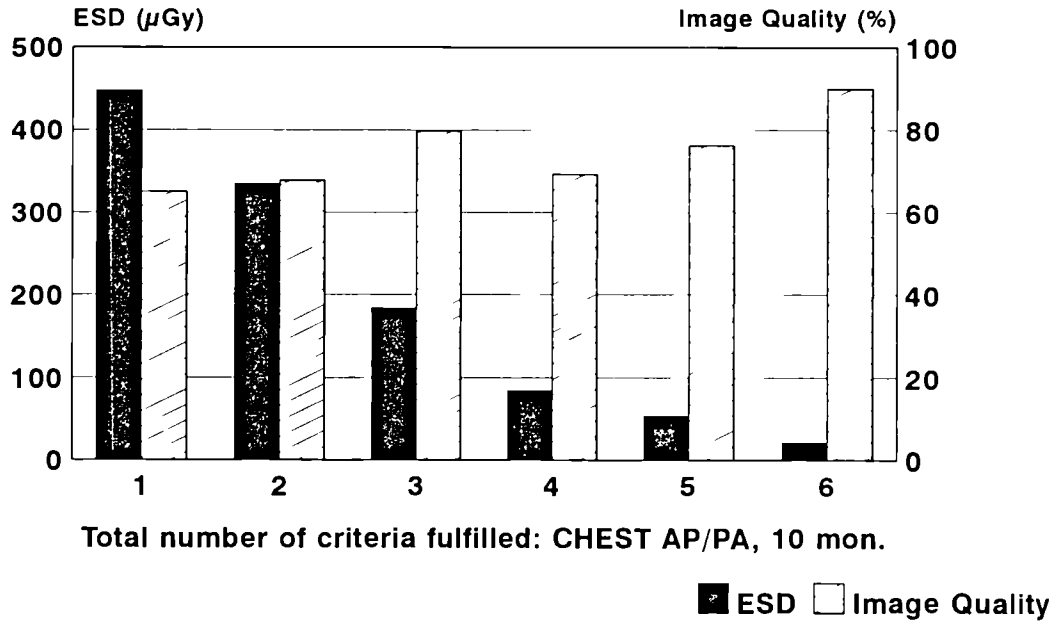

Figure 2 - Impact of good radiographic technique on Entrance Surface Dose (ESD) and Image Quality

OPTIMISATION OF PROTECTION IN MEDICAL DIAGNOSTIC RADIOLOGY

Contract Bi6-214 - Sector C22

1) *Vano Carruana* , Universidad Complutense de Madrid

Summary of project global objectives and achievements

The project was started in October 1986, ending in its first stage in December 1989. Afterwards it was prolonged until December 1991, then up to April 30, 1992. An extensive data acquisition of patient dose values was carried out at different health centres of the Madrid area, during the first aforementioned stage. Due to the malfunctions observed in the evaluated X-ray rooms, both in dose levels or in image quality, a Quality Control (QC) pilot programme was planned to be developed along 1990 and 1991, as a natural extension, including the verification of its effectiveness. The work has been performed in close collaboration with other European Community (EC) research groups. Besides, collaboration in image quality and dose to patient trials managed by the General Directorate for the Science, Research and Development has been contributed.

As explicit objectives to be reached along the period from 1990 to April 1992 the following ones were put forward: 1) Establishing simplified procedures to evaluate image quality and patient dose levels, adapted to the situation of the Spanish Radiology and allowing an application which should not disturb the routine work of the X-ray services; 2) analysis of the causes which may give rise to anomalous dose values and to deficiencies in the image quality; 3) Proposal for correcting actions and evaluation of its efficacy, as well of the action itself as in its easy implementation ability in a routinary way at the X-ray services, and creation of databases which could contribute to the exploitation of the future Quality Control Expert System (QCES), currently in development within a coordinated EC group.

Those objectives have been covered; simplified procedures to evaluate the image quality and imparted dose to patients have been elaborated and partly applied. Moreover, the programme has been extended to paediatric installations, due to the special interest shown by other EC research groups working within the frame of the Radiation Protection Programme. Results have been stored in computer data bases, the group keeping at present a close cooperation with other EC groups in the scope of taking profit in the future of these data along with the exploitation of the QCES.

The establishment of reference dose levels additionally to the EC expert group proposal has been needed to be able to estimate the suitability of the measured dose levels, for some 'simple' X-ray examination projections and for some conventional 'complex' examinations (digestive tract and urography). Likewise, it has been necessary to propose a number of basic criteria to qualify the images obtained with the test objects used in the QC pilot programme. Such a programme has lead to detect the origins of many anomalous findings and to evidence that internal managing of services does often not enable immediate implementation of correcting actions, that explains a number of proposals for correcting actions are, so far, to be executed. It will be worth to evaluate, in the future, reasons for the delay in putting them into practice.

The following highlights can help to appraise the results attained: 1) Study of the evolution of dose to patient levels along a five year period in a big hospital from the Madrid area, performing a detailed analysis of examination groups requiring more attention within the optimisation programmes and making evident the efficacy of the QC actions; 2) Obtaining provisional reference values of dose to patient, valid for Madrid, which have beside shown the need of proceeding in the application of the QC and patient dose reduction programmes, and designing a methodology to perform periodic evaluations, and 3) Design of a simplified protocol for the practice of a dose to patient and image quality evaluation programme.

In more, it has been demonstrated and evaluated the importance of Radiation Protection continued training programmes, directed to staff of the X-ray services. Also, the convenience of reinforcing the dose reduction actions in mammography and paediatrics has been evidenced.

Project 1

Head of project: *Prof. Vano Carruana*

Objectives for the reporting period

1. Monitoring the QC pilot programme through dose to patient controls and quality image evaluations. Proposals for correcting actions in anomalous findings.

2. Verification of effectiveness of the corrective actions through the re-evaluation of image quality and patient dosimetric controls.

3. Computerization of the QC results and exploitation of databases for the survey of levels of patient doses and other related parameters which help to the development of an Expert System.

Progress achieved including publications

1. Image quality

Simplified procedures were established during 1990 to evaluate the quality of the images, using the test objects from the University of Leeds, along with the application of image quality criteria emitted by an EC expert group (CEC Working Document, ref. XII/173/90, second edition, June 1990). Objective criteria to evaluate the quality of images obtained with the test objects have been stated.

2. Patient dosimetry

The simplified procedure for the analysis of patient doses has involved dose measurements at the entrance for simple examinations or the measurement of dose x area product, apart from the number of images and the fluoroscopy time in conventional 'complex' examinations. Aiming to obtain reference dose values adjusted to the Madrid Community, a similar criterion to the one of EC expert group was used, so that 75% of the patients undergoing a given type of examinations in the Madrid area would have received a dose under such a value (see table 1).

3. Correcting actions

The most frequent causes of anomalous doses have been, in brief, kVp inaccuracies, lack of filtration, processor malfunctioning, use of obsolete image systems and non-optimized operation protocols.

Image quality in radiography has been evaluated in 99 rooms, 16 of them featuring a deficient quality. Image quality in radioscopy has been evaluated in 16 units, having been detected 4 under tolerance standards and 5 in which improvements must be observed when optimizing the working parameters. A control carried out on 48 film processors has revealed that 30% of the films were processed in unsuitable conditions. A similar analysis performed on 30 darkrooms and 12 film stores evidenced deficiencies affecting severely the image quality, due to bad condition of the darkrooms (10%) and to unsuitable storing routine (30%).

Notwithstanding, it has been often observed that, in general X-ray rooms in which the image quality has been scored as bad according to test object results, the clinical images produced were scored as good by the radiologists, following the anatomical quality criteria from the CE expert group. Conversely, rooms giving good image quality according test objects yielded bad clinical images, in appearance. The exposure conditions of the test object used to score the image quality in general radiology are quite different to the ones used in the X-ray examinations, that could explain partially the observed discrepancies. A phantom which suits better to the radiation absorption and scattering in the patient is being designed, so that simulations can be made by choosing the actual X-ray examination exposure parameters.

TABLE 1 (values in mGy)

EXAMINATION TYPE	CEC REFERENCE	UNITED KINGDOM AVERAGE	UNITED KINGDOM 3rd QUARTILE	SPAIN AVERAGE	SPAIN 3rd QUARTILE
ABDOMEN AP	10.0	8.4	10.5	12.4	16.0
CERVICAL SPINE	-	-	-	7.1	8.0
DORSAL AP SPINE	-	6.2	7.1	15.5	17.8
DORSAL LA SPINE	-	14.0	19.2	24.8	25.0
LUMBAR AP/PA SPINE	10.0	9.2	11.2	20.0	21.7
LUMBAR LA SPINE	30.0	22.8	30.1	45.1	52.8
LUMBO-SAC. LA SPINE	40.0	38.7	50.2	72.2	84.7
SKULL AP	5.0	4.4	5.0	5.6	5.7
SKULL LA	3.0	2.3	2.8	5.1	6.4
SKULL PA	5.0	4.8	5.5	9.5	11.1
MAMMOGR.(*)	7.0	10.0	-	13.9	16.6
PELVIS AP	10.0	6.6	7.9	19.3	23.8
CHEST LA	1.5	1.5	-	1.6	2.3
CHEST PA	0.3	0.2	0.3	0.5	0.6

(*) With grid

In mammography, a comparative study based on the measurement of parameters related to equipment operation which chiefly affect dose and image quality is being developed. A total of 17 facilities have been evaluated, from which near 50% have old systems, usually with adjustment problems or showing several filtration deficiencies, in which the image quality/dose is very unsuitable. Among the modern equipment it has been often observed inaccuracies in kVp settings and exposure automatic control failures which worsen the image quality. Using low speed films or high absorption grids in these equipment make dose values exceed the surface dose values recommended by the EC. The obtained results have given rise to the renewal of a big deal of the ancient X-ray systems and several processors. Likewise, the used film type has been replaced by one faster in two cases, and by one less noisy in other two, aiming to better the image quality/dose ratio.

Comparative tests for 20 film marks and types for general radiodiagnostics, with 15 intensifying screen models, and 10 film models in mammography have been carried out. The previous evaluation of dose and image quality to be obtained using faster films, together with discussion sessions and demonstration to the radiologists, have lead to important dose reductions.

Evaluations in 6 paediatric rooms from two different centres have been carried out, by measuring entrance doses for different examination types, likewise the image quality. Dose values have been recorded in computer databases classified in four age groups.

At present, a simplified QC programme is already being applied on a routine basis, within a hospital network in which the project has been developed. The programme has enabled to reduce the dose to patient values under the reference values in some examinations. The estimates of average effective dose equivalent from a hospital of this network (1,400 beds and 170,000 X-ray examinations a year) for several examination types along four years are shown in table 2.

TABLE 2

EXAMINATION TYPE	MEAN EFFECT. DOSE EQUIVALENT 1988-89 (mSv)	MEAN EFFECT. DOSE EQUIVALENT 1990-91 (mSv)	EXAMINATION AVERAGE YEARLY RATE	COLLECTIVE DOSE SAVINGS (per.Sv)
SKULL	0,36	0,30	7.500	0,45
SPINE	1,40	0,95	12.000	5,40
CHEST	0,23	0,21	66.000	1,32
ABDOMEN	1,50	1,30	18.000	3,60
DIGESTIVE TRACT	10,1	5,50	2.500	11,50
URINARY TRACT	7,00	6,50	2.000	1,00
HIP AND PELVIS	1,60	1,20	5.600	2,24

4. Computerizing of results

The film type, intensifying screen and cassette, processor type and operating conditions, viewing boxes conditions have been considered, among others, as parameter set related to image quality, and registered for every room analyzed. Besides, the optical density in the test point, resolution and sensitivity at low and high contrast, plus observer scoring the images have been stored.

For patient dosimetry, examination type, radiographer key, patient physical data, total number of exposures in the examination, number of useless exposures, number of radiographic films, time of radioscopy, mAs and kVp, dose x area product, breast, gonad and thyroid dose values, focus-to-skin and focus-to-film distances, entrance dose and Monte Carlo factor table which should be used for the evaluation of effective dose, have been registered, among others. In radioscopy it is also recorded the screening time; mAs and kV in units when automatic brightness control is not used and dose x area product. In order to obtain average weighted values of dose at a local level, the number of examinations per year carried out in each room is also being introduced in the databases.

Aiming to a suitable adaptation of the databases to the QCES, and since the initial design work is being made in mammography, a specific data base has been built, there incorporating several typical parameters from that examination. The procedure for entrance and glandular dose value calculation, likewise for the evaluation of the corresponding statistical parameters, is being computerised.

The databases have allowed, together with a program of additional measurements carried out with anthropomorphic phantoms and Monte Carlo conversion coefficients, to apply our own calculation method for organ dose and effective dose for conventional complex examinations. For the examinations searched, it has been necessary to establish standard protocols and to elaborate tables from the Monte Carlo factors and experimental data for some projections not reflected in previous literature.

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REFINEMENT OF METHODS FOR THE ASSESSMENT OF ORGAN DOSES, AND POSSIBLE REDUCTION OF PATIENT EXPOSURE

Contract Bi-136 - Sector C22

1) *Padovani* , Unità Sanitaria Locale N. 7 Udinese

Objectives for the reporting period

1. Expert system

In the domain of Quality Assurance in diagnostic radiology many tasks require high-level expertise to interpret potentially noisy data, and domain-specific knowledge to understand the system organisation as well as the relations and interactions between subsystems. Some of these tasks may be performed by Knowledge Based Systems (KBS). During the routine use of phantoms in Quality Control (QC) programmes, test images are compared with a baseline reference image to find out deterioration in quality. The results of this surveillance procedure can be used by a KBS as first input data to make hypotheses on malfunctions which may account for the observed variations in the test image.

2. Image quality and patient doses in CT

The optimisation process in diagnostic radiology must take account of both image quality and patient dose. Important data have been collected during the national survey carried out in Italy for the evaluation of current levels of patient exposure and radiological practice in CT. These data can be used to shed light on the intricate interplay between radiographic technique, procedural variables, patient dose and image quality.

3. Patient dosimetry

Improvement and development of the dosimetry system to measure patient doses in diagnostic radiology. Support to international trials of the CEC study groups on the development of quality criteria for diagnostic radiographic images.

Progress achieved including publications

1. Expert systems for quality assurance in medical radiological imaging

The prototype of KBS that has been developed acts as a trouble-shooter during a QC programme for mammographic systems. QC tests are designed to detect malfunctions of the X-ray diagnostic imaging system.

Expert diagnosticians tend to solve problems using heuristic knowledge first, by directly associating observations with diagnostic hypotheses. Since some data about a system can be inaccessible, expensive or dangerous to retrieve, observed data are often noisy and uncertain. They may include spontaneous manifestations of the system, such as overheating of the X-ray tube, or the results of even complex measurement procedures as it is, for example, an image of a test phantom. A diagnostic KBS, which

mimics the expert's behaviour, must be able to produce diagnoses by relating observed data to a pre-enumerated set of possible malfunctions. This process is called *heuristic classification* and aims at connecting the malfunctions to their typical manifestations. It is necessary then to model the possible malfunctions in terms of their corresponding manifestations so as to allow the KBS to establish the relevant connections. These models or *prototypical descriptions* of the malfunctions are often uncertain, approximate and able only to capture the most common characteristics exhibited by malfunctions. For this reason, where the observed data are quantitative as in the case of a phantom image, an interpretation knowledge must exist which specifies how to map numeric data into linguistic terms meaningful for the heuristic classification process. Eventually, the prototypical descriptions of the malfunctions depend on the kind of observed data which are to be associated with. The choice of the data to observe depends on their availability, readiness and relative importance to confirm hypotheses on malfunctions. An easy and costless measurement may be worth doing even if it excludes or confirms low-probability malfunctions.

A straightforward choice for descriptors of malfunctions is represented by the set of the observables of a common mammographic phantom -- the Leeds mammographic test object TOR[MAX]. These observables are called *findings* and are characterised by a list of attributes . Each attribute in turn is characterised by some parameters including a list of possible linguistic values (*the linguistic range*). A set of rules (*numeric-linguistic mapping*) translates the actual numeric value of the finding into a linguistic term. As the emphasis here is on the deviations from the baseline, the linguistic values express the magnitude of the shift of the imagimg system from its initial (optimised) state, and represent in a concise way the conclusion of an interpretation process. The structure that organises the properties of a malfunction is a *frame*. First, the frame has a name which identifies the malfunction it describes. Secondly, the description itself is made up of a set of findings, which are termed *slots* and identify the basic structural elements of the malfunction. Next to each finding there is a list of its possible linguistic values that are fully compatible with the malfunction represented by the frame. A compatibility degree with the malfunction (*possibility value*) is associated with each possible linguistic value of a finding.

The prototype has been tested by means of experimental simulations. Different kinds of malfunctions have been simulated on a well-checked mammographic unit. The relative phantom images were taken and then the phantom findings measured or evaluated. The data obtained in 9 different simulations were used as input data to the prototype. Results show that the ability of the system to infer diagnoses from the TOR[MAX] phantom image is impaired by the low sensitivity of the phantom itself to malfunctions of the radiological system. The threshold for detecting malfunctions only with the phantom can be undesirably high, as it happens in the case of problems with kVp reproducibility and accuracy. Where the effects of malfunctions on phantom observables are above the threshold, TOR[MAX] seems able to give sufficiently different responses to make the KBS able to discriminate between the different groups of malfunctions. Therefore, a KBS can conveniently use the results of the test phantom only to take first level decisions or make coarse diagnostic hypotheses which can be refined by exploiting other independent sources of information.

2. Image quality and patient dose in CT

In 1989 a nationwide survey has been conducted in Italy to determine frequency and technical parameters adopted in each type of CT examination. Questionnaires were sent to about 300 facilities to collect relevant information including kilovoltage, filtration, mAs, number of slices, slice thickness, number of examinations per week. The examinations selected were the 10 most frequently performed and precisely: head, abdomen, cervical spine, lumbar spine, pelvis, petrous bone, hypophysis, orbits, skeletal segments. Organ doses to patients are estimated using Monte Carlo simulations techniques. Conversion factors relating mean organ doses to the free-in-air CTDI at the centre of rotation have been calculated by NRPB (UK) for a variety of make and type of CT scanners. The axial dose profile at the centre of rotation has been measured by exposing a row of TLDs suitably spaced inside a small plastic cylinder.

In 1991 the whole set of conversion factors was available. Table 1 reports how many examinations of each type are performed weekly on average in a sample of 80 installations. Table 1 reports also the estimation of the mean Effective Dose, as defined by ICRP 60, for each of the selected examinations.

Table 1. Weekly average number of CT examinations, mean Effective Dose to the patient and percentage standard deviation.

Examination type	Weekly number of examinations	Percentage	Effective Dose (CV) (mSv)
Head	37.2	39.7	0.67 (40.2)
Abdomen	17.4	18.6	6.67 (42.4)
Lumbar spine	12.8	13.6	5.42 (41.4)
Chest	9.7	10.3	6.03 (49.8)
Pelvis	7.4	7.9	7.64 (47.8)
Cervical spine	2.3	2.4	1.04 (53.6)
Petrous bone	1.8	1.9	0.48 (79.4)
Hypophysis	1.7	1.8	0.46 (67.4)
Skeletal segments	1.6	1.7	
Orbits	1.3	1.4	0.33 (77.7)
Others	0.6	0.6	

3. Patient dosimetry

In the reporting period two European surveys have been conducted for the evaluation of the CEC documents "Quality criteria for diagnostic radiographic images" for adult and paediatric patients.

The trial on paediatric radiology surveyed the 7 more frequent radiographic examinations in 89 European departments in 11 EC countries. Patient doses have been measured by USL-Udine, NRPB, and GSF laboratories with CaF2 TLD-200 dosimetry system developed for the evaluation of the typical low dose values of paediatric radiology. The analysis of data performed by the group of radiologists of Munich University showed that adherence to guidelines of radiographic images can lead to drastic and statistically significant reduction in Entrance Skin Dose (ESD). Table 2 reports the list of ESD proposed as reference and achievable values to be included in the CEC document.The reference doses are the rounded values of the 3rd quartile of

the measured doses in the sample. In the third column are reported the mean ESD values for those cases from the survey sample where at least five out of the six technical parameters proposed in the document were fulfilled. These values represent the potential target dose that can be obtained using modern equipment and optimum procedure and it is proposed that they be referred to as "Achievable Dose".

Table 2. Reference and achievable Entrance Surface Doses for a selection of projections and age groups.

Examination type	Reference Entrance Surface Dose (microGy)	Achievable Entrance Surface Dose (microGy)
Skull AP/PA (10 months)	1700	800
Chest AP/PA (10 months)	150	70
Chest AP (1000 g)	80	30
Abdomen AP (10 months)	700	400
Pelvis AP (4 months)	700	50

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DIAGNOSIS RELATED DOSES: A COMPARATIVE INVESTIGATION IN SOME EUROPEAN HOSPITALS

Contract Bi-054 - Sector C22

1) *Van Loon* - Univ. Hospital VUB
2) *Thijssen* - Univ. Nijmegen Acad. Hospital

Summary of project global objectives and achievements

Global objectives

- Inventory of diagnoses that are frequently encountered and require examinations involving a medium amount of ionising radiation.
- Selection of the most suitable ones regarding the availability of the information of the number and the type of examinations, clarity of the entry and exit points, of the gold standard (unambiguous "proof" of the correctness of the diagnosis), criteria of exclusion.
- Establishment of patient and examination data collection sheets and collection of data in the different hospitals. This pilot study will "compare" same diagnoses in hospitals in two countries, Belgium and the Netherlands.
- Agreement on the dosimetric procedure to establish the patient surface dose comparable between the two countries. Also, this procedure will be linked to previous dosimetric studies done in the EC, TLD dosimetry of entrance dose will be compared with NRPB dosimetry by mailing.
- Collection of dosimetric data for the examinations currently used in the selected diagnoses. University hospitals were chosen, since for most examinations standard procedures are used, so retrospective analysis will give a good approximation of the received dose. Important parameters for later evaluation will be collected: kVp, geometry, sensitometry, size, density, etc ..

Progress achieved

1. Method and results

1.1 Selection of diagnostic groups

Two diagnostic groups were selected taking into account the following considerations:

- The diagnoses must have clinical and social relevance i.e. an important number of patients must suffer from it.
- It must be possible to define a clear and unambiguous set of selection criteria. ('Golden Standard')
- Adequate and sufficient patient data-files must be available in each hospital (about 30-40 patients per D.G.)
- A significant part of the examinations leading to the diagnosis must involve use of ionising radiation.

The Diagnostic groups finally selected were Renal Cell Carcinoma and Lumbar Hernia Discalis.
Criteria were set for both D.G.'s to select patient files. The two sets of selection criteria are given in Appendix A.

1.2 Patient data collection

In the two participating hospitals, patient files were selected from the hospital patient information system (HIS), matching the criteria of one of the two D.G.'s. For each patient all radiological examinations he or she underwent during the diagnostic process were collected. In the figures 1a and b, the mean frequency of examinations for the patients in the two D G 's is given.

1.3 Technique related data

For all radiological techniques occurring in these files the information relevant for the dosimetry was retrieved. The radiological routine in the two departments for these examinations was described in detail, including film formats, kV, beam direction, number of films, etc.
We also collected for the same purpose a list of technical data from the equipment of the room. Some of these data were already available at the departments. Whenever necessary, additional measurements were performed.

Table 1: Image Quality figures for normalised exposure conditions in the two hospitals.

Examination	Lumbar spine 75 kVp	Abdomen 75 kVp	Myelography 75 kVp	IVU 75 kVp	Chest 125 kVp
Brussels	41 1	43 9	41 1	43.9	48.4
Nijmegen	43 1	43 1	44 0	40 0	34 6

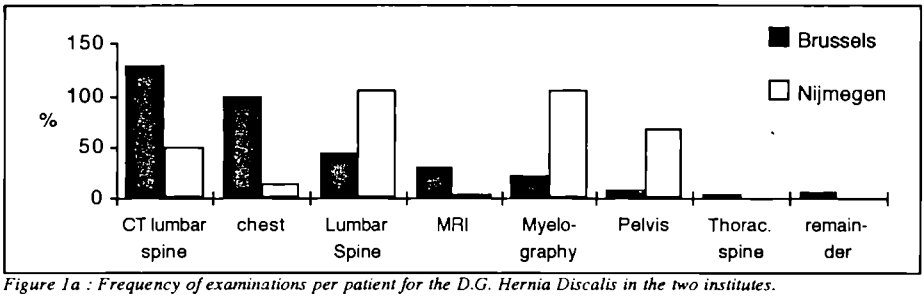

Figure 1a : Frequency of examinations per patient for the D.G. Hernia Discalis in the two institutes.

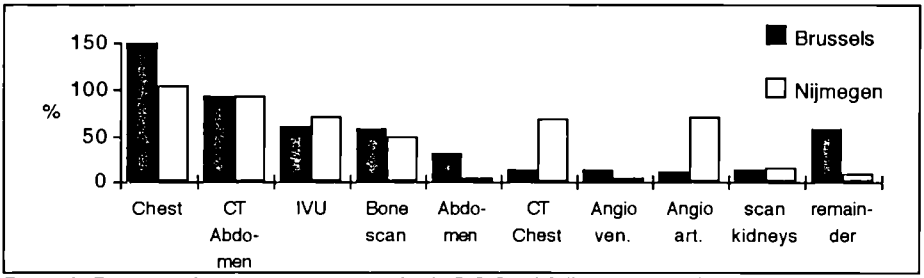

Figure 1b: Frequency of examinations per patient for the D.G. Renal Cell Carcinoma in the two institutes.

1.4 Dosimetry and image quality measurements

A procedure was developed to measure in a standardised way the radiation dose delivered to a standard patient and to evaluate the quality of the images for all examination types and equipment involved. Starting-points for this were: - the dose and quality were measured on a test object representing a 'standard patient'. This made it possible to compare the data between the different hospitals. Working with 'real' patients would have been practically impossible within the given conditions.

- The patient equivalent test object we used, is a piece of PMMA with dimensions 40x 40 x 19 cm for abdominal and lateral chest X-rays. When the central cell of the Automatic Exposure Control was used, a piece of Aluminium with dimensions of 10 x 10 x 4 mm to simulate the spinal cord was added. These dimensions were chosen as a practical implementation of the AAPM abdominal-test object[1]. For PA chest examinations we used a test object of 40 x40 x 9 cm PMMA. This thickness was found by comparing the mean mAs needed for a PA chest-wall X-ray when exposing the test object or a normal patient.

- In the centre of the test objects (at 4.5 or 8.5 cm under the surface) we placed a contrast-detail phantom [2]. In this way we could retrieve information about the image quality for the different hospitals and installations. The Image Quality Figure (IQF) was so far only estimated for the plain film radiographic equipment. Digital Imaging systems were not included yet (as CT and DSA). The IQF was retrieved from images recorded under standard exposure conditions (i.e.. 75 kVp effective or 125 kVp for Chest X-ray and the mAs setting that gives a film density of 1+base+fog). The results of the IQF measurements in the two hospitals are shown in table 1. Note that a better Image Quality results in a lower IQF.

- TLD-100 LiF chips were used for dose measurements. These TLD's were read out in Nijmegen and a cross reference was made with the NRPB. In this way the dose results can be compared with former publications on patient dose.

- For the CT Equipment the Computed Tomography Dose Index (CTDI) was measured in air, on the axis of rotation, as defined by Shrimpton [3]. We used for these measurements small tubes with 15 or 30 TLD (depending on the slice-thickness used). The results of these measurements in the two Hospitals are given in table 2. Figure 2 gives for the plain film radiographic examinations the total surface dose in the two hospitals.

Table 2: Normalised CTDI data for the equipment in two Hospitals (in mGy/ mAs).

	Nijmegen		Brussels	
Examination type	Slice thickness	$CTDI_n$	slice thickness	$CTDI_n$
Abdomen/ Chest	8	0.079	8	0.104
Lumbar spine	5	0.165	4	0.080
			2	0.096

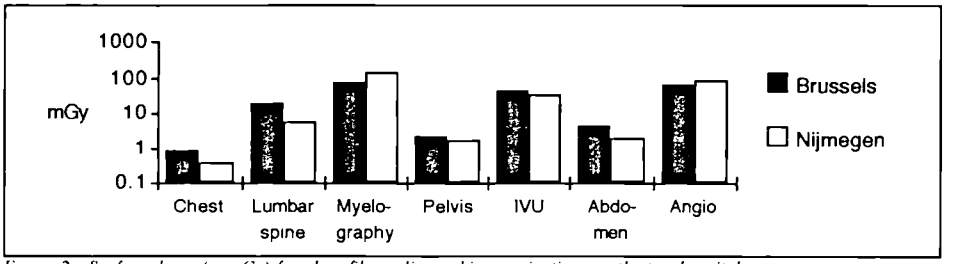

Figure 2: Surface doses (in mGy) for plain film radiographic examinations on the two hospitals.

2. Discussion and conclusions

2.1 Differences between diagnostic algorithm, responsible for a difference in patient irradiation [4]

2.1.1 Diagnosis: lumbar spine hernia discalis

The comparison of the list of the performed examinations between the two hospitals (A and B) does show significant differences in: a) the type of examination used; b) the frequency of the examination, c) the number of exposures per examination

In the hospital A, myelography is always performed before operation, where hospital B only used it in selected cases (9 patients of 43). This can be (partly) explained by the fact that hospital A has been equipped with Magnetic Resonance Imaging late in the study (only 1 MRI in the series, for 12 MRI in B). But we see also that hospital B systematically uses CT, where A only realises CT in a fraction of the cases.

Also interesting is the difference of exposures for conventional radiology of lumbar spine: hospital A uses significantly less exposures per examination than hospital B.

Another difference is that hospital A not always performs preoperative chest film, where hospital B still systematically does (a questionable habit, following different international studies and recommendations).

In conclusion, we can say that significative differences exist between the two hospitals for the diagnosis algorithm, which can not be explained by objective factors, but are probably the consequence of local habits and local conceptions and extrinsic influence of health care organisation.

In casu (diagnosis Hernia Discalis), hospital A mostly relies on myelography for primary diagnosis, where hospital B mostly relies on CT Hospital B systematically performs more exposures in examination of the lumbar spine and systematically uses chest film as preoperative test. These differences can have a significant impact on the irradiation of the patients.

2.1.2 Diagnosis: Renal cell carcinoma

Here the differences are globally less evident. The chest X-ray is equally used in the two institutions (but there is here a real medical indication for it). CT is systematically used for staging in the two institutions.

One difference concerns the number of exposures of the intravenous urography (again less exposures in hospital A, but the difference is marginal).

The major difference here is the use of angiography, which is only used in selected cases in hospital B (4 cases of 36), where it is used in 23 cases out of 32 in hospital A This reflects probably a different opinion of the clinicians upon the value of angiography and CT for the diagnosis of locoregional invasion of the vascular axis.

2.1.3 General conclusion

These aspects of the study clearly demonstrate that differences in the diagnosis algorithm exist between those two relatively comparable institutions, which can not be explained by objective factors. The influence of a global health care organisation, the "weight of opinions" of the clinician, their relation with the department of Radiology, are possible factors which explain those differences.

An optimal use of radiology implies an optimisation of the cost-benefit for the patient and the population of the administered radiation dose versus the diagnostic benefit.

This problem must clearly be seen as a global one between:

- the technological factors (= related to the apparatus)
- an optimal use of technical parameters
- a minimum of exposure per examination
- an optimal diagnosis algorithmic pathway

The problem must be globally managed; this study shows namely the importance of interdisciplinary discussion about diagnostic pathways and, as increasingly accepted, of consensus conferences for optimal diagnostic use of radiological examinations

2.2 Dosimetric data

The absolute figures of the surface dose measured are not very realistic. Only the data for the lumbar spine AP and Chest AP and LAT view are comparable with literature data. This is inherent to the method we used(i.e.. measurements with only 2 different test objects). We have not been able to develop in the time given, a set of test objects appropriate for all X-ray projections we had to deal with in this study. It is, however, clear that it is essential to have a dedicated test object for each projection.

We already have some ideas about building 'tuned' test objects from PMMA and Aluminium plates and we are working on a system to assess the dimensions of such test objects for the projections needed. We also hope that the results of the EC Workshop on 'Test Phantoms and Optimisation in Diagnostic Radiology and Nuclear Medicine'[5] can help us further. We expect in a sequel to this work we will be able to find a solution for this problem.

2.3 Image quality

The Contrast Detail phantom has proven to be a useful instrument in defining the Image Quality of a certain film for different X- ray techniques.

Still it seems rather difficult to compare images from different investigations, since the details a radiologist looks at can vary considerably for various examinations. Therefore we assessed the IQF not from the film exposed with the AEC as in radiological routine, but from using the mAs that gives a film density of 1+ base + fog. In the future we think this method can be extended to all routinely used kV settings.

Special problems are related to the Image Quality of the DSA and CT equipment: that parameter is strongly related to the Field of View used, and require very specific measurement techniques.

2.4 Computed tomography

The results of $CTDI_n$ measurements show quite large differences between the equipment in Brussels and Nijmegen. As shown in the literature[3] this is not very surprising. A comparison between the data from Brussels and from Shrimpton (recorded on equipment of the same type[6]) shows very good agreement.

3. Objectives for the future

A second, larger project is under negotiation with the European Commission (it was classified 'high priority'). This will allow us to continue and extend the work described in this report.

The objectives can be summarised in the following items:

- test objects for dose and Image Quality will be further developed.
- a method to define the quality of CT and DSA images will be further developed and tested.
- the results of this pilot study will be further exploited.
- the data collection will continue in the two institutes and will be completed by data from three institutes in Italy, Spain and France.
- the absorbed dose in different organs will be calculated from entrance dose using available literature data.
- the Image Quality Figure and absorbed dose will be used to rank different strategies mathematically.
- an inventory of reasons will be made that can lead to the choice of examinations and number of images and the medical and/or sociological data will be evaluated.
- the methodology of diagnostic groups will be described in a publication so that the dose and risk evaluation can be done in other institutes.

Notes

1 AAPM (1990); Standardised methods for measuring Diagnostic X-ray exposures; AAPM report no. 31.

2 M.A.O. Thijssen, H.O.M Thijssen e.a.(1989); A definition of image quality: the image quality figure; BIR report 20, p29- 34.

3 Shrimpton PC , Jones DG e.a. (1991); Survey of CT practice in the UK, Part 2: Dosimetric aspects; NRPB report 249.

4 by Prof. Dr. Osteaux, head of the Department of Radiology and Medical Imaging, AZ-VUB Brussels.

5 CEC discussion Workshop: Test Phantoms and Optimisation in Diagnostic Radiology and Nuclear Medicine; Würzburg 15-17 June 1992.

6 Siemens Somatom DRG and DRH.

Project 1

Head of project: *Prof. Van Loon*

Objectives for the reporting period

- Search for Diagnostic Groups (D G) that could be entered in the study.
  Elaboration of a model protocol for inclusion in the study and a data collection form for patient data and for the different examinations
  Evaluation of TLD dosimetry ; possible local read-out and comparison with NRPB.
- Set-up of the hardware in the Radiology department AZ-VUB for determining the nescessary parameters of X-ray equipment (kVp, geometry, sensitometry, ..)
- Collection of the patientdata for the D G 's chosen
- Development of a protocol and test objects nescessary to determine the dose and Image Quality of the examinations involved
- Collection of dosimetric and Image Quality data of the examinations involved.
- Evaluation of the procedure.

Progress achieved

1. Method and results

1.1 Selection af diagnostic groups

After thorough discussion the co-operating physicians from the two hospitals defined two diagnostic groups; Renal Cell Carcinoma and Lumbar Hernia Discales. We tried also to include one D.G. dealing with paediatrics (Peleonephritis was suggested) but organisational difficulties made it impossible to include it in this study. Other D.G's suggested; Gallstones, investigation of Stomach and Intestine, metastases of the vertebral bone, were rejected on one or more of the criteria mentioned in the general part of this report.

1.2 Collection of patient related data

In the Brussels hospital, the only information about radiological examinations that can be found in the Hospital patient data system is that a certain examination was performed (but the absence of information on an examination does not mean it was not performed!) All radiological films are not available for recalculation of dose from film density, size, etc. Some are taken home by the patient[1], some disappear somewhere in the hospital

Investigating radiographers, radiologists and procedures, we found that examinations are performed in a very standardised way The number of films, film formats, localisation of the beam , room where the examination can be performed, etc. , in Brussels were obtained by interviewing several radiographers and observing their procedures

Table 1: Radiographic data on 20 IVU examinations

type	Direction	format	kV mAs	# films
Abdomen	AP	35 x 43	66	3
Tomo kidneys	AP	24 x 30	70 80	3
Bladder	AP	24 x 15	66	1
	AP	24 x 15	96	1
	LAT	24 x 15	96	1
	OBL	24 x 15	96	2

A problem existed with the IVU (Intravenous Urology) examinations. The number of films taken varied considerably To determine a mean value and the variations , radiographers kept records of 20 patients with an IVU examination: the type of exposures, kV, film format and localisation were registered. A 'mean' IVU examination " for a patient with an indication of Renal Carcinoma" was defined from the results (This means that special attention is given to the kidneys) The results are shown in table 1.

Table 2: Examination modalities

Examination	kV	slice	feed	Nr slices	remarks
CT Lumbar spine	125	4 mm	4 mm	± 15	incl. topogram
CT abdomen	125	8	12	± 35-40	incl topogam
CT Chest	125	8	10	±15	incl. topogram

Examination	kV-range	film'ormat	directions	localisation	Nr. films
Chest	125	40 * 40	PA, LAT	lungs	2
Lumbar spine	73- 85	30*40 to 16* 22	PA, LAT and 3 4	D12-heuppoint and LSJ	5
Myelography	73- 96	30*10	PA, 3 4, 7 8 and LAT	L1-S1	12
	general remark myelography: relative long fluoroscopy times!				
IVU	66- 96	35*43 24*30	AP, LAT, 3 4	mid femur spot on kidneys and peritoneum	11
Pelvis	73	35*43	AP	pelvis	1
Angiogrphy	63	matrix 1024	PA	abdomen	30 frames
Bonescan	performed with 555 MBq Tc99m				

Table 2 gives, for all examinations involved in the dosimetric-measurements (i.e that at least 20 % of the patients in one hospital underwent this examination), the parameters for the radiological technique used

1.3 Equipment specifications

The examinations listed in table 2 were performed in 4 radiography- rooms, on 3 CT scanners and in one angiography-room. For all equipment, except the CT, the appropriate kV scale is calibrated, the total filtration is derived and the FFD and film-tabletop distance are measured. These data were collected to enable us (in the future) to calculate organ doses and risk factors from the surface dose data measured in this project. Beam quality and kV measurements were not performed on CT equipment in Brussels yet.

1.4 Dosimetric and image quality results

Table 3 lists the examination modalities and dosimetric and Image Quality results for the plain film radiographic equipment. These data were collected using the protocol, described in general part of this report. Table 4 and 5

Table 3: Measurement data plain film radiographic examinations

examination	kV set	Room	density	dose (mGy)	IQF
Chest PA	125	D	1.22	0 18	49 1
LAT	125	D	1.20	0.60	63.2
Lumb. Spine	70	B	0.90	4.18	38 8
	73	G	1.25	3.50	41.1
	90	B	1.00	2.33	44.9
	85	G	1.65	4.00	40 4
	77	B	0.85	3.30	43.5
	77	G	1.20	3.83	36.9
Pelvis	73	B	0.75	2.07	43.3
	73	G	1.05	2.26	41.1
Myelography	73	G	1.25	3.50	41 1
	77	G	1 20	3.83	36.9
	96	G	1.70	2.17	
	89	G	Scopy	16 8	in 1 min
IVU	66	L	1.15	4.62	37 5
	70	L	1.30	4.55	40.6
	96	L	0.80	1.51	48 2
Abdomen	66	L	1.15	4.62	37 5

Table 4: Measurement results DSA equipment

settings						measured	
kV	Frames sec	matrix	mA	ms	focus	# frames	dose frame (mGy)
63	3	1024	739	53	large	30	2.15

Table 5: CTDI results of Brussels compared to the NRPB report 249

Scanner type	slice thicknes	$CTDI_n$ Brussels	$CTDI_n$ NRPB	diff (%)
Somatom DRH	8	0 104	0.096	8
Somatom DRG	4	0 080	0.096	-12
	2	0 096	0 112	-16

give the dosimetric results of the measurements on DSA and CT equipment in Brussels.

2. Discussion and conclusions

2.1 Patient data collection

The method used to collect patient data has proved to lead to useful results However we found that it can sometimes be very difficult to retrieve all information available in the hospital it can be scattered over different departments, data systems etc , and one has to check carefully the information.

We had several thorough discussions in the team regarding the way the patient data should be collected We all agreed that an ideal, prospective study would be to monitor patients admitted to the hospital with a variety of symptoms A final diagnosis is than stated. Such a method however was beyond the means of this project: it would give a very high extra workload and have severe consequences for the organisation within the department. We are nevertheless convinced that our more practical approach (a retrospective study) has achieved the goal, to gather information and to compare radiological practice in different institutes

2.2 Dosimetry

In Brussels we spent many months last year on the calibration of a TLD system. Although it was a very new, sophisticated system[2], we ended up still having technical problems. Therefore all TLD readings, so far, were performed on the equipment in Nijmegen[3]

A Diamentor © system was used in Brussels for control purposes of the Automatic Exposure Control systems of the equipment. We learned that this is very useful when the actual given mAs during an automatic exposure can not be read from the control panel (as it is often the case with older equipment).

2.3 Comparison of dose data with EC-trail results

The dosimetric results obtained from simplified test objects are not very realistic yet We can make a comparison with preliminary results of the data measured in Brussels during the EC 'Quality Criteria in Diagnostic Radiography' trial in 1991[4]. These results were obtained in the same room and under the same exposure conditions as used in this project The results are shown in table 6. We can see that the dose data of the Chest LAT and Lumbar spine AP views are within the range, measured in the EC trial. For the two other projections (Chest PA and Lumbar spine LAT), the surface doses measured using a test object are much lower than in the EC trial From these results we can conclude that the simplified system of test object we used is not appropriate yet to obtain a realistic figure for the surface dose for all the different X-ray projections in this study However, the dose results we measured till now can perfectly be used to compare the equipment in Brussels and Nijmegen for the data are obtained using the same measuring protocol.

2.4 Computer tomography results

In table 5 a comparison is given between the Brussels CTDI results and those reported by the NRPB[5]. We can see that there are still some small differences between the two, but in relation to the variations normally seen in this field these are quite small

3. Indirect achievements (spin- off)

In Belgium little experience is available in the field of Quality Control in diagnostic radiology. Using the equipment that was procured for this project (The Diamentor system, ionisation chamber, kV-meter) a Quality Control project was initiated at the department Several small and larger equipment problems were discovered, proving to the medical and technical staff the usefulness of Quality Control.

Table 6: Surface doses in mGy for different X ray projections measured at a test object, or on 8 patients in room B, AZ VUB Brussels

Examination type		Test object	EC Trial mean	minimum	maximum
Chest	PA	0 18	0 269	0.16	0 35
	LAT	0 60	0 728	0 28	1 25
Lumbar spine	AP	3 84	5 49	3 00	11 4
	LAT	3 16	11 4	9 30	15 0

Notes

1 Note that in Belgium the films are property of the patient.

2 Rialto system of Vinten at the Middelheim Hospital; Phys B. Schaeken.

3 Harshaw 2000D TLD reader system.

4 Preliminary results AZ VUB Hospital from the 1991 Trial, Quality Criteria for Diagnostic Radiographic Images of the European Community Research Action; restricted information.

5 Shrimpton PC , Jones DG ea.. (1991); Survey of CT practice in the UK, Part 2: Dosimetric aspects; NRPB report 249.

Appendix A

Radiological diagnosis of Renal Cell Carcinoma (RCC).

Diagnosis:
Detection by imaging procedures such as intravenous urography (IVU), ultrasound (US), computed tomography (CT), angiography of RCC, resulting in surgical treatment.

Golden standard:
Surgical and histological proof.

Exit point:
Surgical treatment .

Entry point:
First radiological examination following start of complaints or first examination demonstrating RCC as incidental finding

Criteria of exclusion:
Radiological examination not available or incomplete for review

Examinations to be reviewed for dosimetric study:
IVU, US, CT, angiography, chest x-ray, and other examinations used for diagnostic staging.

Data collection:
Relevant information will be collected on a data sheet.
-patient identification
-chronological summation of all the radiological examinations as cited above
-technical data (physics)
-exposure data including beam direction (AP, PA, LAT,Oblique), field of view (FOV), kV and number of films exposed.

Radiological diagnosis of Lumbar Hernia Discales.

Diagnosis:
Detection by imaging procedures such as standard radiography, tomography, computed tomography, MRI, myelography or discography of a hernia discalis resulting in surgical treatment.

Golden standard:
Hernia discalis proved by operation. (Operation protocol).

Exit point:
Surgical treatment of the hernia.

Entry point:
First radiological examination following the complaint of lower back pain (LBP) or sciatalgy.
In case of chronical LBP we take into account examinations up to one year before surgery.

Criteria of exclusion:
We can only accept patients who can account for all their radiological examinations, even if some of them were taken in other hospitals.
We will also exclude patients who already had surgery for a hernia discalis.

Examinations to be reviewed for dosimetric study:
Standard radiography, conventional tomography, computed tomography, MRI, myelography, discography, bone scintiscan and other pre-op examinations.
Examinations performed in another centre or private practice will be included as if they were performed in the participating centre.

Data collection:
Relevant information will be collected on a data sheet.
-patient identification
-chronological summation of all the radiological examinations as stated above
-technical data (physics)
-exposure data including beam direction, Field Of View (FOV), kV and number of films exposed.

Project 2

Head of project: *Dr. Thijssen*

Objectives for the reporting period

- defining the limits for this pilot study to maximize the value of the results.
- find radiological examinations that are suitable within these limits.
- define entry and exit points for individual patients to be included in the study.
- create the possibility to measure the dose and parameters.
- production of a data bank from the patient data.
- collection of patient data on two selected diagnostic groups.
- calibration of the TLD measurements to the NRPB-system.
- evaluating the time-effects on our TLD-materials for the exchange of TLD chips by mail.
- selection of the method and exams to calculate the entrance dose and radiation risk per exposure.
- set-up and test of measuring protocol for the examinations.
- evaluation of the procedure.

Progress achieved

1. Method and results

1.1 Selection af diagnostic groups

For the purpose of getting an impression of the risks a patient is exposed to during the diagnostic pathway leading to a certain diagnosis, in this pilot study is chosen for two diagnoses: Renal Cell Carcinoma (RCC) and Lumbar Hernia Discalis (LHD). This choice was made after a critical dicussion with our colleagues in Brussels. Criteria for the choice of these diagnoses were:

- The diagnoses must have clinical and social relevance, i.e. an important number of patients must suffer from it.
- It must be possible to define a clear and unambiguous set of selection criteria.
- Adequate and sufficient patient data files must be available in each hospital.
- A significant part of the examinations leading to the diagnosis must be executed using ionising radiation.

1.2 Collection of patient related data

Next the patient files were collected. Only data were used of patients matching the criteria we made up for both Diagnostic Groups (D.G.). As an example the criteria on the D.G. of Renal Cell Carcinoma are enclosed (appendix A). The same criteria were used in Brussels.

For each patient all radiological examinations he or she had during the diagnostic process were listed on a dataform. So we obtained a patient examination file for each D.G. The frequency in which the examinations occur varies from 100% (or even more, because a patient can undergo some examinations more than once) to about 5%.

Decided was to treat examinations that were performed to 20% or more of the patients, as typical for that D.G.. These typical radiological techniques were examined and entrance dose and image quality were determined. The number of films of some examination can vary considerably. The way a IVU examination is performed is strongly related to the medical indication of the patient. Table 1 shows the average examination in case of Renal Cell Carcinoma.

table 1: Radiographic data on a IVU examination in case of Renal Cell Carcinoma.

type	direction	size	kV	mAs	# films
abdomen	AP	24x30	70	80	1
tomo	AP	24x30	70		3
kidneys	AP	24x30	70	100	1
	AP	24x30	66	80	1
	AP	30x40	70	80	1
bladder	AP	18x24	70	80	1

1.3 Equipment specifications

For all radiological techniques occurring in these files the information, relevant for dosimetry and risk estimation, was retrieved. An inventory was made of technical data, describing the equipment in every examination room.(table 2)

table 2: Examination modalities.

Examination	kV	mAs	slice	feed	# slices	remarks
CT lumbar spine	133	473	5 mm	5-6 mm	13	incl. topogram
CT abdomen	125	350	8 mm	8 mm	24	incl. topogram
CT chest	125	350	8 mm	8 mm	16	incl. topogram

Examination	kV-range	film size	direction	location	# films
Chest	150	35x43	PA, lat	lungs	2
Lumbar spine	70-85	35x43	AP, lat	S1-L1	2
Myelography	70-95	15x15 to 12x30	AP, lat, obl	S1-L1	13
IVU	66-70	18x24 to 30x40	AP	KUB, kidneys, bladder	8
Pelvis	73	35x43	AP	pelvis	1
Abdomen	73	35x43	AP	abdomen	1
Angiography	73	matrix 1024	AP	abdomen	30 frames
Bone scan	performed with 600 MBq $_{43}Tc^{99m}$mdp				

In the lists of examinations one diagnostic examination appears that is not performed with X-rays, but still making a considerable contribution to the total dose; bonescan. The examination is performed with $_{43}Tc^{99m}$mdp, with a decay energy of 142.7 keV.
The dosage is given in table 3.

Table 3: Dosage of $_{43}Tc^{99m}$mdp in MBq.

	weight (kg)	<85	>85
age (years)			
20-40		480	600
>40		600	600

Effective dose equivalent: 8 10^{-3} mSv/MBq. Since the average age of all patients in our study is 59.9 years, the effective dose equivalent per patient is about 4.8 mSv.

1.4 Dosimetry and image quality results

To measure the entrance dose, thermoluminescence dosemeters (TLD) were used, in form of LiF crystals. In this study the aim was to retrieve the skin entrance dose, i.e. the radiation that is absorbed in the outermost layer of tissue. Primary radiation as well as backscatter are included. Therefore TLD's were put on the test object, or under the test object between table and perspex if the tube was located under the table. For measurement the TLD-crystals were put in the same thin perspex holder as used for calibration. Every holder contains three crystals. For calibration the TLD's were irradiated free in air and at the same time the exposure was measured by a calibrated ionisation chamber (exposure in R). Afterwards the TLD's are read out with an Automated TL Analyzer System from Harshaw. In this system the crystals are automatically put one by one in an oven, where they are heated by hot nitrogen gas (300° C) for the time of 13 seconds. Each crystal is read twice to make sure that all excited states are returned to their ground state. The optical radiation that is emitted during this return to the original energy states, is detected by a photomultiplier tube and converted to a current. After integrating in time, a charge is obtained which is proportional to the radiation energy absorbed in the crystal. Because the exposure in R of the calibration beam is exactly known, for every TLD-crystal a conversion factor is obtained in mR/nC.

Table 4 shows the examination modalities as well as dosimetric and Image Quality results. Table 5 and 6 give the dosimetric results on measurements on DSA and CT equipment in Nijmegen.

table 4: Measurement data plain film radiographic examinations.

Examination	kV set	Room	density	dose (mGy)	IQF
Chest PA	150	thorax-	1.29	0.08	
lat	150	kamer	1.25	0.31	34.6
Lumbar spine AP	70	poly-50	1.10	3.29	
lat	85			2.05	
Pelvis	73	poly-50	0.82	1.69	43.1
Myelography	70	Sireskop	1.36	5.93	44.0
	85			4.94	
	90		1.45	4.54	42.6
	95		1.45	4.25	42.1
IVU	66	IVP-kamer	1.18	3.68	40.0
	70		1.00	2.44	
	70			5.53	
Abdomen	73	poly-50		1.89	

table 5: Measurement results DSA equipment.

settings						measured	
kV	frames/sec	matrix	mA	ms	focus	# frames	dose/frame (mGy)
73	3	1024	670	62	L	30	2.70

scopy: 81 kV; 2.7 mA; 5.22 mGy/min

table 6: $CTDI_a$ results of Nijmegen.

scanner type	slice thickness	$CTDI_a$ Nijmegen
Siemens HiQ	5 mm	0.165
Somatom DR3	8 mm	0.079

Since our colleagues in Brussels do not have the disposal of a TLD reader, the reading was done in Nijmegen. This implied that their reading could not be performed immediately after irradiation. For this reason the spontaneous decay of a set of irradiated TLD's was checked as a function of time, to be able to compensate this.

table 7: A set of 21 calibrated TLD's were irradiated (exposure 1220 mR). This was measured with a Capintec ionisation chamber. Immediately after irradiation 3 crystals were read and a average value of 1191 mR was found, which is an acceptable deviation of about 2%. During the next five weeks at different moments each time three crystals were read. Table 7 shows the values that were measured.

# days	0	2	4	11	16	19	33
mR	1191	1171	1160	1065	1014	1018	875
SD	62	60	68	66	18	82	75

We can conclude that because of the short time between irradiation and reading (one or two days) in practice no correction is needed.

2. Discussion and conclusions

2.1 Patient data collection

During this study it became clear that it is of main importance to have clear criteria before starting the collection of patient data. Even the year in which the examinations toke place can de determinant for the number of performances of some examinations. Because of new techniques e.g. Ultra Sound or Magnetic Resonance Imaging, other examinations may not be performed in recent times.
It appeared to be very important to use all the data systems in the hospital. Some diagnostic examinination might have been performed at another department. Bone scans in our hospital were performed at the department of Nuclear Medicine.

2.2 Dosimetry

As stated before a test object was used, composed of 19 cm perspex. Only to simulate a spine, we made use of 4 mm Al. It is evident now that in further study our test object has to be adjusted so that it can be used as a realistic substitute for several parts of a human body. The test object used, is a good substitute for soft tissue, but less appropriate for bone and lung. So the mAs-values the equipment chose automatically, and therefore the doses retrieved, can be seen as a good manner to compare the equipments, but the results can not be seen yet as a realistic view to the doses a patient is exposed to.
The calibration of the TLD measurement to the NRPB has not yet been carried through in the doses stated in this report. In fact a correct calibration is of great value when a realistic test object is used. So in our further study our system will be calibrated to the NRPB-system.

2.3 Comparison of dosedata

For the reason stated above, all the examinations are done a second time, making use of more realistic mAs-values, that were set manually. The mAs-values were averages out of 20 patients or estimates made by experienced radiographers.

Table 8: Entrance doses of the test object measured with automatic exposure cell as well as manually, with realistic mAs-values. NRPB values as published in NRPB-R200.

Examination	Pelvis	Abdomen	Lumbar spine AP	Lumbar spine lat
automat.	1.69 mGy	1.89 mGy	3.29 mGy	2.05 mGy
realistic mAs	3.12 mGy	6.67 mGy	6.61 mGy	17.29 mGy
NRPB-R200	6.57 mGy	8.43 mGy	9.19 mGy	22.79 mGy

PATIENT DOSE FROM RADIOPHARMACEUTICALS

Contract Bi7-057 - Sector C22

1) *Mattsson* , Univ. Lund - 2) *Smith* , MRC Clinical Research Centre
3) *Henrichs* , GSF Neuherberg

Summary of project global objectives and achievements

The general goal of the project has been to improve the accuracy of the current data on absorbed doses from radiopharmaceuticals to patients and to produce dose data for new radiopharmaceuticals. A specific interest has been given to data for children of various ages.
This has been done by:
1. Improving the biokinetic data for some new radiopharmaceuticals like Tc-99m MIBI, Tc-99m P53, Tc-99m HM-PAO and Tc-99m DMSA. Repeated uptake and retention measurements have been carried out on patients and healthy volunteers.
2. Giving special attention to the biokinetics and dosimetry for children and new-born (in the case of Tc-99m HM-PAO and Tc-99m DMSA).
3. Estimating the excretion of Tc-99m in breast milk
4. Improving the physical basis for the dose calculations by using detailed voxel-phantoms based on CT-data for Monte Carlo calculations of new S-values for children.

The results have been used to quantify organ doses as well as effective dose equivalents or effective doses.
New dose estimates have been produced for some important new radiopharmaceuticals. Considerable differences in the biokinetics between adults, children and new-born have been demonstrated. Calculations based on CT-derived anatomical data for one individual child demonstrate a way to individual dosimetry and confirm current results based on the MIRD formalism.
The results enable comparison of different radionuclides for labelling and of different pharmaceuticals in the view of balancing diagnostic benefit and radiation dose and to determine the appropriate activity to be administered in order to avoid unnecessary radiation exposure of the patient.

Project 1

Head of project: *Dr. Mattsson*

Objectives for the reporting period

The objectives have been

1) to study biodistribution and retention in patients undergoing investigations with new radiopharmaceuticals and for substances for which there is a lack of data.
For these studies gamma-cameras as well as whole body counters have been used together with measurements on samples of blood, urine, etc. Biokinetic data have been collected for newborn and children up to 18 years of age, who were subjected to nuclear medicine investigations, whenever such opportunities arised.

2) to construct biokinetic models and to make dose estimates including calculations of the effective dose equivalent and the effective dose.

3) to carry out measurements on the excretion through breast milk, of radiopharmaceuticals for which there still is a lack of data.

Progress achieved including publications

Since the beginning of the project on Sept 1st, 1990, the work has been concentrated on experimental studies of the biokinetics of radiolabelled HM-PAO, MIBI and DMSA and of the excretion of radionuclides in breast milk.

1. Tc-99m HM-PAO in children

At the Göteborg East Hospital, the biokinetics of Tc-99m HM-PAO has been studied in eight children aged between 7 weeks and 18 years. In addition to the routine SPECT study of the brain, the children were scanned with a gamma-camera at 1, 7 and 24 hours post injection. Urine was collected during a 24 hour period. The amount of Tc-99m in the brain, lungs, liver, kidneys and intestines were estimated using conjugate counting and biological half-times were calculated.
There is a strong age-dependence on the uptake in the brain, with high values (20%) for the very young children, four times higher than those reported for adults (5%). The uptake in the other organs showed no similar age-dependence.
The absorbed doses to various organs were calculated with the standard MIRD formalism using published S-values for children of various ages. The organs or tissues receiving the highest absorbed doses are the gall-bladder wall, bladder wall, kidneys, liver and upper large intestine wall.

The effective dose per activity unit for a new-born (0.09 μSv/MBq) is more than one order of magnitude higher than the value for an adult (0.007 μSv/MBq).

Table 1. Tc-99m HM-PAO. Effective dose per unit activity administered.

Age	Newborn	1 year	5 year	10 year	15 year	Adult
Effective dose mSv/MBq	0.090	0.040	0.021	0.014	0.0090	0.007

In a separate study, it was found that if the same activity per unit body-weight is given to patients of various ages, this gives equal image quality. With this dosage method patients of different ages will receive about the same effective dose equivalent from an examination with Tc-99m HM-PAO independently of age. An administration of 10 MBq Tc-99m HM-PAO per kg body weight gives an effective dose of 3-5 mSv.

2. Tc-99m DSMA in children

At East Hospital, Goteborg, the biokinetics of Tc-99m DMSA was studied in four infants (between 2 weeks and 6.5 months of age). Anterior and posterior gamma camera images were acquired at 20 min, 1,2,4,6,9 and 24 h p.i.. Urine was collected during 24 hours. The activity in various organs was quantified using conjugate counting. The maximal kidney uptake (8-9 h p.i.), the initial uptake in the liver and the activity excreted via urine were studied during 24 hours.

Using the measured biokinetic data, absorbed doses and effective dose values have been calculated for a newborn and a 1 year old child using published S-values. The results are given in Table 2.

Table 2. Tc-99m DMSA. Absorbed dose and effective dose per unit activity administered.

Absorbed dose per unit activity	Newborn	1 year	
Kidneys (mGy/MBq)	1.5	0.64	
Bladder wall (")	0.21	0.065	
Effective dose (mSv/MBq)	0.084	0.037	

3. Tc-99m MIBI in adults

At Malmo General Hospital, ten adult patients who were undergoing myocardial perfusion imaging with Tc-99m MIBI (methoxy isobutyl isonitrile), were followed with respect to the biodistribution and retention of Tc-99m. Gamma-camera whole body scans were performed at 15 minutes, 6 hours, and 24 hours post injection. Blood samples were taken on the same occasions. Urine was collected up to 24 hours p.i. The activities in different organs and tissues were determined using the geometric mean of posterior and anterior counts corrected for attenuation in the body. The absorbed dose to different organs and tissues was determined using the MIRD formalism and the effective dose was estimated.
The substance is to a large extent eliminated through the hepato-biliary system and excreted via the gall bladder through the gastro-intestinal tract and through the kidneys. Consequently, the upper large-intestine (50 μGy/MBq)), lower large-intestine (22 μGy/MBq), kidneys (29 μGy/MBq) and gallbladder (27 μGy/MBq), receive the highest absorbed doses. The effective dose was estimated to 0.01 mSv/MBq, somewhat higher at rest and somewhat lower at stress. Tc-99m MIBI does not redistribute in the myocardium and for a full investigation, at rest and during stress, two injections have to be given. This gives a total effective dose of 13 mSv for a complete investigation.

4. Radiolabelled MAb:s in adults

At Sahlgren Hospital, the pharmacokinetics of I-131 or I-125 labeled monoclonal antibodies against the human colorectal adenocarcinoma cell line Colo-205 were studied several times in two patients with adenocarcinoma. After iv or ip administration, gamma camera imaging and tissue collection were performed. The pharmacokinetics was dependent on the administration route and probably also on the amount of antibody or on earlier antibody administrations. Estimated absorbed dose to tumour for one of the patients would be 17 Gy after administration of 30 GBq I-131 for therapy. The mean absorbed dose in the whole body would be 5 mGy after an injection of 500 MBq I-123 for diagnosis.

5. Excretion of Tc-99m labelled radiopharmaceuticals in breast milk

At Malmö General Hospital, with the assistance of several other south Swedish hospitals, new data have been collected concerning the excretion of Tc-99m labelled radionuclides in breast milk.
The substances and number of patients involved in this study are presented in Table 3.

Table 3. Excretion of Tc-99m in breast milk after nuclear medicine investigations.

Radiopharmaceutical	Number of patients	Extrapol. excreted fraction per ml at time of injection	$T_{1/2}$	Excreted fraction of inj activity #)
Tc-99m pertechnetate	7	10^{-3}	2.7 h	7%
MAA	11	10^{-4}	4.8 h	7%
DTPA	2	10^{-6}	4.4 h	0.04%
MDP	3	10^{-6}	4.5 h	0.04%

#) Assuming breast feeding every 4th hour, starting 4 hours after injection; the child is given 140 ml at each occasion.

The activity concentration in breast milk is relatively independent on the total milk volume. The difference in $T_{1/2}$ between pertechnetate and Tc-MAA primarily reflects the rate of Tc loss from MAA. The low excretion in breast milk for Tc-99m DTPA and MDP is due to the fact that these substances are excreted through the kidneys and bound to the skeleton respectively. Tc is also firmly bound to these substances.

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Project 2

Head of project: *Dr. Smith*

Objectives for the reporting period

1. To investigate in humans the time-course of biodistribution and excretion of Tc-99m-labelled P53 (Tetrofosmin) and to use this information to derive appropriate biokinetic data for estimation of radiation doses to body organs leading to calculations of Effective Dose Equivalent and Effective Dose. Tc-99mP53 is a novel myocardial perfusion imaging agent developed by Amersham International as a reconstitutable kit preparation.

2. To examine the simple method used in (1) to quantitate organ radioactivity content and compare it with a more accurate method based on whole body transmission scanning with respect to estimates of Tc-99m uptake and radiation dose in individual organs, as well as the Effective Dose.

Progress achieved including publications

1. The radiation dosimetry of Tc-99mP53 in normal humans

Tc-99m 1,2-bis[bis(2-ethoxyethyl)phosphino]ethane (Tc-99mP53) has successfully undergone Phase III clinical trials and is currently the subject of a licensing application for clinical use. The investigations described in this report constituted Phase I studies of this substance which was developed as a possible replacement for Tl-201.

1.1 Methods

Biodistribution and excretion of Tc-99mP53 were measured at two different centres (Harrow and Aberdeen) in male human volunteers. Twelve subjects (22-35 years) were studied, 6 at each centre, both at rest and after exercise (to 85% of peak heart rate). Estimates of whole-body and organ retentions were made separately at the two sites and the total data were used for dosimetry calculations at one centre (Harrow). Radiochemical purity of each preparation was checked prior to injection of 138-173MBq (3.7-4.7mCi). Counting standards for determination of Tc-99m in blood samples and excreta were prepared from the same stock as the injectate, all standards being made up with 1% bovine serum albumin to prevent adherence of the preparation to the walls of glass containers. Subjects were injected after an overnight fast via a cannula placed in the opposite arm to that in which a blood-sampling cannula was inserted.

1.1.1 Blood clearance

Heparinized blood samples were withdrawn at 2,5,10,20,30 min, 1,2,4,8 and 24h post-injection and duplicate 0.5 ml samples were counted together with standards in an automatic gamma sample counter.

1.1.2 Clearance in excreta

Total urine and faecal outputs were collected from the time of injection up to 48h. Urine was collected for the time periods 0-2, 2-4, 4-8, 8-12, 12-24 and 24-48h in plastic containers and each container was counted between opposing NaI detectors. Individual faecal collections in plastic cartons were counted in a similar manner.

1.1.3 Biodistribution

At Harrow this was performed using a whole-body scanning gamma camera (IGE 400AT) fitted with a diverging parallel hole collimator, whilst at Aberdeen this was achieved using several overlapping static views covering the entire body using an IGE 500A Maxicamera and parallel hole LEGP collimator. Imaging was performed at 5, 30 min, 1,2,4,8,24 and 48h post-injection and both anterior and posterior scans were obtained. A number of specific organs exhibited significant uptake of Tc-99mP53, identified as heart, lungs, liver, gall-bladder, kidneys, salivary glands, thyroid, urinary bladder and GI tract. For each measurement time, regions of interest (ROI) were used to measure total counts in the whole-body and organs and background corrections were made using counts in ROIs adjacent to the measured organs. All background-corrected whole-body and organ counts were further corrected for radioactive decay to the injection time and geometric means of anterior and posterior counts were estimated for whole-body and specified organs.

1.1.4 Calculation of biokinetic data

The geometric mean for the first whole-body scan (5 min) was taken to represent 100% of administered activity and all organ and whole-body geometric means were related to this value. Total body retention values were then corrected for the estimated activity in the GI tract and urinary bladder to give retention values for 'total body less contents of GI tract and bladder'. These, and organ values, were described mathematically as multiexponential retention functions, and retention of Tc-99m in blood was similarly described. The ratio of faecal excretion (faeces plus GI content) to urinary excretion (f_F:f_U) was calculated from the total amounts of Tc-99m excreted by these two routes over 48h.

1.2 Results

Clearance and biodistribution data from the two centres were very similar and therefore were pooled into a single group. Activity in whole-blood fell rapidly to less than 0.2% dose.l^{-1} within 30 min, the rate being slightly faster after exercise. Total body retention (less contents of bladder and GI tract) fell rapidly within the first hour by about 20% at rest and 10% after exercise followed by a steady fall to 15% and 25% retention respectively at 48h. After exercise there was reduced concentration in certain organs mainly liver and salivary gland but enhanced uptake in muscle. Uptake of Tc-99mP53 in heart was 1.2% falling only to 1% at 2h and was similar at rest and after exercise. In most other organs, retentions after exercise were about 60-80% of those at rest. Highest initial uptake was observed in liver (4.9-10.6%) but this fell

rapidly and had mostly disappeared by 4-8h. Gall-bladder activity increased rapidly to peak at about 2h (up to 10.7%) generally falling below 1% at 24h. Lung uptake was low (0.7-3.0%) and rapidly cleared within 4h. Salivary glands showed significant uptake (0.6-2.7%) which fell steadily to about 0.5% at 24h. Thyroid uptake was initially low (0.1-0.7%) and became undetectable in most subjects by 4h. The faecal:urinary excretion ratio (f_F:f_U) of 0.54:0.46 at rest was exactly reversed after exercise.

1.3 Dosimetry

Source organ residence times were estimated from the multiexponential retention equations and dose calculations were performed according to MIRD principles using the MIRDOSE II computer program. Models for the GI tract and urinary bladder were used as specified in ICRP53. Since an 'S' value is not currently available for salivary glands, this was calculated specially (5.0×10^{-4} rad.μCi^{-1}). Dose estimates for 25 target organs are given in Table 1, highest values being received by organs in the excretory pathways followed by kidneys and salivary glands. Following exercise, the dose to most organs is markedly reduced. The effective dose equivalent (EDE) is 1.1 $\times 10^{-2}$ and 8.6×10^{-3}mSv.MBq^{-1} at rest and after exercise respectively, calculated for a 3.5h bladder voiding period. There was only a small effect on EDE values (15% or less) for voiding periods of from 1 to 4.8h. The effective dose (ED) is 8.9×10^{-3} and 7.1×10^{-3}mSv.MBq^{-1} respectively at rest and after exercise. Thus a one day protocol requiring a 370 MBq (10 mCi) exercise study followed by a 1110 MBq (30 mCi) rest study would result in a total EDE of 15.4 mSv or total ED of 12.5 mSv. The gall bladder would receive the highest dose (66 mSv).

2. Assessment of errors in the quantitation of organ uptake and dose

In the studies described above, quantitation of whole-body and organ uptake was made by reference to the first whole-body measurement, which represented 100%. This method provides an average correction and does not allow for the variation in gamma-ray attenuation in different body regions. The potential errors resulting from the use of the simple method was investigated by comparison with a more rigorous method of absolute quantitation using a transmission scanning technique. The comparison was performed on the 6 subjects measured at Harrow, on the basis of organ uptake, organ dose and the effective dose.

2.1 Methods

The 6 subjects underwent a whole-body transmission scan performed using the same scanning geometry as for the biodistribution studies. For this purpose a transmission source housing was specially constructed and temporarily attached to the base of the gamma-camera gantry. A perspex container with rectangular void was uniformly filled with Tc-99m solution and placed in a metal tray supported by the special housing. The

transmission source thus moved under the patient couch directly beneath the camera head. From transmission scans obtained with and without a subject, attenuation was determined for each subject in the same regions of interest used in the biodistribution studies. *In vitro* calibrations were also performed with the transmission source to establish a) the variation of attenuation with thickness of a water phantom, and b) the counting sensitivity for Tc-99m sources of varying size in phantoms of different water thickness. Thus, for a given subject, the organ attenuation value was used with (a) to determine the body thickness at that site in terms of water thickness and this value was used in (b) to determine the appropriate counting sensitivity for that organ.

2.2 Results

By comparison with the transmission-correction method in the resting studies, the simple method overestimated the uptake in lungs by 24% because of reduced attenuation in the chest, and underestimated uptake in kidneys by 10%, with ratios for other organs falling between these extremes (Table 2). In the exercise studies, all ratios were reduced by about 7% (+ 16% (lungs) to -16% (kidneys)) due to the enhanced uptake in skeletal muscle. Whole-body counting sensitivity was on average 7.5% higher after exercise presumably due to the increased uptake of Tc-99m in thinner regions of the body, especially the legs. The errors in organ dose values (Table 3) were slightly lower than those in uptake estimates and the effective dose values estimated by the two methods differed by less than 3% in both the rest and exercise studies. These estimates are dependent on biodistribution patterns and cannot necessarily be assumed for other Tc-99m substances. In general, a measured transmission correction is recommended where practically feasible.

Publications

Smith, T., Lahiri, A., Gemmell, H.G., Davidson, J., Smith, F.W., Pickett, R.D. and Higley, B. Dosimetry of Tc-99m P53, a new myocardial perfusion imaging agent. In: *Fifth International Radiopharmaceutical Dosimetry Symposium,* Proceedings of a Conference held at Oak Ridge, Tennessee, U.S.A., May 7-10, 1991 (Eds. Schlafke-Stelson, A. and Watson, E.E.), CONF-910529, in press.

Smith T. (1992). Comparison of two methods of quantitation in human studies of biodistribution and radiation dosimetry. Phys. Med. Biol., **37**, 1065-1076.

Higley, B., Smith, F.W., Smith, T., Gemmell, H.G., Das Gupta, P., Gvozdanovic, D.V., Graham, D., Hinge, D., Davidson, J. and Lahiri, A. Technetium-99m 1,2-bis[bis(2-ethoxyethyl)phosphino]ethane (Tetrofosmin): human biodistribution, dosimetry and safety of a new myocardial perfusion imaging agent. Submitted to J. Nucl. Med., May, 1992.

Table 1. Radiation dose to various organs from Tc-99m P53 (bladder voiding period 3.5h)

Organ	Rest		Exercise	
	mGy/MBq	rad/mCi	mGy/MBq	rad/mCi
Adrenals	4.11 E-03	1.52 E-02	4.32 E-03	1.60 E-02
Brain	2.15 E-03	7.95 E-03	2.72 E-03	1.01 E-02
Breasts	1.83 E-03	6.78 E-03	2.22 E-03	8.23 E-03
Gall Bladder Wall	4.86 E-02	1.80 E-01	3.32 E-02	1.23 E-01
LLI	2.22 E-02	8.21 E-02	1.53 E-02	5.66 E-02
Small Intestine	1.70 E-02	6.30 E-02	1.21 E-02	4.48 E-02
Stomach	4.63 E-03	1.71 E-02	4.60 E-03	1.70 E-02
ULI	3.04 E-02	1.13 E-01	2.01 E-02	7.45 E-02
Heart Wall	3.93 E-03	1.45 E-02	4.14 E-03	1.53 E-02
Kidney	1.25 E-02	4.62 E-02	1.04 E-02	3.86 E-02
Liver	4.15 E-03	1.53 E-02	3.22 E-03	1.19 E-02
Lungs	2.08 E-03	7.71 E-03	2.27 E-03	8.40 E-03
Muscle	3.32 E-03	1.23 E-02	3.52 E-03	1.30 E-02
Ovaries	9.55 E-03	3.53 E-02	7.88 E-03	2.92 E-02
Pancreas	4.98 E-03	1.84 E-02	5.00 E-03	1.85 E-02
Red Marrow	3.97 E-03	1.47 E-02	4.14 E-03	1.53 E-02
Bone Surface	5.58 E-03	2.07 E-02	6.23 E-03	2.31 E-02
Salivary Glands	1.16 E-02	4.33 E-02	8.04 E-03	2.98 E-02
Skin	1.91 E-03	7.08 E-03	2.22 E-03	8.23 E-03
Spleen	3.82 E-03	1.41 E-02	4.12 E-03	1.52 E-02
Testes	3.05 E-03	1.13 E-02	3.41 E-03	1.26 E-02
Thymus	2.54 E-03	9.38 E-03	3.11 E-03	1.15 E-02
Thyroid	5.83 E-03	2.16 E-02	4.34 E-03	1.61 E-02
Bladder Wall	1.93 E-02	7.12 E-02	1.56 E-02	5.78 E-02
Uterus	8.36 E-03	3.09 E-02	7.34 E-03	2.72 E-02
Total Body	3.72 E-03	1.37 E-02	3.81 E-03	1.41 E-02
Effective dose equivalent (mSv/MBq)	1.1 E-02	4.1 E-02	8.6 E-03	3.2 E-02
Effective dose (mSv/MBq)	8.9 E-03	3.3 E-02	7.1 E-03	2.6 E-02

Table 2. Comparison of 2 methods of estimating organ radioactivity content in 6 normal male volunteers at rest and after exercise following i.v. administration of a ^{99m}Tc-labelled myocardial perfusion imaging agent. Results are given as mean (sd) (n=6) for the first whole body scan started 5 min after injection.

Method A = simple method; Method B = transmission method

Organ	Ratio of organ ^{99m}Tc content (Method A/Method B)	
	Rest	Exercise
Heart	0.98 (0.06)	0.91 (0.07)
Lungs	1.24 (0.07)	1.16 (0.11)
Liver	0.93 (0.08)	0.88 (0.08)
Salivary Gland	1.15 (0.08)	1.07 (0.10)
Thyroid	1.22 (0.06)	1.09 (0.02) (n=5)
Gall-bladder	0.95 (0.08)	0.88 (0.08)
Kidneys	0.90 (0.07)	0.84 (0.07)
GI tract	0.99 (0.04)	0.92 (0.06)
Urinary bladder	0.98 (0.05)	0.91 (0.07)

Table 3. Comparison of organ doses (mGy/MBq) and the effective dose (mSv/MBq) estimated by 2 methods in 6 normal male volunteers at rest and after exercise following i.v. administration of a ^{99m}Tc-labelled myocardial perfusion imaging agent.
Method A = simple method; Method B = transmission method

Organ	Organ dose (mGy x 10^{-3}/MBq)					
	Rest			Exercise		
	Method A	Method B	A/B	Method A	Method B	A/B
Heart Wall	3.55	3.61	0.98	4.05	4.31	0.94
Lungs	2.08	2.03	1.03	2.26	2.24	1.01
Liver	4.63	4.82	0.96	3.39	3.59	0.94
Salivary gland	10.0	8.76	1.14	7.05	6.61	1.07
Thyroid	6.12	5.32	1.15	4.40	4.19	1.05
Gall bladder	70.7	74.6	0.95	40.5	45.6	0.89
Kidneys	12.2	13.2	0.92	10.3	11.8	0.87
GI tract (ULI, LLI)	25.2	25.5	0.99	17.6	18.1	0.97
Urinary bladder	19.2	19.1	1.01	16.3	16.1	1.01
Effective dose (mSv x 10^{-3}/MBq)	8.82	8.91	0.99	6.99	7.17	0.98

Project 3

Head of project: *Dr. Henrichs*

Objectives of the sub-project (1990 - 1992)

A prerequisite for the calculation of exposures due to internally deposited radioactive emitters (e. g. in nuclear medical diagnosis) is the knowledge of so-called Specific Absorbed Fractions and Specific Effective Energies, which describe the radiation transport within the human body. In the past, these calculations were performed on the basis of mathematical anthropomorphic phantoms describing the anatomy of a reference body. The voxel - phantoms developed by Drexler et al., which are based on CT-scans of real persons, can now be used also for internal dosimetry.

It was the aim of the GSF-contribution to this project, to develop methods for the calculation of the factors mentioned above for one individual infant (a baby of 8 weeks) on the basis of voxel-phantoms derived from CT-scans. By comparing the results derived by this method to those based on reference phantoms, the applicability of this new method was to be tested.

Progress achieved including publications

Most of the work for the project was concentrated on the development of computational tools to simulate the transport of radiation within the body of a baby.

The method chosen makes use of so-called Monte-Carlo techniques. The necessary geometric information concerning the positions, sizes and shapes of the relevant tissues and organs is taken from a computer-tomography investigation of a 7 week old baby. For the simulation of the radiation transport, an existing computer code was used, which was developed for the dosimetry of external irradiations, especially for diagnostic radiology, by Drexler, Zankl et al., GSF. The program was modified to allow for using arbitrary internal sources in any tissue of interest.

The code was developed, implemented and tested on a parallel-computer system, which is especially well suited for Monte-Carlo simulations the computational power of such a system guarantees the possibilty to reduce statistical uncertainties as far as necessary: The mean relative standard deviations, which depend not only on the number of photon histories but also on the distances between source and target tissues, lies generally below 5 %, in few cases it reaches 10 %.

The program was used to simulate the transport of monoenergetic photons with energies listed in Table 1. The source and target tissues and organs taken into account are listed in Table 2. For electrons, the approved

asumption of a complete absorption in the source organ was applied, taking into account the actual individual target tissue mass.
The computer runs resulted in energy-specific values of Specific Absorbed Fractions (SAF), thus giving the fraction of energy absorbed in the target tissue in relation to the energy emitted.

Taking standard information on the emission spectra of radionuclides (ICRP publication 38), it was possible to calculate on this basis the Specific Effective Energies, giving the absorbed dose in the target tissue per radioactive desintegration in the source tissue. This was done for the two radionuclides $^{99}Tc^{m}$ and ^{131}I, because according to a report of the German Federal Health Office, more than 70 % of nuclear medical diagnostics make use of these radionuclides. In addition, for radioprotection purposes, the same calculations were performed for ^{137}Cs, as this nuclide is the radioisotope, which dominates the exposure of the general public in many possible cases of nuclear accidents.

These results were used to calculate the dose conversion coefficients for these radionuclides, that means the dose equivalents per unit activity incorporated. The activities were assumed to enter the body directly by injection into the blood, which is for iodine and cesium also a suffient approximation to the case of an ingestion. The information needed concerning the biokinetic behaviour of the incorporated activities was taken from ICRP publication 53 on the dosimetry of radiopharmaceuticals. For this purpose, iodine and cesium were assumed to be incorporated as ions, Tc as pertechnetate-ion.

On the basis of the ICRP biokinetic data, the numbers of radioactive desintegrations in all relevant source organs were calculated; the product of this result with the mentioned SEE-values gives the organ doses in the target organs of interest. In combination with the organ weighting factors, it is possible to derive the effective dose equivalents.

The resulting doses are summarized in Table 3. There they are compared to the dose values, which can be calculated with the same biokinetic data but with the help of the reference anthropomorphic phantoms as published by M. Cristy (Oak Ridge National Laboratories) and as commonly used by the ICRP. These doses were calculated for two different ages "newborn" and "1 year".

The comparison shows a good agreement between the results of the different methods. As mentioned earlier, the data derived in this project (voxel phantom) give the doses for a seven week old baby. Tey fit very well into the intervall defined by the other two ages.

Summary
The results of the project and its calculations prove, that the voxel phantoms can be a reliable tool to quantify doses resulting from incorporated radioisotopes.

The advantage of this kind of phantom in comparison to the mathematical anthropomorphic phantoms lies in the better description of the individual anatomy, in particular with respect to the shapes and locations of organs. Furthermore, these phantoms allow quantitative determination of the reliability, that means the degree of representativity, of internal radiation transport simulations.

Due to the uncertainties and the individual variability of biokinetic data, the possible improvements for radiation protection purposes by this new technique are of minor importance. But on the other hand, the further improvement and development of this technique will help substantially with the individual dosimetry in nuclear medicine.

Tabel 1
Photon energies (in MeV), for which the calculations of SAF-values were performed

0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.15
0.2	0.3	0.4	0.5	0.7	1.0	1.5	2.0	3.0	

Tabel 2
List of organs and tissues taken into account

Source organs	Target organs
Adrenals	Adrenals
Urinary bladder content	Urinary bladder wall
Brain	Brain
	Eyes
Heart	Heart
Large intestine + content	Large intestine wall
Small intestine wall + content	Smalll intestine wall
Kidneys	Kidneys
Liver	Liver
Lungs (seperately left and right)	Lungs
Ovaries	Ovaries
Pancreas	Pancreas
Skin	Skin
Spinal cord	Spinal cord
Spleen	Spleen
Stomach content	
Stomach wall	Stomach wall
Testes	Testes
Thymus	Thymus
Thyroid	Thyroid
Soft tissues	Soft tissues
Uterus	Uterus
Skeleton	Skeleton
Red bone marrow	Red bone marrow
Total body	Total body

Table 3
Dose values (in Sv/Bq) resulting from the incorporation of various radionuclides as calculated by means of a voxel phantom and of two different anthropomorphic phantoms

Nuclide	Tissue	Voxel Phantom 7 - weeks	Anthropomorphic Phantoms Newborn	1 year
^{137}Cs	effective	$1.9 \cdot 10^{-8}$	$3.6 \cdot 10^{-8}$	$1.2 \cdot 10^{-8}$
^{131}I (assumed uptake: 25%)	thyroid	$4.5 \cdot 10^{-6}$	$4,7 \cdot 10^{-6}$	$3.4 \cdot 10^{-6}$
	effective	$1.3 \cdot 10^{-7}$	$1.4 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$
^{131}I (thyroid blocked)	effective	$3.4 \cdot 10^{-10}$	$5.6 \cdot 10^{-10}$	$4.0 \cdot 10^{-10}$
$^{99}Tc^{m}$ i.v. without blocking the thyroid	thyroid	$2,7 \cdot 10^{-10}$	-	$2.3 \cdot 10^{-10}$
	remainder	$1.6 \cdot 10^{-11}$	-	$1.7 \cdot 10^{-11}$
	effective	$1.2 \cdot 10^{-10}$	-	$0.7 \cdot 10^{-10}$

Publications

K. Henrichs, H. G. Paretzke, N. Petoussi, M. Zankl
Dosimetrie inkorporierter radioaktiver Stoffe mit Hilfe von Voxel-Phantomen
invited paper for Annual Conference of the German Physical Society (DPG), March 30th - April 3rd, Berlin.

K. Henrichs, M. Zankl, N. Petoussi
Voxel Phantoms for the Dosimetry of Incorporated Radionuclides
in preparation, to be submitted to "Radiation Protection Dosimetry"

QUALITY CRITERIA AND DOSE REDUCTION IN COMPUTED TOMOGRAPHY

Contract Bi7-067 - Sector C22

1) *Jessen* , Univ. Aarhus Hospital - 2) *Galvão* , LNETI

Summary of project global objectives and achievements

Project global objectives

Part of this coordinated contract has been concerned with formulating quality criteria based on assessment of the influence on patient doses from quality assurance programmes in computed tomography. Special efforts were planed by LNETI to optimize some CT paediatric examinations and to establish quality criteria for those examinations. Aarhus University Hospital intended to prepare some pilot studies on quality criteria for adults after objective measurements of image quality parameters.

The work also includes further development of the methods for radiation dose assessment in computed tomography based on TLD and ionisation chamber dosimetry and to achieve a harmonization of dosimetric intercalibration. Investigations, should be performed, of the role of quality assurance and constancy tests on patient dose and image quality.

Based on earlier nationwide surveys of the clinical use of CT examinations in Portugal and Denmark and on dose measurements performed for scanning parameters used in routine examinations calculation of organ doses should be performed by using the newest conversion factors. An assessment of collective effective dose from computed tomography in the two countries has to be addressed for comparison.

Project global achievements

1. Quality criteria

Image Quality Criteria have been established for some common radiological examinations for adults and for children under the EC Radiation Protection Programme. The goal has been, by providing such guidelines to achieve a comparable level of image quality throughout Europe using optimum radiographic techniques and so avoiding unnecessarily high radiation doses to patients. Another goal is that an application of these guidelines will provide the framework for an expansion to other radiological examinations as computed tomography. The image quality in computed tomography is effected by many parameters and the complexity of this technology and the variability of scanning parameters results in higher numbers of possible quality reducing factors than in conventional radiology.

The most important image quality parameters such as noise, spatial resolution, slice thickness (sensitivity profile), low contrast detectability and dose has to be described in a well defined way in a test object so the clinical images can be assessed in a comparable way. An international standardisation is in progress on these topics in the IEC document 62B

(Secretariat) 148, about evaluation and routine testing in medical imaging departments and has to be included in further work on optimization and constancy tests of equipment for computed tomography.

Image quality criteria have been formulated for paediatric examinations of the brain and for adult examinations in the abdomen and mediastinum in this contract period in order to perform tests in clinical practice and introduce terminology and methodology to cooperating radiology departments. The goal has also been to gain experience for a more comprehensive test of routine examinations, where standard protocols very often are used but not necessarily optimized in respect to dose.

It can be concluded by the paediatric study performed by LNETI that for a very high percentage (more than 95%) a dose reduction of 50 to 75% maintain the clinical information and a dose optimization therefore is possible. For each patient the surface dose was measured which very much support the statement about the dose reduction. In the preliminary study at Aarhus University Hospital on the two types of adult examinations it has not been possible to demonstrate the same change of dose reduction so clearly but this study has to be extended including other scanner types.

If the dose assessments are based on phantom studies measurements rather than on patients, than the position of the patient in the gantry aperture has to be recorded in order to be able to correct for displacement dependencies which for some CT systems can be significant.

2. Dosimetry and quality control

The Computed Tomography Dose Index (CTDI) has in several European field studies been determined by integration of the dose profile for a single slice measured at the centre of rotation free-in-air by TLD. It is an easy method but the values very much depend on the shape of the pre-patient filter and therefore such CTDI values must be corrected for this influence before they are used for organ dose calculations and a set of conversions factors have to be established for each type of CT-scanner. The investigations shows that no simple relation exist between CTDI values determined free-in-air and values determined in a phantom. Confusions have to be avoided due to the use of the definition given by the American Food and Drug Administration (FDA) and now adapted by the IEC, where the CTDI value are determined in a phantom.

Two parallel series of quality control have been carried out in Portugal where 4 CT systems been followed for 10 months and in Denmark where 2 systems has been followed for 4 months. All systems have service and maintenance once a month performed by the manufacturers representative and the tests were carried out before and after each monthly maintenance. It can be concluded from both series that the constancy of the scanners performance are very high and that the monthly service practised by most manufacturers seems sufficient and no extra tests improve that performance. A daily check of the noise level can be recommended, and should be registered.

A first phase of a dosimetric intercalibration between the contractors have been performed and will continue in the next contract period.

3. Effective doses from CT in Portugal and Denmark

Two nationwide surveys have been carried out in Portugal (1990) and in Denmark (1989) under previous contracts in this coordinated contract. New conversion factors produced by NRPB are used to calculated doses to 27 organs or regions based on simple measurements of free-in-air axial doses for the different scanners at the exposure settings used in clinical practice. NRPB has estimated
typical doses by calculation of the energy deposition in an anthropomorphic mathematical phantom under defined conditions of irradiation using Monte Carlo techniques. These doses are normalised to unit tissue dose on the axis of rotation of the scanner in the absence of the phantom. Using ICRP 60, tissue weighting factors give the effective dose in the two surveys which are listed in the table for comparison.

	examinations per 1000 inhab.	effective dose per CT-exam. mSv	collective eff. dose per caput mSv
Portugal	23 (90/91)	4.5	0.10
Denmark	14,5 (89)	3.4	0.05

The number of examinations per 1000 inhabitants in Portugal reflects the higher collective effective dose per caput to the Portuguese population. Differences in the health care systems may partly explain the figures.

In Denmark all scanners are installed in public hospitals in Portugal this is only the case for 32%. Another factor is the frequency of examinations per body region where the head still is the body region most frequently examined in both countries by computed tomography. In Portugal it accounts for 42%, but in Denmark 61% of all CT-examinations.

Two contractors meetings has been arranged in the one year period of this co-ordinated project - Lisbon May 91 and Aarhus May 92.

Project 1

Head of project: *Dr. Jessen*

Objectives for the reporting period

Work has been undertaken towards

- objective measurements of image quality parameters and assessments of limits for acceptable Quality Criteria.
- a further evaluation of the methods for dosimetric measurements of CT scanners
- calculations of organ doses based on latest conversion factors produced by NRPB for the CT systems in the Danish survey from 1989 and an estimate of the collective effective dose to the Danish population from CT
- investigations by phantom measurements of variations in dose to sensitive organs caused by details of the diagnostic procedures and the steep dose gradients
- coordination of the project as a whole

Progress achieved including publications

1. Image quality parameters and image quality criteria

Constancy tests of objective quality parameters measured in a test object and the influence of the monthly service and quality control have been performed in a time period of 4 months for two different systems. The test object is cylindrical with a 218 mm diameter and made of perspex. There are 5 cylindrical holes in the phantom, where different inserts are placed. The noise and the mean CT numbers for linearity are evalueted by determining the mean and standard deviations of CT numbers. Spatial resolution is determined as a full-width-half-maximum (FWHM) of the point spread function of a 0,3 mm wire in air. 6 materials have been used for linearity tests (perspex, air, water, teflon, solution of calciumchloride and hexane).

Doses have been measured as surface and center doses in a phantom for a single slice with a pencil-shaped ionisation-chamber and as a dose profile free-in-air at the centre of rotation with TL chips and integrated to give the Computed Tomography Dose Index CTDI. The systems are a Somatom DRH (system 1) and a Somatom CR (system 2). Table 1 gives the mean, standard and maximum deviation expressed as percentages for all the tests collected before and after each monthly service and quality control.

Table 1: Mean, standard and maximum deviations in percentage before and after monthly service

Image parameters	System 1			System 2		
	mean % dev.	S. dev. %	max % dev.	mean % dev.	S.dev. %	max % dev.
Noise	-6.3	6.9	-15.3	-3.7	11.5	-20.6
PSF	5.1	7.5	14.8	-0.01	6.8	8.6
Dose	-3.1	7.3	-17.5	-1.5	1.6	-3.9
Linearity	0.2	0.5	1.4	-0.01	0.3	-0.6
Dose Profile FWHM	0.6	1.3	2.1	-0.6	1.4	-2.2
CTDI	-5.8	7.9	-11.0	-3.4	3.9	-7.4

Quality Criteria for two types of examination have been formulated by radiologists with 12 criteria for each type. One set for the abdomen and another set for the mediastinum representing two different contrast regions. A pilot study has been performed on a Somatom DRH where images from 30 different patients with a total of 41 examinations (24 in the abdomen and 17 in the mediastinum) have been clinically evaluated. Informations about the patient, the scanning parameters and a "Yes/No" score if the individual criteria were fulfilled have been recorded and computer analysed. Three dose levels were used, but the low dose group contains to few patients for any conclusions. For the two other levels (21,6 mGy and 24,0 mGy, given as the surface dose on a 22 cm phantom) there was a total "Yes" score of 69% in the abdomen for both dose levels and an increase from 65% to 73% in the mediastinum study in accordance with increased dose values.

2. Dosimetric investigations in CT

Further studies of the correlation between dose measurements free-in-air and in phantoms have been performed for some new CT systems both with TL and with a pencil shaped ionisation chamber. A direct comparison for systems using TL and ionisation chamber measurements for thin and thick slices respectively are presented in table 2. Dose profiles for a single slice at the centre of rotation have been measured free-in-air with TL chips and integrated to give the computed tomography dose index (CTDI). Measurements with the same geometry have been performed with the ionization chamber. Phantom measurements have been performed in a Perspex phantom of 22 cm in diameter. Surface measurements for a single slice with an ionisation chamber giving the socalled Multiple Scan Average Dose (MSAD) are compared with the results for multiple scans (7 contiguous slices) measured as maximum dose values with TL in the same position as the ionisation chamber. A considerable difference between the CTDI value and the MSAD value is demonstrated for systems known to have shaped filters. In some systems the beam is collimated after the patient and in front of the detector for the very narrow slices which for contiguous slices more than doubles the dose to the patient. The ratios for doses measured with the ionisation chamber at the centre of rotation with/without 5 mm Al extra filtration and for doses on the surface and the centre of the phantom demonstrate that no simple relation describe the pre-patient filtration.

Table 2: Comparison of free-in-air and phantom dose measurements

	mAs	Slice thick-ness (mm)	Free-in-air			Phantom		
			CTDI (mGy)	IC (mGy)	In-air/ 5mm Al	MSAD (mGy)	Mulitslice (mGy)	Surface/ Centre
Ge Pace	320	1	152.1	126.3	1.71	62.7	*	1.39
		10	146.6	102.3	1.66	52.6	61.5	1.38
Somatom CR	330	2	51.1	40.7	1.22	42.2	35.5	1.54
		8	48.6	37.6	1.27	36.4	45.4	1.55
Somatom HiQ	510	1	276.8	242.9	1.38	218.7	187.5	1.75
		10	106.9	86.3	1.39	77.2	84.0	1.76
Somatom Plus S	420	1	74.0	88.0	1.26	75.8	*	1.63
		10	50.9	52.7	1.28	45.5	44.2	1.64
Tomoscan LX	580	1,5	73.5	71.0	1.32	49.6	*	1.37
		10	107.2	104.0	1.40	71.5	74.6	1.45

3. Calculation of organ doses and assessment of the collective effective dose from CT

Calculations of organ doses and an assessment of the collective effective dose from CT to the Danish population were performed on the basis of the survey from 1989 in Denmark and the GSF conversion factors in the previous contract. New conversions factors have been produced by NRPB taking into account the pre-patient filtration. Comparison of the two sets of conversions factors for a CT system with a flat filter was performed and good agreement was demonstrated (ref. 1) A recalculation of the whole dataset from the 1989 survey in Denmark for all CT systems in use was performed and a collective effective dose from CT examinations in Denmark in 1989 is estimated to be 250 man Sv giving 0,05 mSv per caput or 5-8% of the collective effective dose from conventional X-ray examinations. This is a reduction of 20% compared with the earlier calculations when shaped pre-patient filtration is taken into consideration in the conversion factors. Calculation of the collective effective doses for the portuguese population based on the 1990/91 survey in Portugal has been performed by the same method.

The highly collimated X-ray beams in computed tomography result in steep dose gradients which may result in large variations in organ doses depending on the details of the diagnostic procedures. For a thorax examination performed on an Alderson phantom the location of the upper slice was changed by 2 cm. TL measurements in the thyroid, the sensitive organ in this region, shows a factor 3 increase in dose and this caused an increase of the calculated effective dose of 17% from 6,5 mSv to 7,6 mSv for a standard thorax examination.

Under this contract period special tests of all CT systems in Denmark used for Quantitative Computed Tomography (QCT) in computerized treatment planning have been performed. The

systems have been analysed for the sensitivity to variations in the size, shape and position of the phantom in the gantry aperture with the new RMI electron density CT phantom, Model 465. The results are published in ref. 2 and demonstrates that also new types of scanners have to be tested if intended for QCT.

Publications

1. Jessen, K.A., Juul Christensen, J., Jørgensen, J., Petersen, J. and Sørensen, E.W. Organ Doses and Effective Dose Equivalent in Computed Tomography. Radiat. Prot. Dosim. (1992) In press.

2. Jessen, K.A., Franklin, P., Jensen, L.C. and Juul Christensen, J. Phantom Measurements for Quality Control in Quantitative Computed Tomography. Submitted to Radiat.Prot.Dosim.

Project 2

Head of project: *Dr. Galvão*

Objectives for the reporting period

Work was developed in order to:

- optimize some CT paediatric examinations and contribute to the establishment of Quality Criteria;
- investigate the role of quality assurance on patient doses and image quality;
- estimate collective and patient effective doses for the portuguese population;

Some actions were planned to improve the cooperation between project partners: development of methodologies for radiation dose assessment, harmonization of methods and dosimetric intercalibration of TLDs and ionization chambers.

Progress achieved including publications

1. Optimization of paediatric CT examinations

Optimization studies of paediatric CT examinations started with the brain, the most frequently scanned organ. This investigation was restricted to the routine examination assuming that the goal of optimization is the production of diagnostic useful images with the lowest radiation dose, what does not mean "the better image with the lowest dose".

1.1. Images produced with reduced radiation doses, in a group of 50 paediatric patients, see Table 1, were clinicaly evaluated. Each patient was submitted to brain scan according to the standard procedure defined in each case by the radiologist to fulfil the diagnostic requirements. Two additional scans with lower radiation dose were carried out in a choosen plane and this two images and the image in the same plane included in the standard examination were analysed at least by two radiologists. This image analysis, 168 images in the study, was done by the answer and score of a questionnaire with the following items: Ventricular system (limits, choroidens plexus); parenchyma (white-grey matter differentiation; internal capsule: thalamus, morphology of cortex furrows); vascular structures, lesion (dimension, limits, aspect), limits of subdural-eqidural space, artifacts (beam hardening, others).

In more than 95 % of the images produced with lower radiation doses (50 % to 75 % reduction) clinical information was kept. Images with lost information are being analysed in what concerns clinical information and physical and technical parameters.

For each patient it was measured the surface dose for the standard examination, using a set of TLD dosemeters located around the patient head. Mean doses by age group, see Table 2, show that actual examination dose increases with age. The mean surface dose was estimated in the study group in 19 mGy and 44

mGy, respectively for a single set of brain scans (without contrast) or for a double set of scans (with contrast).

1.2. Phantom measurements were carried out to investigate the influence of head size on surface dose and on high contrast spatial resolution and low contrast detectability.
Variation of surface dose per miliampere - second with head size was studied with a set of cylindrical PMMA phantoms with diameters of 10, 12, 14 and 16 cm. Results show that surface dose increase when diameter decreases, reaching a limit value in the isocentre. It was realized that doses from examinations carried out with body not centered in the isocentre can be significantly different (in the order of 2 to 3) from that measured with the body centered.

Surface doses per miliampere - second measured in the paediatric group and in phantoms of different sizes showed good agreement, spatial resolution and low contrast (0,25%) did not show any reduction for scanner programmes used with the study group (slices of 6 and 9 mm; 120 to 480 mAs) and in the range of head phantom sizes (10 to 16 cm).

Table 1. Patient Paediatric Group

Age group (year)	Number	Sex	Number
0 - 1	12 (*)		
>1 - 5	24	male	25
> 5 - 10	8		
> 10 - 15	6	female	25

(*) 2 less than 1 month

Table 2 Surface Dose by Age Group

Age (years)	Without Contrast (mGy)	With Contrast (mGy)
0 - 1	12.8	28.7
>1 - 5	21.3	36.4
>5 - 10	34.3	58.8

2. Role of QA on patient doses and image quality

Quality Control (QC) was carried out during 10 months in 4 CT installations, each one equiped with a different scanner- Philips - Tomoscan 350, GE - CT 9800, Siemens - Somaton 2N, Siemens Somaton HiQ. All this scanners have service and maintenance ones in a month assured by the manufactured representative.

Tests and measurements were carried out before and after each monthly maintenance. Each set of tests and measurements included; alignment of X-ray field and light; accuracy of slice thickness; spatial resolution; low contrast detectability; CT numbers; noise; dose free-in-air in isocentre; surface dose in a PMMA cylindrical phantom.

Tests and measurements were done with technical parameters used in each installation to perform a routine brain examination and using a RMI-463 phantom and TLD dosimeters (LiF). Results were summarized in table 3 and 4.

Table 3 Constancy of Scanners Performance

	Maximum Variation Observed	
	before-after maintenance	to the mean or to the reference value
Slice thickness (mm)	0.7	1.0
resolution (mm)		
hight contrast	0.25	0.5
low contrast (1)	16	15
doses (mGy)	20.4	7.9 (12.6%)
isocentre		
superficial		4.5%

Table 4 Stability of Image Quality

	Maximum	Variation
	before-after	to the mean value
CT Numbers		
bone	7.6	16.7
acrylic	3.5	2.2
air	4.8	5.3
water	1.0	2.3
Noise	0.5	0.8

3. Adult patient effective doses

Effective doses from CT examinations were estimated for the portuguese population using the data base obtained in the CT survey carried out in Portugal in 1990/91 (1). Doses were calculated by Aarhus University Hospital (Medical Physics Dep.) based on isocentre free-in-air CTDIs measured for routine examinations (head, chest, abdomen and pelvis), on average technical parameters, conversion factors from NRPB and ICRP 60 tissue weighting factors.

The effective doses due to the examinations of head, chest, abdomen and pelvis are respectively; 1.7 mSv, 5.6 mSv, 7.3 mSv, 5.1 mSv. Mean effective dose per CT examinations is 4.5 mSv.

The collective effective dose (from CT examinations) for the portuguese population (9.8 millions) was estimated in 1009 man-Sv or 0,10 mSv per caput.

References

(1) Carvalho, A.F.: Oliveira, A.D., Amaral, E.M., Carreiro, J.V. & Galvao, J.P. 1992. Assessment of patient doses and image quality in computed tomography - Results of a survey in Portugal. Radiation Protection Dosimetry. To be published

METHODOLOGY FOR EVALUATING THE RADIOLOGICAL CONSEQUENCES OF RADIOACTIVE MATERIALS RELEASED IN ACCIDENTS INCLUDING UNCERTAINTY ANALYSIS AND ECONOMIC IMPACT

Contract Bi6-128 - Sector C24

1) *Kessler*, KfK Karlsruhe

Summary of project global objectives and achievements

The overall objective of the project is to develop improved and more complete models, data sets and systems for use in probabilistic accident consequence assessment (ACA). This work is being undertaken primarily in close cooperation between the Kernforschungszentrum Karlsruhe (KfK) in FRG and the National Radiological Protection Board (NRPB) in the UK.

An important objective of the project is to maintain and further develop the ACA program package COSYMA (Code System from MARIA) for use within the European Community. The full COSYMA system, intended for detailed studies and research on a large computer, has been distributed through the Commission of the European Communities to interested parties within the EC and other countries. However, its support and maintenance (including modelling and data improvements and up-dates), and continual adaptation to the needs of users continue to be a significant part of the project, much of this work being undertaken at KfK.

A second and more simple COSYMA system is now being developed, intended to allow non-expert users to undertake ACA studies. This system will enable more routine accident consequence assessments to be performed on a small computer, such as a PC. A feature of this system will be an interactive interface. Much of the work on the simplified COSYMA system is being undertaken at NRPB. It is possible that in the future alternative simplified systems could be developed which would contain different degrees of flexibility but which would be consistent in basic assumptions and data.

Specific modelling aspects of the work which is largely being undertaken at KfK includes the refinement of models for assessing the off-site economic costs of accidents, for calculating deterministic and stochastic health effects and the corresponding loss of life expectancies.

The project also includes code distribution and giving advice to users during the implementation, test and assessment phases. In particular, during the NEA/CEC Intercomparison Exercise on Probabilistic Accident Consequence Assessment Codes, this becomes an important aspect, when results from COSYMA obtained by different users have to be analysed and interpreted.

NRPB topics under this contract are described in an associated Final Report.

Project 1

Head of project: *Prof. Kessler*

Objectives for the reporting period

After the completion of the program package COSYMA and the presentation of its main features and ingredients during a CEC seminar in Athens in May 1990/1/, the international distribution of the code, the preparation and updating of its documentation, and the feedback with users were key tasks of the reporting period. In parallel, the participation at the NEA/CEC Benchmark exercise and the analysis and interpretation of results obtained with COSYMA running at different institutions required a significant amount of effort. Work on preparing a simple version of COSYMA for use on a PC has been performed in close cooperation with NRPB. Models and data sets of COSYMA have been completed and extended, in particular those for assessing ingestion doses, foodbans and economic consequences.

Progress achieved including publications

1. The program package COSYMA

As a result of a joint venture between KfK and NRPB, the program package COSYMA has been developed within the MARIA programme. During a seminar held in Athens in May 1990, its structure, models, data sets and endpoints have been presented and discussed. To prepare the distribution of COSYMA to interested parties in the EC and other countries, a one week training course has been organized with support of CEC at KfK from 17 to 21 September 1990. To that purpose, a variety of documents were prepared including an overview report /2/ and the user guide /3 /.

As a result of the discussions during the meetings mentioned above and application runs performed with COSYMA, several modifications were necessary, such as the inclusion of missing options and data. The most important ones are as follows:

modelling aspects:
- quantification of hereditary effects and loss of life expectancy by fatal somatic effects in a simplified manner;
- completion of the ingestion pathways with different options for calculating collective doses and for introducing food-bans;
- more flexible coding of countermeasures and economic modelling;

data sets:
- preparation of a land-sea matrix for Europe;
- replacement and extension of dose-conversion factor libraries for groundshine, inhalation and ingestion with data from NRPB;
- inclusion of default files for activity-in-food data for general use within the EC, prepared by NRPB;
- inclusion of special activity-in-food files for activation products and for use in Korea, prepared by GSF.

These improvements are contained in the Version 91/1 of COSYMA, which has been released in February 1992. The corresponding documents - in particular the user guide - have been updated to take account of the modified input/output options. The technical descriptions of the ingestion pathways (incl. foodbans) and economics have been completed /4,5/. In the meantime, 32 institutions in the EC and other countries got copies of the program package for implementation on their computers together with the revised documentation.

2. Expert judgement

The probability distributions and correlations placed on model parameters in the extensive uncertainty and sensitivity studies with UFOMOD /6/ were derived from internal discussions among those involved in model development and from literature reviews. With the aim to develop and standardize knowledge acquisition and elicitation techniques for uncertainty analyses, the CEC supported an expert judgement study focused on the dispersion-deposition module of COSYMA/NE. The principal contractor was the Department of Mathematics and Informatics at the Delft University of Technology in The Netherlands. NRPB and KfK provided technical and logistic cooperation. Within Germany, 10 experts from 6 institutions could be identified, and interviewed about uncertainty distributions of variables relevant for atmospheric dispersion and deposition processes.

As a consequence of this study, a joint CEC/USNRC Project on Uncertainty Analysis is being arranged with input from KfK and NRPB experts competent in the various modelling areas of COSYMA. Preparatory work on task definition, identification of panels and sharing of responsibilities have been performed under the MARIA project.

3. NEA/CEC Benchmark study

An international code comparison exercise sponsored by CEC and OECD/NEA was initiated during the 1st Meeting of the ad-hoc group on probabilistic accident consequence assessment codes, Paris, 16-17 January 1991. The exercise is coordinated and managed by a small project management group comprising representatives from CEC, NEA, KfK, NRPB, SRD and USNRC, whereby a large part of the planning for the exercise has been carried out by SRD.

During the 'pre-launching'-period, a basic document has been prepared and accepted in April 1991, containing the main objectives, the task specifications and the endpoints of the Benchmark calculations. In the subsequent pilot study with one source term, the task specifications, endpoint requirements, data transfer routes and evaluation procedures were tested and the results discussed in October 1991. With revised task specifications, the program input and the calculations with COSYMA were performed for the Benchmark tasks C1 to C4 for two different source terms. During a meeting in June 1992 the results and experiences were discussed, what led to a further revision of the task specifications for all Benchmark tasks. Within the next period until end of 1992, all Benchmark calculations for tasks C1 to C10 will be treated by KfK/NRPB and results will be analysed and interpreted.

In parallel, several other institutes participate with COSYMA at an EC internal Benchmark evaluation, which will be documented in a separate report. During the whole exercise, guidance has been provided by KfK for participating users (input data, interpretation of results) and evaluation programs have been modified in order to cope with the requirements on the form of presenting endpoints.

4. Development of a PC version of COSYMA

To generate a simplified version of COSYMA for smaller computers and less experienced users, computing times and storage requirements have been reduced by the simplification of models and the reduction of data libraries of the full program package, based on a KfK/NRPB agreement on reducing model complexity, options and endpoints presented in the PC version. The software has been transferred for integration to NRPB, where the user interface and the program logic for PC-COSYMA is being developed. An ongoing discussion takes place between both institutes about the menu driven user input and the general user interface on the basis of preliminary program versions.

5. Economic Consequences

For the program system COSYMA an ECONOMICS module has been developed for assessing the off-site economic consequences of accidental releases of radioactive material to the atmosphere. The model philosophy incorporated into this module is based on a new model that was developed within the framework of collaboration between NRPB and KfK. The aim of the ECONOMICS module in COSYMA is to convert many of the various consequences caused by an accident of the above mentioned form into the common framework of economic costs; this allows different effects to be expressed in the same terms and thus to make these effects comparable.

The structure of the ECONOMICS module has been determined to a large extent by the form and availability of the input data. There are two types of input data in the module: (1) data from preceding COSYMA modules which quantify the magnitude and distribution of health effects and the impact of countermeasures, and (2) economic data, mainly in terms of cost per unit quantity, to convert the preceding data into monetary values.

The latter data have to be derived in most cases from statistics of the national economy. As COSYMA is designed as a European code system, economic input data have to be established for each country separately by the user. The set of economic default data that is included in COSYMA refers to the economic situation of the Federal Republic of Germany. Another set of data that refers to the United Kingdom is presented additionally in the User Guide /3/.

The following consequences are treated in the various subsystems of COSYMA and the results calculated in previous modules may be used as a basis for cost calculations in the ECONOMICS module: early and late health effects, forced movement of people (evacuation, relocation), decontamination, and restrictions on the production and distribution of foods (food bans). The cost categories treated in each case are for health effects: medical treatment costs and costs arising from the lost contribution to society of an individual suffering from a health effect; for the forced movement of people: transport costs, accommodation costs, loss-of-income costs (i.e. costs due to losses in the economic production) and costs of lost capital services (i.e. costs due to the non-use of capital); for decontamination: total expenditures arising from the decontamination procedures; for food bans: costs of lost agricultural products, costs of lost agricultural capital and costs of the disposal of foods.

The most important cost category for the forced movement of people is that of loss-of-income costs. Because cost calculations in COSYMA should be applicable for all European countries, the model used in this case is rather general, it is based on

average nation-specific cost data on a per-capita basis. Besides this, a calculation procedure has been developed that will be applied for the Federal Republic of Germany which takes into account also site-specific economic peculiarities. Calculation is based in this case on the number of employees in different economic sectors of the evacuation/relocation area.

A detailed description of the ECONOMICS module in COSYMA is presented in /5/.

References

/1/ Proceedings of the "Seminar on methods and codes for assessing the off-site consequences of nuclear accidents", Athens, 7 to 11 May 1990, Vol. 1 and 2, Commission of the European Communities, Report EUR 13013, (1991)

/2/ COSYMA: A new program package for accident consequence assessment. Joint report by Kernforschungszentrum Karlsruhe GmbH and National Radiological Protection Board. Commission of the European Communities, Report EUR-13028 (1991)

/3/ I. Hasemann, J.A. Jones
COSYMA: User guide
Commission of the European Communities, Report EUR-13045 (1991), Report KfK-4331 B (1991)

/4/ C. Steinhauer
COSYMA: Ingestion pathways and foodbans
Report KfK-4334 (1992)

/5/ D. Faude
COSYMA: Modelling of Economic Consequences
Report KfK-4336 (1992)

/6/ F. Fischer, J. Ehrhardt, I. Hasemann
Uncertainty and sensitivity analyses of the complete program system UFOMOD and of selected submodels
Kernforschungszentrum Karlsruhe GmbH, Report KfK-4627 (1990)

Further publications in the reporting period

J. Ehrhardt, J.R. Simmonds
The structure and content of COSYMA
(in publication /1/)

H.-J. Panitz, J.A. Jones
The modelling of atmospheric dispersion and deposition in COSYMA
(in publication /1/)

J.A. Jones, H.-J. Panitz
The choice of atmospheric dispersion model and meteorological sampling scheme for use in accident consequence assessment
(in publication /1/)

C. Steinhauer, J.R. Simmonds
The modelling of the ingestion pathway in COSYMA
(in publication /1/)

J. Brown, J. Simmonds, J. Ehrhardt, I. Hasemann
The modelling of external exposure and inhalation pathways in COSYMA
(in publication /1/)

J. Ehrhardt, C. Steinhauer, J.A. Jones
The modelling of health effects in COSYMA
(in publication /1/)

C. Robinson, I. Hasemann
Land use and demographic grids included in COSYMA
(in publication /1/)

K. Burkart, I. Hasemann, J.A. Jones, J.R. Simmonds
The modelling of countermeasures in COSYMA
(in publication /1/)

S. Haywood, C. Robinson, D. Faude
Developments in modelling the economic impact of
off-site accident consequences
(in publication /1/)

D. Faude, S. Haywood, C. Robinson
The modelling of economic consequences in COSYMA
(in publication /1/)

F. Fischer
Uncertainty and sensitivity analyses of UFOMOD
(in publication /1/)

J. Ehrhardt, I. Hasemann, J.R. Simmonds
Illustrative applications of accident consequence assessment codes
(in publication /1/)

J. Ehrhardt, K. Burkart, F. Fischer, I. Hasemann,
H.-J. Panitz, C. Steinhauer
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new program system UFOMOD for assessing the radiological
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Nuclear Technology 94, p. 177 - 195 (1991)

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Nuclear Technology 94, p. 196 - 203 (1991)

METHODOLOGY FOR EVALUATING THE RADIOLOGICAL CONSEQUENCES OF RADIOACTIVE EFFLUENT RELEASED IN ACCIDENTS

Contract Bi6-127 - Sector C24

1) *Cooper*, NRPB

Summary of project global objectives and achievements

The overall objective of the project is to develop improved and more complete models, data sets and systems for use in probabilistic accident consequence assessment (ACA). This work is being undertaken primarily in close cooperation between the Kernforschunsgszentrum Karlsruhe (KfK) in FRG and the National Radiological Protection Board (NRPB) in the UK.

An important objective of the project is to maintain and further develop the ACA program package COSYMA (Code System from MARIA) for use within the European Community. The full COSYMA system, intended for detailed studies and research using a large computer, has been distributed through the Commission of the European Communities to interested parties within the EC and other countries. However, its support and maintenance (including modelling and data improvements and up-dates), and continual adaption to the needs of users continue to be a significant part of the project, much of this work being undertaken at KfK.

A second and more simple COSYMA system is now being developed, intended to allow non-expert users to undertake ACA studies. This system will enable more routine accident consequence assessments to be performed on a small computer, such as a PC. A feature of this system will be an interactive interface. Much of the work on the simplified COSYMA system is being undertaken at NRPB.

Specific modelling aspects of the work which are largely being undertaken at NRPB include the development of models for the off-site economic costs of accidents, for the calculation of external γ dose from deposited material, (particularly in urban areas) and the formulation of advice so that an appropriate choice among the available models for atmospheric dispersion can be made. The project also includes an assessment of the uncertainty in the results of ACA codes, and work to describe the ranges of parameter values using expert judgement.

KfK topics under this contract are described in an associated Progress Report.

Project 1

Head of project: *Dr. Cooper*

Objectives for the reporting period

The COSYMA system is an important tool for research and application, and as such requires continuous up-dating, testing and improvement. The code and its databases were to be maintained and improved throughout the period of the project by KfK and NRPB. The increasing availability of small computers, and the need of people without experience in ACA code development to carry out routine analyses, necessitate the development of a reduced and simplified version of the code, capable of running on an advanced PC. Work to develop this simplified system was to be carried out.

Continuing work was to be carried out on the analysis of the uncertainty in the predictions of ACA codes. This included the use of expert judgement to determine the ranges of values for the input parameters.

Work on the validation of EXPURT, a detailed model for deposited γ doses in urban areas, was to be carried out. Work was to continue on the development of COSYMA by including the results of the EXPURT model in COSYMA. Work was to be carried out to allow advice on the choice of atmospheric dispersion models for different applications of ACA codes to be given. Work to compare the predictions of different models for the economic costs of accidents would continue.

Progress achieved including publications

1. <u>The simplified version of COSYMA</u>

A number of runs of the NE and NL sub-systems of COSYMA have been carried out to examine the feasibility of running the system on a small computer, and to see where the complex models contained in the full system could be simplified. A series of probabilistic runs of the NE sub-system with a range of simplifying assumptions have been carried out for 2 source terms for a PWR at a UK site. Source term A represented a very large degraded core accident at a PWR, while source term B was a smaller accident in which about 10% of the volatile material was released.

The model included in COSYMA for the actions of the population during the sheltering and evacuation period is very complex. The results of the sensitivity studies considered here showed that these parts of the model could be simplified without altering the predicted numbers of early deaths by more than about 50%, and generally by only about 10%.

Both source terms show a sensitivity to the number of phases assumed for the release and therefore the ability to consider a release as a series of phases should be kept in the simplified version of COSYMA.

2. <u>The PC version of COSYMA</u>

A version of COSYMA for running on an advanced PC is being developed, incorporating a number

of simplifications including those identified from the study above. This version is primarily intended for routine users of the COSYMA code who do not generally want access to many of the more complex features included in full COSYMA. A detailed specification for the options to be included in the system has been agreed with CEC and KfK. The system consists of three parts:
1) a user-friendly input interface to prompt for the values of input parameters,
2) a simplified version of programs forming the full version of COSYMA,
3) a user-friendly output interface for the presentation of the results.
The input interface uses a series of menus to prompt the user in choosing the endpoints of the system which are required, and in setting the values for the input parameters required by COSYMA. Default values are provided for all of the input parameters. The output interface guides the user through the presentation of the results using a series of menus. The endpoints considered by the system, for both deterministic and probabilistic applications, are the calculation of the spatial distribution of activity concentrations, individual and collective doses, risks of health effects and the extent and impact of countermeasures. A preliminary version of the system was demonstrated during the reporting period. The system will be made available through CEC in 1993.

3. Choice of atmospheric dispersion model and guidance on meteorological sampling

Comparisons between the results of calculations using the different dispersion models in COSYMA, concentrating on the modelling of wind direction changes during travel, were carried out. These have been used to provide advice on the choice of dispersion model for particular applications of COSYMA. Calculations have been undertaken using a trajectory dispersion model with different meteorological sampling methods. The results were used as the basis of advice on designing sampling schemes for use with COSYMA. Documents giving guidance on these topics have been prepared for inclusion in the user guide.

4. Uncertainty analyses

This progress report summarises the work done in an analysis of the uncertainty in the predictions of the consequences of hypothetical accidental releases of radioactive material to atmosphere using the MARC-2A computer program. The analysis follows on from earlier work in which the uncertainty in the predictions of some of the individual modules of the MARC program was analysed. However in this analysis the uncertainty in the predictions of the whole of the program was considered.

The study considered the uncertainty in the parameter values describing the transfer of material through the environment from the release point to man, the calculation of doses from the concentrations of material in air, in foods and deposited on the ground, the health effects arising from those doses and some aspects of the economic costs of the accident.

A total of 98 uncertain input parameters was considered and 150 runs of the MARC program were carried out for each of five analyses considered. Each of these runs of MARC included an assessment of the consequences of the release in about 100 sequences of atmospheric conditions. The output of the MARC-2A program is in the form of complementary cumulative distribution functions for each of a number of endpoints of the accidental release. These include the numbers of health effects in the exposed population, the impact of countermeasures in terms of the numbers of people evacuated or relocated, the amount of agricultural produce which could not be consumed due to food restrictions, and some indicators of the economic cost of the accident. The quantities considered in the analysis were the expectation value and some of the percentiles of the ccdfs for the different endpoints. In addition, the amount of CPU time required by the programs was also

analysed. The uncertainty in each of these endpoints was considered, and the input parameters whose uncertainty makes major contributions to the overall uncertainty were identified for each. However, only the results for early death and fatal cancer are described in this progress report.

The study investigated the uncertainty in the predicted consequences of two hypothetical accidental releases from a Pressurised Water Reactor (PWR) in the UK. The releases considered were those designated UK1 and CB2. UK1 represents a very large degraded core accident, and has been found to dominate the predicted risks of early death from all accident sequences considered in risk assessments for the reactor design. CB2 represents smaller but more likely accidents. Both source terms make major contributions to the overall risks of late health effects from the reactor.

The most important parameter uncertainties contributing to uncertainty in the number of early deaths were identified using Partial Rank Correlation Coefficients and Partial Correlation Coefficients. This analysis included several uncertain parameters related to calculating numbers of health effects from skin irradiation. One of these has been identified as the most important parameter uncertainty for early deaths. A second one is also highly ranked. Given the preliminary nature of this analysis, it seems reasonable to identify the whole topic of prediction of early health effects from skin irradiation as an important source of uncertainty rather than trying to identify specific parts of the calculation of skin effects as being the ones with the most important uncertainties. Similar remarks apply to the model for calculating deposited γ doses in urban areas, and it is probably reasonable to identify the calculation of deposited γ doses in urban areas as being an important source of uncertainty in the MARC model.

The upper envelope of the ccdfs for fatal cancers for UK1 from each run of MARC is roughly twice that corresponding to the ccdf for the best estimate parameter values, while the lower limit is about an order of magnitude below the best estimate value. Similar ranges are observed for the smaller CB2 source term. The most important parameter uncertainties contributing to the overall uncertainty in the expectation value of fatal cancers for UK1 are the risk coefficient at high dose rates and the dose and dose rate effectiveness factor. A number of parameters have reasonably high values of the indicators. The ordering of these lower ranked parameters derived from the different indicators is rather different, with parameters ranked highly by one indicator not necessarily having a high ranking according to other indicators. Similar results were obtained for the CB2 source term.

5. Expert judgement

The ranges adopted for the parameter values in the MARC uncertainty analysis were obtained without using formal techniques of expert judgement. This topic was covered by a group at the University of Delft in a separate CEC contract. The uncertainty in the atmospheric dispersion part of consequence assessments was examined. NRPB, together with KfK, assisted in this work in a number of ways. We have had a number of discussions with, and given advice to, the researchers at the University of Delft, and have identified a number of UK experts to take part in the study.

6. Deposited γ doses

A model was developed at NRPB several years ago for calculating the external γ dose from material deposited in urban areas; the model includes the effects of transfer of the deposited material between different surfaces in the urban area. The model was developed using data available prior to the Chernobyl reactor accident which are mainly based on studies on caesium. Several studies and measurement programmes have been carried out since Chernobyl, particularly in Scandinavia and Germany, and data from these studies are now being used to test EXPURT predictions. Areas which

have been tested include the modelling of processes such as the partitioning of material onto various surfaces during wet and dry deposition and the weathering of material off buildings and roads.

Results obtained with the EXPURT program have been used to improve the modelling in COSYMA of deposited γ doses. COSYMA uses a data file of dose per unit deposit. Appropriate data files for different levels of urbanisation ranging from rural to inner city areas were calculated using EXPURT, and used in COSYMA for calculating consequences of hypothetical releases. Comparisons showed that the use of a file representing a weighted average of the different areas considered gave an adequate representation in COSYMA of consequences predicted for different levels of urbanisation. A deposited γ dose data file for use with COSYMA, derived from EXPURT, will be made available to COSYMA users.

7. MECA/COCO-1 Economic model intercomparison

A review of two economic consequence models, COCO-1 and MECA, developed under an earlier phase of the CEC MARIA project, has been undertaken by NRPB, the Universidad Politécnica de Madrid (Spain), and KfK. A contract report has been prepared which describes the findings of this review and the effects of these findings on the recent and future development of the two models.

The COCO-1 (Cost of Consequences Off-site) model has been developed during collaboration between NRPB and KFK, and has been implemented in the economics module of the COSYMA code. Two databases for COCO-1 have been developed; one primarily based on UK data and one based on FRG data. The MECA2 (Model for Economic Consequence Assessment) model has been developed by the Universidad Politécnica de Madrid, and evaluates economic costs using economic parameters and data appropriate to Spain. The MECA model is coupled to the MACCS 1.5 ACA code.

To initiate the study, a review of the economic assumptions in the two models was commissioned from Professor Christopher Heady of the School of Social Sciences of the University of Bath in the UK. Professor Heady, although associated with the development of the COCO-1 model, undertook an independent review of the features and assumptions of both models. His findings were contained in a report which will be annexed to the contract report.

Professor Heady concluded that there were a significant number of differences between the COCO-1 and MECA models, some arising from differences in national economic statistics and data (or in the availability of these), and some arising from differences in modelling approach. The differences in data and behavioral assumptions either reflect genuine national differences or are relatively unimportant and may be resolved by the incorporation of simple additional aspects to both COCO-1 and MECA. The differences in modelling method and approach are more serious and required further consideration. As a result a number of revisions have been made to the MECA model, and as a result a new version of this model is now available.

The review showed clearly the similarities and differences between the two models, and is an important aid to a fuller understanding of both the models and their supporting data.

8. CEC/NEA accident consequence code comparison

NRPB participated with KfK in this exercise, submitting agreed joint results of COSYMA for comparison with the predictions obtained by other participants with other codes. Support to other COSYMA users in the exercise was also provided, in particular with setting up population and

agricultural distributions around the site chosen and selecting an appropriate meteorological sampling scheme.

9. Provision of revised food chain libraries for COSYMA

As part of a separate contract from CEC, NRPB and Gesellschaft für Umweltforschung (FRG) developed an agreed food chain model for application in Europe. As part of the MARIA contract, NRPB has generated appropriate libraries of nuclide concentration in foods for use with COSYMA.

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METHODOLOGY OF PROBABILISTIC UNCERTAINTY ANALYSIS OF COMPUTATIONAL ASSESSMENTS

Contract Bi6-125 - Sector C24

1) *Hofer*, GRS

Summary of project global objectives and achievements

The work to be carried out within the 1990 - 1991 period of the Programme consisted of three parts:

1. A so-called Driver programme for the software package for uncertainty and sensitivity analysis developed under the contract.
   Its tasks are to

   - guide the user through the steps of a probabilistic uncertainty and sensitivity analysis
   - support selection of a suitable combination of options from those offered by the programmes in the package
   - perform the data transfer between the programmes as well as, where possible, between the programmes and the assessment model
   - support design extensions for parameters where the quantitative expressions of the state of knowledge (or where the expressions of state of knowledge dependence) cannot be readily handled by MEDUSA.

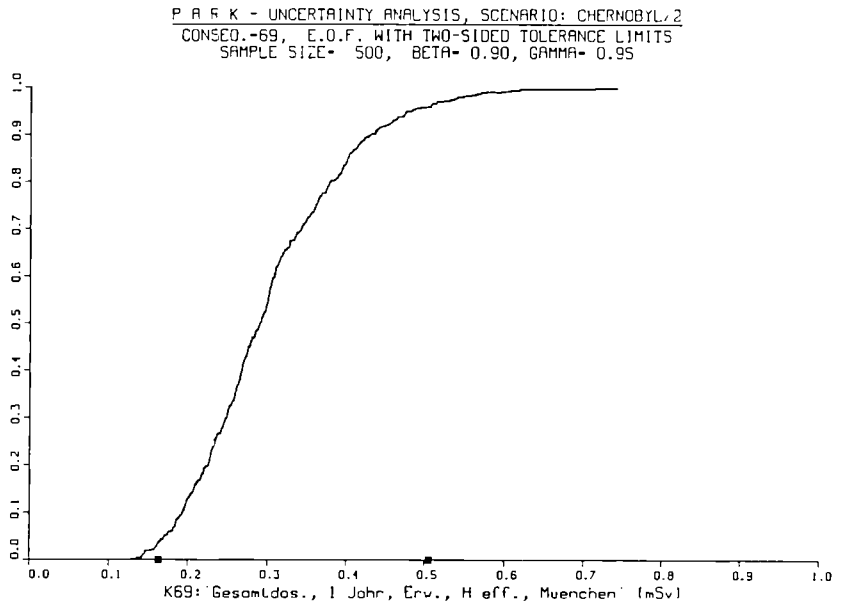
   The aim was a largely continuous flow of the analysis requiring as little user interference as possible.

2. After completion of the Driver programme the package is available for use on mainframe computers. It would greatly promote the performance of uncertainty and sensitivity analyses and encourage the use of the package within the community if a Personal Computer version were available supplemented by sample analyses to illustrate its application. This PC version of the complete package, including the Driver programme, was to be produced in the second part of the project.

3. The value of an uncertainty and sensitivity analysis depends largely on the quality of the subjective probability distributions needed for propagation of the state of knowledge through the model. A major source for the required quantitative expressions of the state of knowledge (as well as state of knowledge dependence) is expert judgement which needs to be elicited. In the third part of the project guidance was to be provided for the preparation of the analysis input .

Achievements

1. Introduction



In the sense of a prediction, based on measurements from the first week,
Figure 1 says:
"In the first year, following the Chernobyl accident, the total effective dose equivalent to the average adult of the population of Munich is between 0.16 and 0.51 mSv with 90 % subjective probability."
The dose equivalent was assessed with the aid of the "Programmsystem zur Abschät-

zung radiologischer Konsequenzen (PARK)" /1/. The subjective probability distribution in Figure 1 quantitatively shows the approximate combined effect of over 500 uncertain parameters in the model. A more precise statement is:

"One can be at least 95 % confident that the indicated interval contains at least 90 % of the combined influence of all quantified uncertainties".

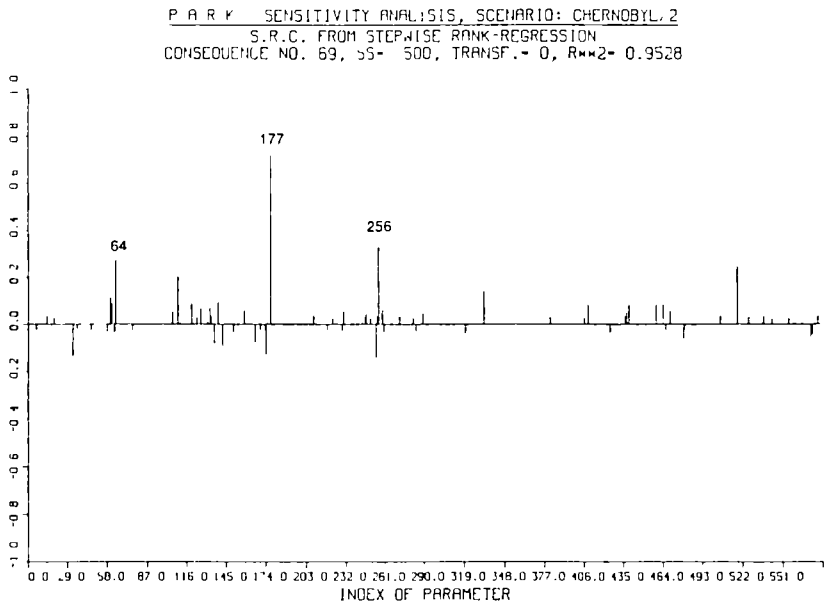


Figure 2 says:

"Parameters 64, 177 and 256 contribute most to the uncertainty in the assessed dose commitment."

64: Cs 137 concentration (soil), in situ measurement at the Munich station

177: Cs 137 water storage capacity of grass

256: Cs 137 transfer factor for milk

In other words, improvement of the state of knowledge about these parameters of the

/1/ Jacob, P., et al., Real Time Systems for the Assessment of the Radiological Impact of Radionuclides Released to the Atmosphere, Nuclear Technology, Vol. 94, pp. 149-160 (1991)

PARK application reduces the uncertainty of the assessed dose commitment most efficiently.

This is merely one example out of the uncertainty and sensitivity analyses that have so far been performed with the methodology developed and implemented in the software system SUSA under the project of contract Bi6-125.

2. Programmes

2.1 The driver of SUSA/2/

The driver of SUSA (Software **S**ystem for **U**ncertainty and **S**ensitivity **A**nalysis) is an interactive programme that provides guidance through the parameter uncertainty and sensitivity analysis via a sequence of so - called panels. In dialog with the user, it prompts for the necessary input data to run the appropriate option of the respective supporting programmes of SUSA, which are DIVIS /3/, MEDUSA /4, 5/, EQUUS /6/, SAMOS /7/ and TUSSIS /8/. It elicits the input data necessary to run the individual programmes and manages the data transfer within the software system. The interface to the computer model enables automatic initiation of the required model runs under the control of SUSA.

SUSA runs on IBM compatible mainframe computers under the operating system MVS/XA or MVS/ESA using ISPF/PDF.

With the present version of the driver SUSA permits a largely continuous flow of the analyses requiring as little user interference as possible thereby enabling the user to concentrate his effort on the specification of the analysis input. Figure 3 is a schematic of the data flow within SUSA. The input to be provided by the user is indicated in the rectangle on the left. The oval is to depict the role of the driver

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/2/ Kloos, M., GRS-A (1992)
/3/ Kloos, M., Nowak, E., Hofer, E., GRS-A 1760 (1990)
/4,6,7,8/ Krzykacz, B., GRS-A 1496, 1720,1700,1699 (1988, resp. 1990)
/5/ Krzykacz, B., Hofer, E., (1988)

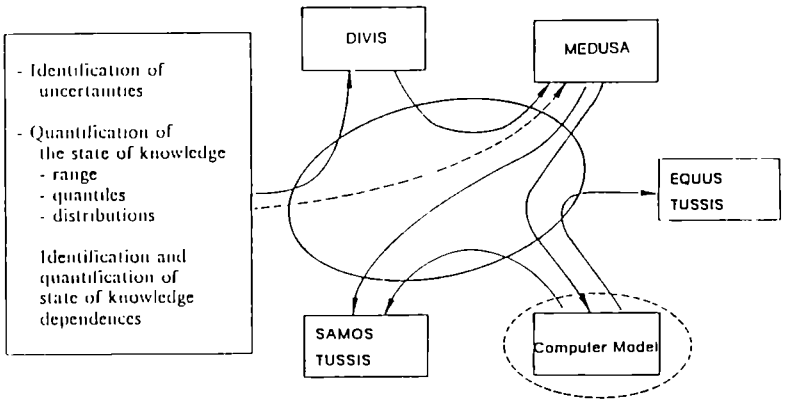

Figure 3: Data flow among SUSA modules and the applied computer model

Analyses of applications of several computer models can be handled in parallel since SUSA-sessions may be interrupted and continued at any stage of the analysis. The input so far provided as well as the data sets generated will be stored under the identifier of the respective SUSA-application. All the analysis input, inclusive references provided, is printed in a format suitable for documentation supplementing the analysis results.

2.2 SUSA-PC the personal computer version

SUSA-PC runs on an IBM 386 or 486 PC (or compatible) with a mathematics coprocessor. It requires at least 4 MB installed memory and as software environment:

Microsoft	-	WINDOWS	3.0	or higher
Microsoft	-	EXCEL	3.0	or higher
Microsoft	-	FORTRAN	5.0	or higher.

Additionally, use is made of subroutines form the mathematics and statistics subroutine library IMSL-PC. A users guide and installation instructions are contained in /9/.

/9/ Kloos, M., SUSA-PC, A Personal Computer Version of the Software System for UncertaiSensitivity Analysis of Results from Computer Models, Version 0.1, Users Guide (1992)

With the above hardware and software SUSA can cope with

100	uncertain parameters
1 000	model runs and
50	model output quantities to be analysed

if the model provides only one value for each output quantity per model run. Should the output quantities be index-valued (i. e. per run the model provides a value for each of several indices of the output quantity, e. g. the indices may be different points of time) the capacities are

100	uncertain parameters
200	model runs
10	index-valued model output quantities to be analysed
500	index values each
50	user- selected index values (at which the uncertainty and sensitivity analysis is to be performed).

Model code that is not too complicated may be implemented in a FORTRAN skeleton offered by SUSA. In this case model runs are initiated automatically. Otherwise, the model code may run on a mainframe computer or workstation. Some requirements concerning the accessibility of uncertain parameters in the code as well as the transfer of parameter and model output values between mainframe or workstation and PC must be met.

The dialog with SUSA-PC is very simple and user-friendly. Only the following actions are required:
In the menu bar:

- Click or move the pointer to the menu you want to work with.

In the menu:

- Click or move the pointer to the command you want to select.

In the dialog boxes:

- Enter your input into the corresponding input boxes, or click or move the pointer to the option button you want to choose or activate.

- Click or move the pointer to the OK button to confirm your input and to continue with the session.

- Click or move the pointer to the CANCEL button to prevent SUSA from storing the input given under the selected menu command and to return to the first dialog box of the activated command or to activate the menu bar.

After the display of output files:

- Click or move the pointer to the GO ON button to store the information and to continue.

- Click or move the pointer to the RETURN TO MENU button to cancel the information given under the selected menu command and to return to the menu.

Illustrative sample applications are provided with the SUSA-PC load discs and are explained in the SUSA-PC Tutorial contained in /9/.

3. Recent analyses

3.1 Analyses

Recently, results from computer model applications for the

- calculation of fog formation rates in a nuclear power plant containment

- atmospheric dispersion modeling

- performance assessment of a waste repository

- assessment of radiological consequences of accidental releases

were analysed with SUSA. The latter three analyses were performed after termination

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/9/ Kloos, M., SUSA-PC, A Personal Computer Version of the Software System for Uncsitivrom Computer Models, Version 0.1, Users Guide (1992)

of this project. The analysis of results from the application of a thermo- and fluiddynamics code is presently being conducted. Earlier analyses using the SUSA modules are listed

in /10/ and were presented at the USDOE/CEC workshop in Santa Fe (1989) and at the CEC Seminar in Athens (1990).

3.2 Uncertainty analysis and quality assurance

Uncertainty and sensitivity analysis should be part of any quality assurance programme. Several of the analyses performed with SUSA have revealed coding errors in the computer models and have initiated code improvements. There is a strong indication of coding errors if

- parameters are ranked as important contributors to code output uncertainty although they should have no influence on the respective output quantity;
- parameters are ranked as unimportant though they are expected to contribute significantly to output uncertainty;
- code runs performed in the course of the analysis end abnormally for some parameter vectors. The sensitivity measures to an additional output quantity with the attributes "normal ending" and "abnormal ending" may be used in trouble-shooting;
- CPU-time requirements for the runs with the alternative parameter vectors differ significantly. This may be justified but may also be an indication of modeling deficiencies or algorithmic inefficiencies. Again, the sensitivity measures with respect to an additional output quantity "CPU-time" may provide guidance for improvements;
- general (not application specific) internal parameters as well as modeling assumptions are among the top ranked contributors to code output uncertainty. This may indicate that the respective states of knowledge need to be improved before applications can be expected to produce meaningful results.

/10/ Kloos, M. The Mainframe Version of the Driver to the Software System for Uncertainty and Sensitivity Analysis of Results from Computer Models-Version 2, GRS-A 1772 , Gesellschaft für Anlagen- und Reaktorsicherheit, Garching, Fed. Rep. of Germany (1991).

In any case, it is highly recommendable to perform analyses of selected model applications prior to the dissemination of codes to clients by the code developers and before the code is used for production runs in licensing as well as in design, siting, operations, accident management, emergency protection and countermeasure decisions.

Project 1

Head of project: *E. Hofer*

Objectives for the reporting period

- Completion of the Driver
- Preparation of the PC-Version of the package
- Provision of guidance for preparation of the analysis input

Progress achieved including publications

- Further CLISTs, Panels and Skeletons for the user dialog with the driver program,
- Supplements for the options "conditional distribution", "inequality" and "design extension" to model state of knowledge dependence;
- Supplements for the link between SUSA and the computer model, to run the model under the control of SUSA;
- Supplements to MEDUSA to determine the correlation coefficients between parameters after transformation to the multivariate normal distribution by numerical integration. So far only estimates derived from Monte-Carlo-simulation were available. The supplement may in many cases save CPU-intensive iterations in the search for the transformed correlation coefficients. Where an analytic solution is available the transformed coefficients may be provided as input.
- Extensions and Improvements to version 1 of the driver program of SUSA:
  - A FORTRAN-program to derive the sample correlations, parameter rankings, ordered samples as well as the matrix of differences between specified and sample measures of association in the case of an extended design (options "conditional distribution" or "design extension" for the modelling of state of knowledge dependence).

- Automatic initiation of the computer model runs if the following conditions are satisfied:
  - existence of a data file each, with the input data and the JCL of the model or
  - existence of a source file to read the parameter values and to derive the model output plus a file with the corresponding JCL;
- Extension to MEDUSA to handle the dependence option "inequality" within the driver program;
- Improvements to the flow of the dialog within the operation mode for the derivation of uncertainty and sensitivity statements;
- Inclusion of an option in TUSSIS to select and view results from individual model runs. This is to assist the clarification in cases where model runs ended abnormally;
- Development of the Personal Computer version SUSA-PC (0.1) under MS-EXCEL /9/;
- Compilation of guide-lines for the representation and probabilistic quantification of parameter uncertainty and dependence /11/;
- Analysis of an application of the containment code FIPLOC-M to calculate the fog formation rate for the case of a single volume as well as a 15-compartment geometry considering modeling as well as parameter uncertainties /12/.

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/9/ Kloos, M., SUSA-PC, A Personal Computer Version of the Software System for Uncertainty and Sensitivity Analysis of Results from Computer Models, Version 0.1, Users Guide (1992)
/11/ Krzykacz, B., GRS-A, (1992)
/12/ Weber, G., Hofer. E., Krzykacz. B., Uncertainty and Sensitivity Analysis of Fog Formation Rates Calculated with the Containment Code FIPLOC-M., to appear in : Journal of Aerosol Science.

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aktorsicherheit, Garching Fed. Rep. of Germany (1990).

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OPTIMIZATION OF OFF-SITE RECOVERY ACTIONS FOLLOWING NUCLEAR REACTOR ACCIDENTS

Contract Bi6-227 - Sector C24

1) *Alonso* , Universidad Politécnica de Madrid

Summary of project global objectives and achievements

The main objectives of the Project have been the following two:

i) Development of models for the evaluation of countermeasures against chronic exposure, after a radiological contamination of the environment.

ii) Comparison of models for assessing the off-site economic consequences of nuclear accidents: MECA (Model for Economic Consequence Assessment), developed in a previous period of the contract, and COCO-1, developed by NRPB and KfK and currently implemented in COSYMA.

1. With regard to the first objective, two new models have been developed:

- URBAPAT, which considers the gamma external exposure in urban environments, simulating the migration of deposited material on different surfaces, and predicting the effect on doses of countermeasures like surface decontamination or relocation.

- AGROPAT, which consists of several submodels to estimate doses by ingestion of different contaminated foodstuffs, with flexibility to evaluate the impact of different countermeasures affecting the transfer of radionuclides through the foodchain from soil and plants to man.

The effectiveness of possible countermeasures is assessed in terms of the dose reduction achieved, and the impact associated to the countermeasures is based on their economic consequences. A ranking between the evaluated alternatives is established according to their cost per unit dose averted (cost-effectiveness). Uncertainties in model parameters are treated by repeating the cost-effectiveness analysis for a large number of samples of uncertain parameters, giving an estimation of the confidence that the user may have in the effectiveness of each countermeasure.

Both models can be used for dose projections simulating the dynamics of radionuclides in different environmental compartments. Site specific features can be easily included into the models, as well as they can consider the impact of countermeasures on the radionuclide evolution in each environmental compartment and on the resulting doses. Another important feature is that the models incorporate the capability to deal with uncertainties in the input parameters, using Latin Hypercube Sampling method to obtain

samples of parameter values that, after running the model several times, provide an estimation of the uncertainty in the results.

2. The economic consequence models COCO-1 and MECA are being compared. A review of the economic assumptions in both models, performed by Prof. Heady of the School of Social Sciences of the University of Bath (UK), has identified areas of omission in both models and those aspects in which they could be improved. As a result of the conclusions of the review, a new version of the MECA model has been produced, named MECA2.

The comparison of results for similar problems is the way to verify their functioning coupled to general probabilistic accident consequence assessment codes. This is being done through the participation with COCO-1, integrated in COSYMA, and with MECA2, coupled to MACCS 1.5, in the NEA/OCDE - CEC "Intercomparison Exercise on Probabilistic Accident Consequence Assessment Models" whose final calculations are expected for August 1992.

Project 1

Head of project: *Prof. Alonso*

Objectives for the reporting period (January 1990-April 1992)

1) Development of computer programs for the evaluation of

   · the gamma external exposure, and the adequate countermeasures, after a radiological accident involving deposition of radioactive material on different urban surfaces (URBAPAT), and

   · the transfer of radionuclides through the agricultural foodchains, the influence of countermeasures and the resulting doses by ingestion of contaminated food (AGROPAT).

   Including economics models, based on MECA2, for the estimation of costs arising from the application of countermeasures, and cost-effectiveness analysis capability.

   Incorporating capacity to perform uncertainty and sensitivity analysis of the results due to the variations in model parameters, using Latin Hypercube Sampling techniques.

2) Comparison of the economic consequence models MECA and COCO-1, and maintenance of MECA.

Progress achieved including publications

1. Development of URBAPAT and AGROPAT models

The implementation of countermeasures after an accident should produce, according to international recommendations, more good than harm, and should be optimized so that they will produce the maximum net benefit. One of the techniques more commonly used for optimization is cost-effectiveness analysis. It requires a careful examination of the benefits achieved with the protective measure, essentially the dose averted to the collectivity, and of the costs to the society that it will imply. Therefore, detailed models for the assessment of long-term doses and costs of countermeasures are needed. The models developed within this Project, URBAPAT and AGROPAT, integrate both aspects together with an evaluation of the uncertainty arising from our imperfect knowledge of several parameters affecting both doses and costs.

URBAPAT (URBAn PAThway) is a computer model, written in FORTRAN 77 and operating under VAX/VMS, for the evaluation of the gamma external exposure, and the adequate countermeasures, after a radiological accident involving dispersion and deposition of radioactive material on different urban surfaces.
The code estimates the evolution of radioactive material in the urban environment using a dynamic model consisting on 21 compartments, that simulate five different urban surfaces with their particular retention properties. For the assessment of the gamma external exposure in urban areas, one of the main contributors to the long-term individual dose, the model considers the contribution of each surface to the dose rate delivered by five radionuclides (Cs-137, Cs-134, I-131, Te-132, Ba-140) in different locations outside and inside three types of buildings (semi-detached houses, terrace houses and multi-storey buildings). The population is classified in various groups, attending to their stay time in each location.

The model can evaluate the dose avoided by the introduction of countermeasures like decontamination of the urban surfaces or relocation. An assessment of their associated costs using MECA2 economics models permits performing the needed cost-effectiveness assessment of the different alternatives. A ranking between the evaluated alternatives is established according to their cost per unit dose averted.

Since much of the parameters needed by the model are not known with accuracy, and much of them could vary from one site to another, the capability to perform uncertainty and sensibility analyses of the results obtained has been one of the priorities in the development of URBAPAT. The well-known Latin Hypercube Sampling code (LHS, Iman and Shortencarier 1984) for the generation of samples of parameters, and the PCCSRC code (Iman, Shortencarier and Johnson 1985) for the sensitivity analysis have been integrated with URBAPAT. This allows to delimit the overall uncertainty in the results, not only in dose and cost estimates but also in the ranking of the countermeasures, as well as to identify those parameters that should be studied more deeply due to their contribution to the uncertainties.

URBAPAT can be used for the following applications:

- Estimation of the evolution of radioactivity deposited on urban surfaces, the dose rate and integrated dose, considering parameter uncertainties.

- Evaluation of the effectiveness of an individual countermeasure, in terms of dose reduction.

- In general, as a decision-aiding tool for situations involving radiological contamination of the urban environment.

The second model, **AGROPAT**, is designed to evaluate the effectiveness of countermeasures against the internal exposure resulting from the ingestion of contaminated foodstuffs. AGROPAT includes several dynamic models of radionuclide transport through the agricultural foodchain from fallout to man, considering different agro-compartments and foods. Countermeasures affecting that transport can be easily simulated by modifying the appropriate model parameters.

The model has been written in MS-FORTRAN and is based on TIME-ZERO software (Kirchner 1990), being easily installable in any PC compatible. It offers a good menu driven interface to the user, that confers a great flexibility to the models. It is possible to introduce changes in model parameters, run the program, and have a graphical output in the same session. The capability to perform uncertainty and sensitivity analysis is also incorporated, with LHS, Factorial Design and Monte-Carlo methods available for sampling of parameters, and correlations between input and output directly analyzed.

AGROPAT comprises four foodchain submodels, used to calculate differential and integrated activity concentrations for different food products: i) cows's milk and beef; ii) grain, poultry and pork; iii) leafy vegetables; and iv) potatoes. Current demonstration version only considers I-131 and Cs-137. The model can simulate both discrete events and continuous processes, which permits a full adaptation to site-specific characteristics and to seasonal effects. Model predictions are being validated against real data taken from the CB scenario of the VAMP exercise, co-organized by IAEA and CEC.

2. Comparison of MECA and COCO-1. Maintenance of MECA

Concerning the comparison of the economic consequence models COCO-1 and MECA, a review[1] of the economic assumptions in the two models was performed by Prof. Heady of the School of Social Sciences of the University of Bath (UK). His findings have been very valuable, since areas of omission and aspects in which the models could be improved have been identified.

As a consequence of the review, the MECA model has been modified, originating the version 2 of the model, MECA2. The submodels affected by the revision are those related with the calculation of the cost of evacuation and relocation, the costs of temporary and permanent interdiction, and also the model for the costs of latent health effects.

The first version of MECA was linked to the U.S. code MACCS version 1.4. In 1990, MACCS 1.4 was superseded by a new version, MACCS 1.5, which had a different structure. Both updated versions of MACCS and MECA were coupled in mid-1991.

The comparison of COCO-1 and MECA is not only theoretical, but also practical. Both models, integrated in COSYMA and in MACCS 1.5 respectively, are participating in the NEA/OCDE - CEC "Intercomparison Exercise on Probabilistic Accident Consequence Assessment Models", whose final calculations are scheduled for August 1992.

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DEPOSITION OF RADIONUCLIDES AND THEIR SUBSEQUENT RELOCATION IN THE ENVIRONMENT FOLLOWING AN ACCIDENTAL RELEASE TO THE ATMOSPHERE

Contract Bi7-010 - Sector C24

1) *Underwood*, SRD AEA Technology - 2) *Roed*, Risø National Laboratory
3) *Paretzke*, GSF Neuherberg - 4) *Nixon*, UKAEA SRD

Summary of project global objectives and achievements

Objectives

The objective of the project is to improve, as necessary, the models and parametrizations used in estimating (a) the intensity and spatial distribution of deposited activity and (b) the total health/economic impact of such deposits in assessments of the consequences of accidental releases of radioactivity. To this end, the aim is to attain a better understanding of:

- the influence of various weather conditions on deposition, particularly weather conditions which can lead to high deposition fluxes such as fog, snow or intense rain;

- the resuspension of deposited ^{137}Cs activity;

- the weathering of deposits in urban and rural environments and its impact on long-term external exposure;

- the ultimate fate and dosimetric impact of radionuclides carried by urban run-off water;

- the impact that a change in the method of representing the atmosphere's dispersion capability would have on the end-points of consequence assessment.

Achievements

1. The influence of weather condition on the intensity and pattern of deposition

Below-cloud scavenging coefficients for both rain and snow have been measured by GSF using a tracer method involving tagged monodisperse particles. During the winters of 1990/91 and 1991/92, 65 samples were taken in 16 different rain and snowfall events. The scavenging coefficient was found to range from 4.1 10^{-5} to 4.0 10^{-1} s^{-1} depending in particle size. The scavenging coefficient was found to depend linearly on the precipitation intensity. At a particle size of 0.7 (1.1)μm the slope was 0.030 (0.022) $s^{-1}/(mm\ hr^{-1})$.

GSF also measured wet-deposition rates using the background atmospheric aerosol. It was found that the scavenging efficiency of snow is up to one order of magnitude higher than that of rain and that the dependence on particle size is similar to that of rain, with particles <0.5μm and >1.5μm in diameter being more efficiently scavenged.

Risø has measured wet and dry deposition to urban surfaces using particles marked with ^{7}Be as a tracer for caesium particles. Plastered plates were placed under varying degrees of shelter from the weather in order to examine the difference between wet and dry deposition. It was found that deposition was very dependent on the degree of sheltering and that dry deposition was small compared to wet deposition even on vertical walls.

An approach has been developed by SRD for explicitly treating foggy weather conditions within the the context of probabilistic consequence assessment (PCA) for atmospheric releases. This deals with both the assessment of the magnitude of the enhancement in deposition in such

conditions and with the utilization of routinely-available meteorological data to flag the presence of fog and to assign values to required parameters.

2. Weathering and run-off of ^{137}Cs in urban and rural environments

A number of surfaces, including walls, roofs, roads and lawns, have been continuously monitored by Risø during the past six years in order to find the effect of weathering and routine 'decontamination' procedures such as street cleaning. It was found that the weathering rates were very different for the various urban surfaces: for walls and lawns it was very low, but for roads it can be very high, depending on the volume of traffic. A computer code TACTUS is being developed at Risø to predict the effect of weathering: it has 16 compartments describing the migration of ^{137}Cs in the urban environment. The predictions of TACTUS were found to be in good agreement with the measured data.

Since 'green' areas have been found to make a major contribution to the radiation dose even in cities, Risø has measured the profile of ^{137}Cs in 2 soils (both of sandy loam type). In both, a small tendency to downward migration was seen.

GSF has been recording and evaluating γ-spectra from 50 sites in Southern Bavaria for over five years in order to examine the time behaviour of the γ-dose rate with time. Since they also have established that, even in urban environments, some years after a deposition of caesium most of the additional γ-radiation arises from undisturbed vegetated surfaces, the focus of attention has been the reduction in kerma-rate over grassland due to the migration of caesium into the soil. In 1986, after a dominantly wet deposition of caesium, a reduction of gamma dose rate in air due to initial migration into soil and to surface roughness of (0.63±0.08) was observed; in 1991 the dose rate was reduced by a factor of (0.34±0.06). The new measurement confirmed the previously derived analytical approximation that the reduction factor, f, after time t can be represented as $f(t) = 0.36\exp(-\ln(2)t/T) + 0.31$, with T=1.87 years.

3. Resuspension of deposited ^{137}CS activity

GSF has measured the resuspension of ^{137}Cs at a specific site within an urban environment in Goiania, Brazil, following the accidental contamination there in 1987. Preliminary results on air concentrations indicate a rather local source of resuspension and negligible differences in air concentrations between 1m and 2m height above ground. Apparently over 90 percent of airborne activity is attached to aerosols larger than the cut-off point of an EPA air-sampler. There is pronounced seasonality of resuspension/deposition and an overall decrease with time. Measurements on street dust show that after 3 years there has been very little spreading of the urban contamination, in contrast to the Soviet reports on similar measurements in towns and villages of the Chernobyl region.

On the basis of the above results, an assessment has been made of the importance of resuspension to the total radiation exposure of a critical group following such a local ^{137}Cs urban contamination. By far the largest contribution (>95%) to the total radiation exposure results from external irradiation and, in particular, during time spent outdoors. The contribution from inhalation of resuspended material is very small (<0.1%).

Risø has made measurements to determine the contribution of resuspension to the recontamination of surfaces previously cleaned. Rain collectors with a surface area of 10m^2 were placed at 1m and 3m above the ground: the rainwater was collected and measured monthly. The rain samplers near the ground collected more ^{137}Cs , indicating that the resuspended material in air had a high local component and that the the concentration profile was steep. In terms of absolute amounts, it was found that the contribution of resuspended material to the recontamination of already contaminated surfaces could be significant.

4. Ultimate fate of deposited radionuclides

SRD carried out an approximate comparative assessment of the radiological impact of radionuclides carried into the urban drainage system during intense rain episodes following an accidental release to atmosphere. First, a review of the urban drainage pathway was completed in order to highlight key aspects. Then, a mathematical model for a combined sewerage system was developed, which keeps track of the quantities of radionuclides taking various routes to the 'outside' of the system, as a function of rainfall intensity and duration: the amounts or concentrations of radionuclides in sewage sludge and effluent are calculated. The model was then used to perform illustrative calculations for typical values of system parameters in order to provide quantitative information for radiological assessment purposes.

Consideration was given to a large number of potential pathways by which dose could be delivered to man. For example, the effluent may be discharged to the sea, where it could pollute the marine food chain, or it could be discharged to the freshwater environment, posing a hazard to drinking-water supplies; sludge could be used on agricultural land, leading to contamination of the terrestrial foodchain. Comparisons were made with doses arising from material *retained* on urban surfaces and also with other dose pathways which do not stem from deposited material. The results demonstrated that individual doses arising from the spreading of contaminated sludge onto agricultural land could be appreciably higher than those arising from direct deposition, although the area of land involved is much lower. Also, the collective doses arising from some of the contributions to the urban drainage pathway can be higher than some of the dose contributions currently included in consequence assessment. Thus the urban drainage pathway cannot generally be dismissed without further justification in particular cases.

5. Sensitivity of PCA results to atmospheric dispersion modelling

SRD has investigated the net impact of changing the basic dispersion modelling used in a modern probabilistic-consequence-assessment (PCA) computer program. The prescriptions for obtaining the dispersion parameters (σ_y and σ_z curves and depth of the atmospheric boundary layer) were changed in the PCA code CONDOR to one based on more recent parametrizations of the atmospheric boundary layer in terms of similarily variables such as the Monin-Obukhov length and the u_* scaling velocity in highly convective conditions.

Comparisons were first carried out for a single radionuclide (^{137}Cs) in fixed weather conditions, and it was found that the new model tended to produce lower concentrations (due to larger σ values). In most cases the differences are less than a factor of 4, with the greatest discrepancies found close to the source (<10km) in unstable conditions and further downwind (out to 100km) in neutral and stable conditions. The use of a new boundary-layer height parametrization had little impact on concentrations.

Secondly, comparisons were carried out, again for time-invariant met. conditions, using a full inventory from a typical PWR accidental release, and the endpoints examined were the risks of early and late fatality and the total numbers of deaths. Not much change was found for late deaths but discrepancies of up to an order of magnitude were found for early death in some weather conditions. Finally, the results of full probabilistic calculations with time-varying meteorology were compared: it was found that the differences between the two models were much reduced when the relative probabilities of various weather conditions were included. Thus the net impact of the model changes on the conventional endpoints of PCA is small, with the older models tending to produce more conservative estimates.

Project 1

Head of project: *Dr. Underwood*

Objectives for the reporting period

The objectives of this project were:

(a) To develop techniques for explicitly treating foggy weather conditions within the context of probabilistic consequence assessment (PCA) for atmospheric releases. Two aspects need to be considered: assessment of the magnitude of the enhancement in deposition in such conditions and the utilization of routinely-available meteorological data to flag the presence of fog and assign values to required parameters.

(b) To assess the radiological impact of radionuclides carried into the drainage system by run-off from urban surfaces during intense rain episodes following an accidental release to atmosphere, in comparison to other urban radiological impacts conventionally calculated for atmospheric releases.

Progress achieved including publications

1. Modelling the impact of fog

The first task was to develop the scientific basis for calculating how the condensed water in a fog would be partitioned between the naturally-occurring aerosol (on which fog droplets would normally form) and the additional released aerosol, and how it would be shared amongst particles of different size.

The released aerosol was taken to have a log-normal size distribution in its dry state, and be characterized by its total mass concentration, the mass-median aerodynamic diameter, the geometric standard deviation of the number distribution, the fraction (by volume) of soluble material in the particles and the dry particle relative density. Typical ranges of these parameters were defined, bearing in mind broad physical constraints and past analyses.

The increase in deposition produced by the released particles taking up water is expressed in terms of the 'enhancement factor', defined as the ratio of the mean deposition velocity after water uptake to that before.

A detailed determination of how the condensed water is shared amongst all the particles present in fog requires solution of a set of coupled differential equations representing the growth of particles of different initial size and the consequent effect of the loss of water on the saturation ratio of the air. However, two approximate approaches were developed which avoid explicit numerical integration of the differential equations but which nevertheless take account of (a) the limited amount of condensed water available, (b) the low degree of supersaturation in fog and (c) the widely varying timescales associated with the growth of particles of various sizes.

The results of this study [1] showed that the enhancement factor approaches a value of order 100 at low mass concentrations, provided the particles contain around 10% or more soluble material. This is a large factor capable of having a major impact on some of the parameters used to quantify the consequences of accidental releases of airborne radionuclides. The enhancement factor falls as mass concentration increases, but even at high values of the latter the factor is often significantly above unity, demonstrating that activation of droplets is not a prerequisite for appreciably enhanced deposition.

Overall, it was found that the key parameters required to specify the deposition velocity in fog are the total mass concentration and the mass-median aerodynamic diameter. Approximate estimates of the other parameters will usually suffice. Thus the study indicated that it should be possible to make an adequately reliable estimate of the impact of fog in probabilistic consequence assessment despite the fact that detailed information on the released aerosol characteristics for various accident scenarios may be deficient.

Following on from this study, the two approximate approaches mentioned above – one suitable for high number concentrations and one suitable for low number concentrations – were incorporated into algorithms for use within a conventional PCA code. These algorithms have to take account of the fact that as the plume moves downwind the mass concentration of the aerosol (and its size distribution) changes due to dilution and deposition, thereby contributing to a redistribution of water amongst various particle size groups; i.e the fog modelling has to be coupled to the dispersion/deposition treatment. Conversely, the latter has to be capable of handling the higher deposition velocities appropriate to fog droplets.

Four generic scenarios are considered [2]: (i) a narrow band of coastal advection fog; (ii) an area of widespread radiation fog; (iii) orographic fog encountered on elevated terrain; (iv) conditions of very high relative humidity, albeit without the formation of fog. The methodology developed in the earlier study has to be tailored to the specific nature of each scenario. The values of pertinent meteorological parameters, such as the liquid water content of the fog, are deduced from routine data where possible (see below) or set to typical values.

In addition to calculating the magnitude of the impact on deposition of the above weather categories, the PCA code must have some way of detecting the presence of each category in the sequence of meteorological data utilized. Relevant meteorological data which are routinely available at many stations, such as 'present weather', visibility and relative humidity, are discussed from the viewpoint of providing the necessary information.

Overall, the approach developed is pitched at a level of complexity that is appropriate to the PCA context: it does not involve major additional computing yet does reflect the physical constraints of the system and accounts for the specific characteristics of the released aerosol. Implementation of this method in a PCA computer code will allow, in the first instance, an evaluation to be made of the net impact of fog on the conventional end-points of PCA and, subsequently, the routine inclusion of an explicit treatment of fog in PCA, should the need be generated.

2. Estimating the impact of run-off into the urban drainage system

First, a review was carried out to gather background information for the development of an approach to quantifying the urban drainage pathway. The review [3] covered the following aspects:

2.1 Urban drainage systems

Here, the pertinent features of the various types of urban drainage systems common in Europe are described, including a discussion of flow rating and the provisions made for overflows. The stages of sewage treatment are described, as are the methods for sewage-sludge treatment and disposal.

2.2 Radionuclide behaviour in the system

The processes of removal during transport in sewerage pipes, removal from the liquid phase during sewage treatment, concentration in sewage sludge and dilution on discharge of effluent are considered. In particular, pertinent experimental studies (small scale) and field data are reviewed, and consideration given to whether the experience of heavy-metal contamination yields any pertinent information.

2.3 Radiological and economic implications

Here, doses to the public, worker doses and economic costs are discussed. Within the context of doses to the public, contributions from terrestrial pathways and aquatic pathways are considered. Under the heading of economic costs, the costs of countermeasures (such as having to make alternative arrangements for disposal of contaminated sewage) are discussed, as is the possible disruption to the sewage treatment process.

This review revealed what are the key features of the urban drainage system pertinent to an assessment of the impact of radionuclides in run-off water entering the drains, and highlighted the important parameters needed for quantification of the consequences. It became clear that empirical information on the partitioning of radionuclides between the solid and liquid phases in combined sewage systems is sparse.

For combined sewerage systems – which are still quite widely used in a number of European countries – the route taken by radionuclides through the system is influenced by the absolute rate at which water is entering the system as a result of overflow provisions in the system. Thus, in the second phase of the work a mathematical model was developed for a combined system which keeps track of the quantities of radionuclides taking various routes to the 'outside' of the system, as a function of the rainfall intensity and duration, and thereby calculates the amounts or concentrations of radionuclides in sewage sludge and effluent. This model provides a useful vehicle for checking the sensitivity of the radiological impact to uncertainties in the chemical behaviour of the radionuclides in the system.

The model was then used to perform illustrative calculations for typical values of system parameters in order to provide quantitative information for radiological assessment purposes[4].

Consideration was given to a large number of potential pathways by which dose could be delivered to man as a result of contaminated urban run-off entering the drains. For example, the effluent may be discharged to sea, where it would pollute the marine food chain, or it could be discharged to the freshwater environment, posing a hazard to drinking-water supplies. Alternatively, the effluent could be used directly for irrigation purposes, thereby contaminating crops. On the other hand, the sludge could be used, for example, on agricultural land, leading to contamination of the terrestrial foodchain (and also to a source of external radiation).

Approximate numerical estimates of individual and collective doses were made for the more important pathways, assuming a rainstorm of quite high intensity, and used in comparisons with doses arising from more conventional pathways. In the main, the dose from the urban drainage pathway was compared to dose arising from radioactive material *retained* on surfaces after deposition in rain: for the model used, the ratio is independent of the level of contamination in the rainwater, and all the calculations were carried out for a notional unit contamination density. This type of comparison was applied to doses arising from ingestion of contaminated foodstuffs, with the contamination arising in the urban-drainage case either from irrigation using effluent water or from the spreading of contaminated sludge on agricultural land. Similarly, the various urban drainage pathways themselves can be inter-compared, again using unit concentration in rainwater. Comparisons were also made with other dose pathways which do not stem from deposited activity, for example the inhalation pathway, by using a typical value for the ratio of concentration in rainwater to concentration in air.

The results demonstrated that individual doses arising from the spreading of contaminated sludge onto agricultural land could be appreciably higher than those arising from direct deposition, although the corresponding area of land involved is much smaller in the former case (and hence collective doses are smaller). Also, the collective doses arising from some contributors to the urban drainage pathway (particularly via contaminated drinking water and irrigation water) are higher than the doses from some of the pathways that are currently included in consequence assessment.

A judgement of how important is the impact of the urban drainage pathway is also influenced by the ease with which countermeasures could be implemented and their likely cost. In the case

of contaminated sludge, other methods of disposal are available, such as landfill. Although there would no doubt be additional costs associated with making alternative provisions, these are likely to be small compared to other costs associated with the accident. In the case of freshwater contamination, the provision of an alternative supply may well be more problematic and costly.

Overall, then, on the basis of the the simplified calculations and comparisons undertaken here it is not possible to dismiss the potential impact of urban drainage pathways. However, there are large uncertainties involved in the calculations, and the availability of more detailed information in the future may significantly affect the provisional estimate of the relative importance of these pathways. For example, in the case of sludge-spreading some evidence is starting to appear that the availability of radionuclides to crops may be much lower in this case than in the case of direct deposition. In the case of freshwater contamination, the contribution from rural catchment area has to be considered in addition to that from urban drainage and could dominate: mathematical modelling for freshwater pathways is still under development.

With regard to the question of explicitly including the urban drainage pathways in consequence assessment, the question of how to handle the contribution from freshwater contamination is subsumed under the wider question of how to handle freshwater contamination (via all routes) within probabilistic consequence assessment, which is to be addressed in the next phase of the research. The issue of sludge disposal is more relevant to the identification of critical groups than to the conventional types of calculations carried out in PCA which are, for practical reasons, of a more broad-brush nature and do not deal explicitly with very small parts of the spatial domain where significantly different farming practices may be in operation.

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(2) Underwood B Y (1992) Modelling fog in probabilistic consequence assessment. SRD/16185947/92/R2 (contract report).

(3) MacKenzie J (1991) A review of radionuclide transport in urban drainage systems. SRD R562 (HMSO, UK).

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Project 2

Head of Project: *Dr. Roed*

Objectives for the reporting period

1. Deposition on urban surfaces.
   - i Investigation of the distribution of dry deposited material on various surfaces especially in the urban area.
   - ii Investigation of wet deposition onto - and run-off from - various urban surfaces.

2. Weathering of deposits on urban surfaces.
   - i Impervious surfaces (roofs and roads).
   - ii Other surfaces such as grass, trees and soil.

3. Resuspension.
   - i Examination of the spatial correlation of resuspendend Cs-137 as concentration with deposited activity.
   - ii Investigation of concentration of resuspended Cs-137 as a function of height.

Progress achieved including publications

Introduction

Risø's task in this phase of the urban programme was to determine the distribution of both wet and dry deposition (including that from resuspended material) and to follow any movement of the deposited radioisotopes.

Measurements were made in the Swedish town of Gävle, the most contaminated city outside Eastern Europe, in the Danish town of Roskilde and at the Risø National Laboratory.

1. Deposition on urban surfaces

In order to determine the deposition on urban surfaces, a number of plastered plates were placed at various locations in the town of Roskilde. Particles marked with ^{7}Be were used as a tracer for caesium particles. The plates were placed under varying degrees of shelter in order to examine the difference between dry and wet deposition. *In situ* measurements in the town of Gävle were performed (a) on well sheltered surfaces to find the dry deposition component and (b) on exposed surfaces to determine the total deposition. The results of these measurements are given in Table 1. It can be seen that the deposition of ^{7}Be was very dependent on the degree of sheltering and dry deposition is small compared with wet deposition even on vertical walls.

Table 1 - Deposition on different plaster surfaces

Name	Facing	Description	Height (m)	Cs-137 (cps)	Be-7 (cps)
P/332 "Gartner-gaarden"	South	No shielding	2.5	1.31	20.38
P/333 "Varme-vaerket"	East	Some shielding against wind	2.5	0.95	4.45
P/334 Under Bridge	North	Completely shielded from rain	4.0	1.01	BDL
P/335 "Sct. Olsgade"	South	Sheltered against wind	2.5	0.92	3.31
P/336 "Roskilde museum"	East	Some shelter against wind	2.5	0.90	5.93
Unused mortar sample				1.02	0.00

2. Weathering

A number of surfaces including walls, roofs, roads and lawns have been continuously monitored during the past six years in order to find the effect of weathering and routine "decontamination" procedures such as street cleaning. One of the investigations in Gävle had three objectives. They were

i. To determine deposition on a vertical plastered wall

ii. To validate the *in situ* shielded gamma spectroscopy measurements by taking samples from the wall at different heights above the ground.

iii. To compare the ^{40}K content in the samples in order to determine the contribution from "splash-up" (Table 2).

Table 2 - Caesium and potassium activities for plastered walls in Gävle

Sample No.	Height (cm)	Area (m^2)	Cs-137 (Bq/m^2)	Cs-134 (Bq/m^2)	K-40 (Bq/m^2)
372	40	381	3864	372	8.11
373	80	373	349	32	0.67
374	120	244	561	52	0.76

The overall activity on the wall was found to be approximately 1000 Bq m^{-2} and the measured activity in the samples ranged from 350 to 3800 Bq m^{-2}; this is considered to be in good agreement. Furthermore, it can be seen that the large contribution of ^{137}Cs at 40 cm above the ground was due to splash-up as the concentration of ^{40}K was more than an order of magnitudes higher than that on the surfaces more than 40 cm above the ground.

To predict the effect of weathering, the computer model TACTUS is being developed in the Risø Laboratory. The model comprises sixteen different compartments decribing the migration of ^{137}Cs in the urban environment [3]. The model parameters were derived partly from measurements and partly from theoretical calculations. In Fig. 1 the model prediction is compared with experimental results. All numbers are relative to the initial deposition on a horizontal retentive surface. The prediction was in good agreement with the measured data.

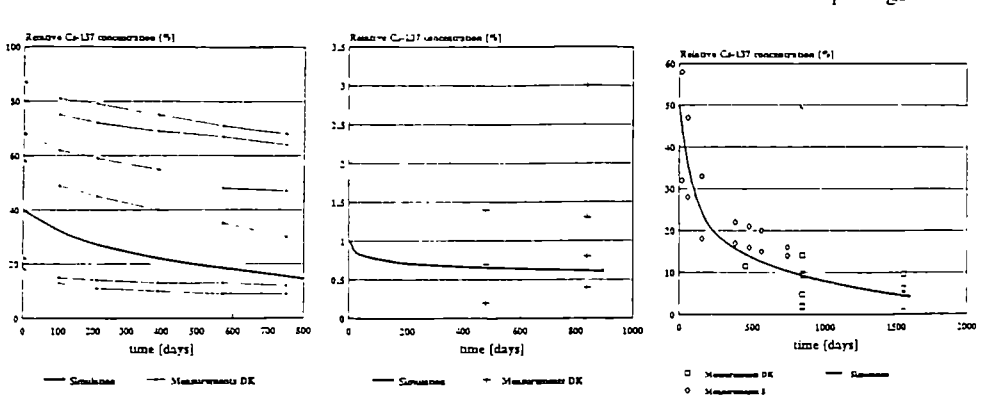


Figure 1 - TACTUS simulations on different surfaces

It had been shown earlier that "green" areas make a major contribution to the radiation dose and are therefore important surfaces even in urban areas. The distribution of ^{137}Cs in the soil profile has been measured for two soil types (A and B) in Gävle (Figure 2). The results of a texture analysis of these soils are given in Table 3. Both soils are described as sandy loams. The soil profiles were measured two and four years after deposition. In both cases a small tendency to downward migration was seen. The difference in the profiles is probably due to the higher content of organic matter in the top 2 cm of soil A (as indicated by the high humus content). The shorter tail on profile B in 1990 compared to 1988 may be the result of an increased transfer rate through a visibly much sandier layer located approximately 5 cm down the profile.

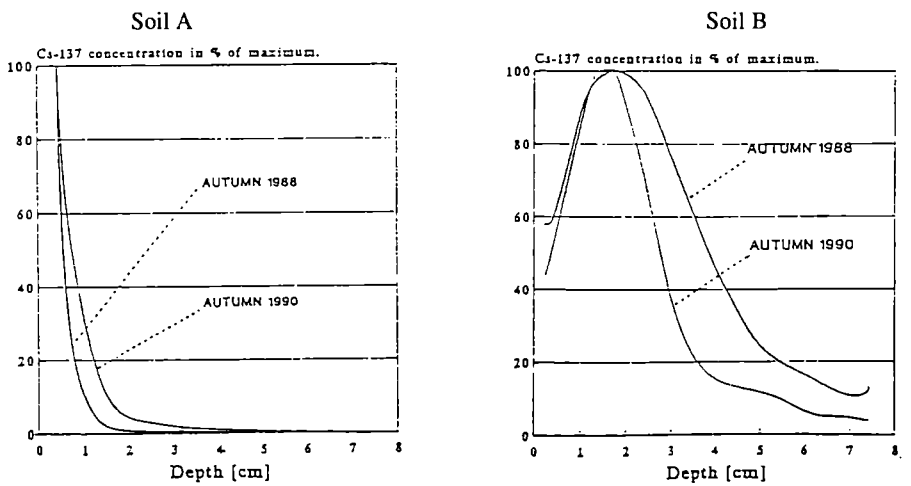


Figure 2 - Gävle soil profiles.

Table 3 - Characteristics of two soils in Gävle

	Humus organic	Clays < 2 um	Silts 2 - 20 um	Sand 1 20-200 um	Sand 2 0.2-2 mm	pH
Soil A:						
Top 2 cm	10.0%	6.8%	12.7%	45.2%	25.3%	6.5
3-5 cm	5.4%	6.6%	14.0%	50.9%	23.1%	
Soil B:						
Top 2 cm	2.4%	13.1%	19.2%	49.7%	15.6%	4.7
3-5 cm	1.9%	13.0%	19.1%	51.3%	14.7%	

3. Resuspension

In order to determine the contribution of resuspension to the recontamination of surfaces, previously cleaned, two rain collectors were used at Risø. One was placed 1 m above ground level and the other 3 m above the ground; both had a surface area of 10 m^2. The rainwater was collected and measured monthly. At the end of each month the collectors were cleaned with HNO_3 solution (1%) and the washing added to the rainwater collected. The rain sampler nearer the ground collected the most ^{137}Cs. This indicated that the resuspended material in air had a high local component and that the concentration profile was steep.

4. Conclusions

1. It was found that the dry deposition component, even on vertical surfaces, was small compared to that from wet deposition.

2. The weathering rates were very different for different urban surfaces. For walls an lawns it was very low, but for roads it can be very high depending on the volume of traffic.

3. The contribution of the resuspended material to the recontamination of already decontaminated surfaces can be significant.

The conclusions are based on only a few measurements. In order to draw firm conclusions and to further develop our decontamination strategy many more measurements are called for.

Publications

1. Roed, J., *Deposition and Removal of Radioactive substances in an Urban Area.* Final report of the NKA Project AKTU-245, 1990.

2. Andersson, K.G., *The Characterization and Removal of Chernobyl Debris in Garden Soils*, Risø National Lab., DK-4000 Roskilde, Denmark, Risø-M-2912, 1991.

3. Andersson, K.G., *TACTUS: A code for simulation of the flow of Caesium-137 in urban surroundings*, IAEA, Vienna, Nov. 1990.

Project 3

Head of project: *Dr. Jacob*

Objectives for the reporting period

A) Direct measurement of the wet deposition of atmospheric aerosol. Here, the trace element content of the atmospheric aerosol will be used to quantify aerosol deposition parameters. Trace elements on aerosols transported over long range may be scavenged predominantly by processes in clouds, i.e. by rain-out, whereas wash-out determines the deposition of trace elements with dominant local sources. The use of a set of trace elements which encompasses both these deposition routes will allow wet deposition to be studied in detail under various meteorological conditions. The use of generated aerosol and trace elements will provide a complete picture of wet deposition: wash-out both on its own and together with rain-out can be studied. The methods will be applied to precipitation in the forms of rain and of snow.

B) Continuation of recording and evaluating γ-spectra for 50 sites in Southern Bavaria. The time behaviour of the reduction of the γ-dose rate in the first five years after deposition will be approximated by analytical functions.

C) Development of a resuspension model which will enable an estimate to be made of the redistribution of initial contamination and thus the usefulness of decontamination measures in urban environments after major radioactive contaminations.

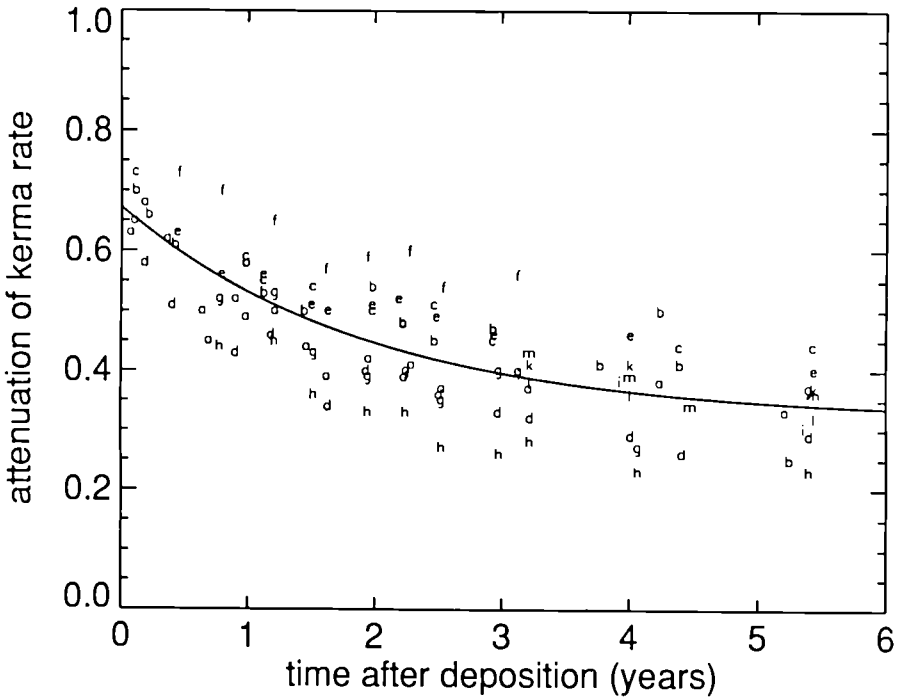
Progress achieved including publications

A) To study the below-cloud scavenging process a tracer method was established. In field experiments monodisperse particles ($\sigma_g \approx 1.2$) in the size range 0.3-4.0 µm tagged with a fluorescent dye tracer had been released near ground during precipitation events. With the determined tracer concentration in aerosol and in precipitation the scavenging coefficients can be calculated. The relevant meteorological parameters had been recorded during sampling. During winter 1990/91 and winter 1991/92 alltogether 65 samples at 16 different rain and snowfall events had been taken. The scavenging coefficient range from $4.1\ 10^{-5}$ to $4.0\ 10^{-1}\ s^{-1}$ dependent on the particle size. The scavenging coefficient was found to depend linearly on the precipitation intensity. At a particle size of 0.7 (1.1)µm the slope was 0.030 (0.022) $s^{-1}/mm*h^{-1}$. To quantify the dependence of the deposition process on the hydrometeors in more detail a new rain droplet spectrometer was developed. This optical system will allow to measure droplet size distribution and velocity in situ during the field sampling.

The measurement of wet deposition of atmospheric aerosol was done during two winter saisons. Aerosol was sampled size fractionated by a Berner impactor (size range 0.01-16 µm cut off diameter) and analysed by PIXE (Particle Induced X-ray Emission), preciptation by a wet-only sampler and analysed by ICP-AES (Atomic Emission

Spectrometry). The focus of this investigation was the determination of the scavenging efficiency of snow. It was found that the scavenging efficiency of snow is up to one order of magnitude higher than that of rain and that the dependence on particle size is similar to that of rain: small aerosol particles(< 0.5 µm) and large aerosol particles (> 1.5 µm) are scavenged most effective.

B) On streets and pavements processes like wash-off, street cleaning and rub-off by traffic were found to decontaminate the surfaces relatively fast. Therefore, even in urban environments, some years after a deposition of cesium most of the additional γ-radiation is contributed by undisturbed vegetated surfaces, like grassland. The measurement results for the reduction of the kerma-rate in air above grassland due to the migration of the cesium into the soil and the surface roughness are given in the Figure for twelve sites (each marked by a small letter) in Southern Bavaria. In 1986 after a dominantly wet depositon of the cesium a reduction of the gamma dose rate in air due to the migration into the soil and due to the surface roughness of (0.63 ± 0.08) was observed, in 1991 the dose rate was reduced by a factor of (0.34 ± 0.06). The new measurement results confirmed the previously derived analytical approximation
$f(t) = 0{,}36 \bullet \exp(-\ln 2 \bullet t/T) + 0.31$, with T = 1.87 years.



C) In and around the IRD-laboratory house in Goiania, Brazil (Fig. C1), the resuspension of deposited Cs-137 was measured. To this purpose the specific activity of surface soil and street dust as well as the airborne Cs-activity was measured. The aerosol collection was done by EPA-type air samplers (ca. 30 m^3/h) at different heights and locations, by large (0.8 x 0.8 m^3) water surfaces and by sticky papers (Fig. C2). Typical time integration periods were 14 days.

Preliminary results on air concentrations indicate a rather local source of resuspension and negligible differences in air concentrations between 1 m and 2 m height above ground. Apparently over 90 percent of airborne activity is attached to aerosols larger than the cut-point of EPA-air sampler. There is a pronounced seasonality of resuspension/deposition and an overall decrease with time.

The street dust results show after 3 years a rather minute dispersion of the initial urban contamination. This is in contrast to the Soviet reports on similar measurements in the towns and villages of the Chernobyl region and requires clarification.

An assessment of the importance of resuspension to the total radiation exposure of a critical group after Cs-contamination of a town is given in Fig. C3. By far the largest contributions (> 95 %) to the total radiation exposure from such a local urban contamination with Cs-137 results from external irradiation and, in particular, during the time spent outdoors. Although the specific activity of aerosols can be rather high, the contribution to the total exposure from inhalation of resuspended material is very small for Cs-137 (< 0.1 %). Because of the small yield of own agricultural products in an urban environment also the contribution from ingestion of contaminated own agicultural products is small (< 5 %).

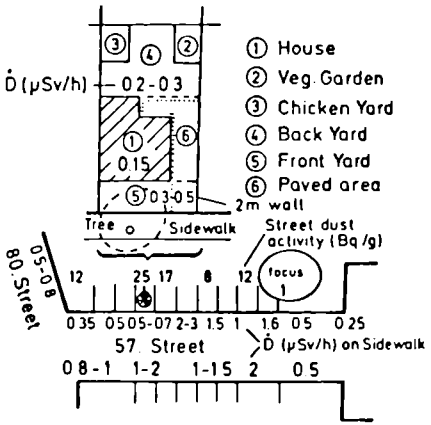


Figure C1: Measurement locations and data in Goiania

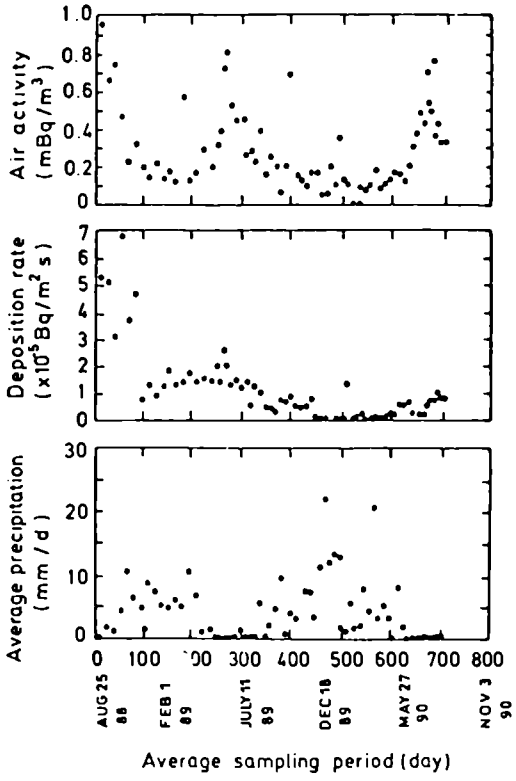


Figure C2: Air activity at 2 m, deposition rate on collector and average rain precipitation during 88 - 90 in Goiania

Exposure Sources	Exposure Quantity	Daily Living Habits and Exposures								
		Child (5a)			Woman			Man		
Effective DE/Kerma (Sv/Gy)		0.8			0.75			0.75		
	Excess $\dot{K}$ (nGy/h)	Exp.Time (h/d)	Dose (µSv/d)	%	Exp.Time (h/d)	Dose (µSv/d)	%	Exp.Time (h/d)	Dose (µSv/d)	%
Indoors at home	50	14	0.56	12.0	14	0.52	18.4	10	0.37	16.6
Outdoors in garden	200	5	0.8	17.1	5	0.75	26.3	2	0.3	13.3
Outdoors in Rua 57	1000	4	3.2	68.5	2	1.5	52.5	2	1.5	66.5
Elsewhere	0	1	0		3	0		10	0	
1. Total External Exposure		24	4.56	97.6	24	2.77	97.2	24	2.17	96.5
Inhalation DF (nSv/Bq)		6			9			9		
	Air Conc. (mBq/m^3)	T (h)	BR (m^3/h)	Dose (pSv/d) %	T (h)	BR (m^3/h)	Dose (pSv/d) %	T (h)	BR (m^3/h)	Dose (pSv/d) %
Indoors at home	0.2	10	0.3	7.4	8	0.35	17.6	8	0.5	11.5
		4	0.8		6	1.15		2	1.2	
Outdoors in garden	0.3	5	0.8	7.2	5	1.15	15.5	2	1.2	6.5
Outdoors in Rua 57	1.5	4	0.8	28.8	2	1.15	31.0	2	1.2	32.4
Elsewhere	0	1	0.8	0	3	1.15	0	10	1.2	0
2. Total Inhalation Exposure		24		43.4 < 0.1	24		64.1 < 0.1	24		50.4 < 0.1
Ingestion DF (nSv/Bq)		8.5			14			14		
	Mass Conc. (mBq/g)	Daily Cons. (g/d)	Dose (µSv/d)	%	Daily Cons. (g/d)	Dose (µSv/d)	%	Daily Cons. (g/d)	Dose (µSv/d)	%
Soil in playground/on food	10000	1	0.085	2.0	0.1	0.014	0.5	0.1	0.014	0.6
Own egg	25	50	0.011	0.2	50	0.017	0.6	50	0.017	0 8
Own chicken	50	10	0.004	0.0	30	0.021	0.7	30	0.021	0 9
Own vegetables	40	20	0.007	0 1	50	0.028	1.0	50	0 028	1 2
3. Total Ingestion Exposure			0.107	2.3		0.08	2 8		0.08	3 5
Sum 1 - 3 (µSv/d):			4.67	100		2.85	100		2.25	100
Effective Dose Equivalent/year (in Sv/a):			1.70			1.04			0.82	

Figure C3: Calculated radiation exposures for three persons in a Cs contaminated house in Goiania, Brazil (T= Residence Time, BR= Breathing Rate)

Publications

Tschiersch, J., B. Hietel, P. Schramel and F. Trautner, Wet deposition of aerosol by rain and snow, in: AEROSOLS, Science, Industry, Health and Environment (S. Masuda and K. Takahashi, Eds.), Vol. 2, pp. 1033-1036, Pergamon Press, Oxford, 1990.

Tschiersch, J., B. Hietel, P. Schramel and F. Trautner, Saharan dust at Jungfraujoch, J. Aerosol Sci., 21, Suppl. 1, pp. 357-360, 1990.

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Trautner, F., G. Frank, J. Tschiersch and G. Voigt, A method to quantify wet and occult deposition of aerosol to wheat plants, J. Aerosol Sci., 21, Suppl. 1, pp. 295-298, 1990.

Frank, G. , F. Trautner and J. Tschiersch, Determination of scavenging efficiency by using fluorescent aerosol, J. Aerosol Sci., 22, Suppl. 1, pp. 537-540, 1991.

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Tschiersch, J., G. Frank, B. Hietel, P. Schramel, F. Schulz and F. Trautner, Aerosol deposition to a snow surface, J. Aerosol Sci., 22, Suppl. 1, pp.565-568, 1991.

Schwikowski, M., U. Baltensperger, H.W. Gäggeler, D.T. Jost, B. Lehmann, M. Lehmann, A. Neftel, J. Tschiersch, Aerosol concentration, chemical composition and size distribution of Saharan dust at Jungfraujoch, Switzerland, Proceedings of the CHEMRAWN VII Conference, Baltimore, Maryland, USA, 2-6 Dec., 1991.

Schwikowski, M., F. Maupetit, W. Winiwarter, P. Seibert, J. Tschiersch, A single case study of Saharan dust in March 1990, Proceedings of EUROTRAC Symposium`92, Garmisch-Partenkirchen, FRG, 23-27 March, 1992.

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P. Jacob, R. Meckbach: Recent developments in In-situ γ spectrometry. Proc. IRPA 8, Worldwide Achievement in Public and Occupational Health Protection against Radiation, Montreal, pp. 305-308. International Radiation Protection Association, Montreal (1992).

E. C. S. Amaral, H. G. Paretzke, M. A. Pires do Rio, M. J. Campos, Radioecological Measurements after the Goiania Accident. Proc. 9th Int. Congress on Radiation Research, Toronto (1991).

H. G. Paretzke, J. A. Garland, Assessment of the Radiological Significance of Surface Contamination by Entrained Radioactivity, to be published in J. Env. Radiat. Biol. (1992)

Project 4

Head of project 4: *Dr. Nixon*

Objectives for the reporting period

The aim of this project is to evaluate the impact of changing the representation of the dispersive capability of the atmosphere on calculations of the consequences of accidental releases of airborne radioactive gases and aerosols. The vehicle for carrying out this investigation is a model uncertainty/sensitivity analysis of the atmospheric dispersion module of the CONDOR code (a state-of-the-art probabalistic consequence assessment code). In contrast to the more usual parametric uncertainty analyses, this study will examine the impact of changes in some aspects of the modelling implemented in the atmospheric dispersion module. The study will emphasize the impact on standard consequence endpoints, *eg* health effects, rather than limiting the analysis to the variation in dispersion characteristics, *eg* concentration levels.

Progress achieved including publications

1. Methodology

The initial task of the project was to decide upon its scope and specific aims. This included identifying exactly which parts of the atmospheric dispersion model were to be analysed. It was decided that, although it would have been enlightening to completely revise the atmospheric module for use in the project, the limitations of the resources available made this impracticable. Hence a limit to the extent of the sensitivity study had to be drawn. It was decided that the basic philosophy of a straight-line Gaussian plume used in the current version of the PCA code CONDOR would be retained in the alternative model. Also, this study confined itself strictly to dispersion of material, and thus the mechanisms for plume depletion were not considered. The areas chosen for change in the alternative model were the standard deviations of the horizontal and vertical Gaussian deviations of the plume (σ_y and σ_z) and the depth of the atmospheric boundary layer (L). These two aspects of dispersion were chosen since they are likely to represent the greatest source of uncertainty and because they are areas in which the scientific community has invested considerable effort in recent years.

A review of parameterisations of σ_y, σ_z and L was performed and several models for each parameter were compared both with each other and also with the models in CONDOR. It is well known that σ_y and σ_z both show, to varying degrees, height dependence. This dependence is not modelled by the current CONDOR dispersion model, and so the alternative parameterisation was chosen specifically to incorporate this feature. One common method of achieving this was via the use of Similarity Theory. Similarity Theory is used to categorise meteorological conditions into three basic classes, viz convective (CBL), neutral (NBL) and stable (SBL) boundary layers (this represents a move away from the Pasquill-Smith scheme implemented currently in CONDOR). Three sets of governing equations for the σ's are then used, one for each type of meteorological condition. This categorising system can also be used in a similar manner for the calculation of L.

The final choice of the exact parameterisations used as part of this scheme was then made. The models were chosen to fulfil the following criteria: (i) to have strong theoretical and experimental support in the scientific community, (ii) to incorporate height dependence into σ_y and σ_z and (iii) to be readily implemented into the CONDOR system. The alternative model was then developed, incorporated into CONDOR and tested.

The sensitivity analysis was then performed. The aims of the study in terms of endpoints for comparison were as follows:

(i) To observe the effect on the predicted concentration levels downwind of the release point and the crosswind Gaussian profile at various points during plume travel for a single nuclide release in each of a number of fixed meteorological conditions,

(ii) Having completed the above, to observe the effect on the predicted consequences of a full PWR release of radioactive material with and without the implementation of countermeasures in each of a number of fixed meteorological conditions,

(iii) Finally, to perform full probabilistic risk assessments to observe the change in societal risk, both with and without the implementation of countermeasures.

All the above were performed for both buoyant and non-buoyant releases.

The calculation of the depth of the atmospheric boundary layer, L, is done outside CONDOR and the results read into the system via CONDOR's meteorological database. This enabled the alternative and the current atmospheric modules to be run with both the new and original calculations for L. Thus the impact of the alternative parameterisations for the σ's and for L could be assessed independently.

2. Results and conclusions

The single-nuclide (^{137}Cs) release runs performed predicted the concentration levels using the alternative model to be generally lower than those using the current CONDOR model. This suggests that the current model has a tendency to produce conservative predictions. In most cases, the differences in concentration between the two models for single nuclide releases are less than a factor of about 4, with the greatest discrepancies found close to the source (< 10 km) in unstable conditions and further downwind (< 100km) in neutral and stable conditions. The use of the new boundary layer height parametrization had little impact on the concentrations, particularly when used in conjunction with the original CONDOR dispersion model.

For the full PWR releases with time-invariant meteorological conditions, the endpoints examined were risk of early and late fatality and numbers of deaths. The two dispersion models produced almost identical results for late death in all weather categories used. However, discrepancies of about an order of magnitude between the two models were detected for early death in some categories. In the full probabilistic runs, the differences between the predictions of the two model were much reduced when the relative probabilities of the various weather conditions were taken into account: the magnitude of the differences is generally less than a factor of two, even for the early-death endpoint.

To summarize, it was found that the use of the new dispersion model and/or the new boundary layer calculation have little effect on the predicted consequences of CONDOR obtained in a probabilistic assessment. Only for early-death predictions in some (time-invariant) meteorological conditions do the results from the two dispersion models differ by an order of magnitude. Even here, it should be borne in mind that uncertainties in other parameters, such as deposition velocity to skin and washing time of individuals (since skin contamination is a major contributor to early death for the large releases), are likely to lead to equal or greater uncertainty in early-death predictions. The study found that generally the new dispersion model predicted lower consequences than the current CONDOR model, suggesting that the present model produces conservative estimates of consequences.

Publications

Hancox J J and Boardman J (1992) The impact of an alternative representation of the atmosphere on predictions of the probabilistic consequence code CONDOR. CUA/REP/1992/15-A (contract report)

RADE-AID, THE DEVELOPMENT OF A RADIOLOGICAL ACCIDENT DECISION AIDING SYSTEM

Contract Bi7-012 - Sector C24

1) *Wagenaar*, TNO - 2) *Ehrhardt*, KfK Karlsruhe - 3) *Morrey*, NRPB

Summary of project global objectives and achievements

The current RADE-AID project concerning the development of a Radiological Accident DEcision AIDing system is a continuation and an extension of the work on the system during the period 1988-1989. Within this period a prototype computer program was developed to assist in decision-making concerning countermeasures following radiological emergencies. The program helps a decision-maker structure the problem and investigate the consequences of different countermeasures. The program also included facilities for the presentation of data related to the emergency. In order to demonstrate the potential of this decision tool, some illustrative applications were developed.

During the current project the computer system has been further developed with particular reference to the user-interface, the decision logic and a database of model predictions supplied for use with the system.

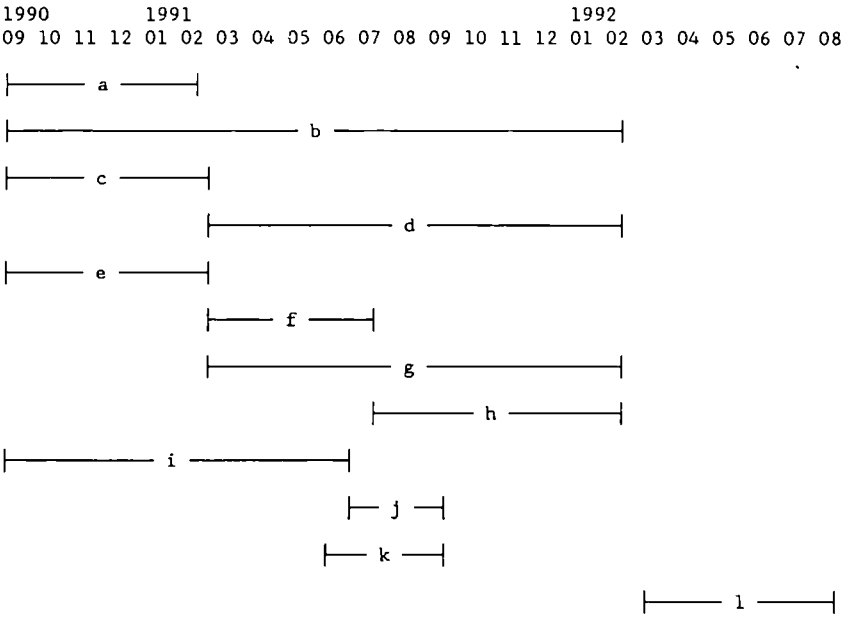
Consultation with decision-makers to prove the practical value of the system was also an important subject within the project.

Two separate computer programs are developed: DATARADE and DATUM. DATARADE is a multi-attribute analysis tool for radiological applications; it contains the database of model predictions mentioned above. DATUM is an associated multi-attribute analysis tool for general applicability.

The following activities were undertaken during the project:

a. List user-interface improvements (TNO)
b. Implement user-interface improvements (TNO)
c. List input elicitation improvements (TNO)
d. Implement input elicitation improvements (TNO)
e. Design database (NRPB)
f. Implement limited UK version of database (NRPB)
g. Provision of German & Netherlands data for database (KfK, TNO)
h. Implement full database (NRPB)
i. Establish contacts with decision-makers (TNO, NRPB, KfK)
j. Detailed discussions with decision-makers (TNO, NRPB, KfK)
k. Preparation of progress report (TNO, NRPB, KfK)
l. Preparation of final report, user guides etc. (TNO, NRPB, KfK)

In the diagram below the time-schedule of the activities is indicated.



Full development of the software has been completed and it is now available, together with a comprehensive user manual (attached to this report). The software has been developed to assist both decisions on countermeasures after an accident, and complex decision-making more generally.

To assist decisions on relocation after an accident, a generic database is available with the software, containing ranges of likely consequences of relocation decisions. The database has been designed to facilitate the inclusion of site and accident specific data by the user, as required.

In addition to the development of the software, contacts have been made with decision-making groups within the United Kingdom, Germany and The Netherlands, with a view to developing the software as appropriately as possible. From these contacts some feedback on the software has been received, although, understandably, the decision-making groups were unable to devote significant time to the project.

In one respect the original aims of the project have not been fulfilled. The database provided with the software is not as wide-ranging as originally envisaged. This is partly due to difficulties encountered in obtaining appropriate site specific data, and partly because the database was bound to be generic in nature, and so a limited database was seen to provide a sufficient range of general information.

Project 1

Head of project: *Dr. Wagenaar*

Objectives for the reporting period

The objectives for the reporting period (September 1990 - August 1992) for TNO were (as shown in section I):

- constitution of a list with improvements on the user-interface (activity a);
- implementation of the improvements on the user-interface (activity b);
- constitution of a list with improvements on the elicitation of input data (activity c);
- implementation of improvements on the elicitation of input data (activity d);
- provision of Netherlands data for the database (activity g);
- establishment of contacts with decision-makers (activity i);
- discussions with decision-makers (activity j);
- preparation of progress report (activity k);
- preparation of final report, user guides, etcetera (activity l).

Progress achieved

Lists with improvements on the user-interface and the elicitation of input data have been constituted and have been approved by KfK, NRPB and TNO. The implementation of both the improvements on the user-interface and the improvements on the elicitation of input data has been completed. Improvements include several methods to define weights and value functions, several options to investigate results (including sensitivity analysis) and an option to print a summary of the current problem.

In discussion with NRPB a definition of an interface between the decision analysis part of the program and the database has been drawn up. The design of the interface has been made and implementation has been completed.

A comprehensive user manual has been drawn up to allow use of the software in a wide area (refer to annex 1).

Contacts with decision-makers have been established. However those contact have not resulted in more detailed discussion with decision-makers nor in the complete provision of the data from The Netherlands for the database.

Contact with decision-makers has not been restricted to authorities responsible for radiological protection. Exercises with the decision-aiding tool have also been performed in the field of selection of methods and techniques for cleaning of (chemically) contaminated areas.

A paper entitled "Using a multi-attribute decision tool to aid decisions on countermeasure strategies" has been presented at the "International seminar on Intervention Levels and Countermeasures for Nuclear Accidents" (7-11 October 1991, Cadarache, France).

An invited paper has been given at the scientific meeting "Five years after Chernobyl: consequences of the accident for the Soviet-Union and the Netherlands" of the Netherlands Society for Radiological Protection (June 5th 1991, Rotterdam, The Netherlands).

A demonstration of the software tools will be given at the "Third International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release to Atmosphere from a Nuclear Installation (25 - 30 October 1992, Schloss Elmau, Germany).

Cooperation and coordination with organizations involved in research related to the RADE-AID project has been continued from the previous period and has been extended. In this relation two organizations may be mentioned: the Institut de Protection et de Sûreté Nucléaire (Mr. A. Despres) and the University of Leeds (Mr. S. French). Within the framework of the project TNO has also participated as an observer in the International Chernobyl (IAEA/CEC) project.

Project 2

Head of project: *Dr. Ehrhardt*

Objectives for the reporting period

Work at KfK was more directed towards the applicability of the RADE-AID methodology in decision support systems for nuclear emergencies (see also Contract Bi7-0045). To that purpose the usefulness of an integrated approach combining both knowledge based system methods and multi-attribute decision analysis techniques realized in an expert system was to be investigated for evaluating alternative courses of emergency actions. In addition, ad hoc assistance was to be provided for the RADE-AID development in modelling problems or calculation tasks.

Progress achieved

As part of a computerized real-time decision-aiding system for assisting the emergency management in the case of a nuclear accident, the expert system shell X-ESY has been developed by the Deutsches Forschungszentrum für Künstliche Intelligenz, Kaiserslautern, FRG, under contract with KfK (see Fig. 1).

To develop the structure and content of the rules to be implemented into the system several meetings with German experts involved in decision-making have been organized by KfK. Based on case studies with different release characteristics, countermeasure strategies, environmental situations, and the corresponding spectrum of consequences precalculated with the program package COSYMA, various questions and problems were discussed for pre-release and release conditions, such as:

* principle rules of emergency response,
* relevance of different consequence types and quantities in the decision process (doses and/or health effects, economic impact),
* the availability of technical equipment and manpower,
* the size of areas with sheltering and evacuation and the timing of these actions including the behaviour of the population,
* the role of existing recommendations and emergency plans.

As an essence of these meetings, a fundamental rule structure could be identified. However, the fact that people involved in decision-making have not been confronted till now with the whole spectrum of consequences, they have not yet developed preferences, judgements and weights for balancing the various consequence types. Therefore, with the experience gained during the RADE-AID development, example sets of preference functions and weighting factors have been generated without input from the decision-maker side and integrated in the form of separate routines into the rule structure of the expert system. Thus, a combination of a rule-based system with multi-attribute value theory resulted, which allows to explore the interaction between both methods and their potential application in computerized real-time decision support systems. The expert system builds parts of the comprehensive decision support system presently under development at KfK with support of the Federal Ministry of Environment and the Commission of the European Community, DG XII, under contract Bi7-045.

First steps have been made with respect to investigations on the usefulness of 'fuzzy set theory' as a methodological tool for propagating and quantifying uncertainties in the expert system. Fuzzy set theory is considered as an

adequate method for application in health and environmental impact assessments, and computer tools are now available which facilitate the easy application of such methods including the generation of software. KfK placed a contract with the Ingenieurunternehmen für Umweltanalyse und Forschung GmbH (IUF), Berlin, aiming at the preparation of a feasibility study on the applicability of fuzzy set theory in the expert system mentioned above. Within this contract, the following problems will be treated in cooperation with KfK:

a) Quantification of uncertainties in input data and rule parameters with the help of fuzzy set theory.

b) Propagation of uncertainties through the different transformation steps of the expert system until the final output 'ranking of countermeasure strategies'.

Results of the study will be available at the end of September 1992.

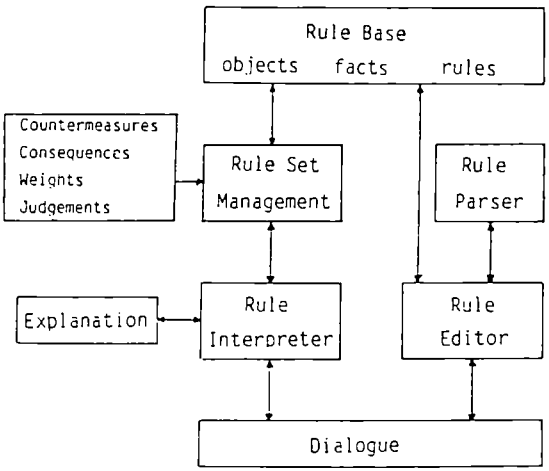


Fig. 1 Structure of the expert system X-ESY

Project 3

Head of project: *Mrs Morrey*

Objectives for the reporting period

Following discussion with the other project participants and the CEC, some of the objectives originally planned for this reporting period were modified. It was agreed that, given the intended use of the database as an exploratory, generic tool, development of datasets specific to a few specific sites was not useful. Instead, a generic database would be produced, with datasets for notional sites which indicated the ranges of consequences that might be expected within the EC.

In addition, detailed analysis of the implications of relocation decisions at a few specific sites would be undertaken.

Continued contact with organisations with applications for the software would also be sought.

Progress achieved

A generic database has been produced and is available for distribution as part of DATARADE. It is described in detail in Annex 2 of this report. A paper, which included discussion of this database, was prepared jointly with TNO for presentation at an international seminar.

Detailed analyses of the consequences of a range of relocation strategies were carried out for four accident scenarios occurring at one site. The health, monetary and social consequences of nineteen relocation strategies were evaluated. Simple cost-benefit analysis was applied to the results in order to provide some perspective on the effectiveness of the different strategies. In addition uncertainty in the economic model and the sensitivity of monetary consequences to likely variations in the cost of the man-Sievert was investigated. These results clearly demonstrate the complexity and competing pressures facing those with responsibility for making decisions on relocation.

Contact initiated during the previous reporting period was maintained at a low level with the UK Nuclear Installations Inspectorate and the Ministry of Agriculture, Fisheries and Food. As a result both of discussions with these, and internal applications of the software, further recommendations for improving the software were passed to TNO.

ANNEX: Description of the database developed as part of DATARADE

The database has been developed for accidents occurring at three notional sites in the UK. In order to obtain meaningful results, notional nuclear sites at real, but unidentified, locations have been used. In this way, realistic variations in population density are taken into account, leading to more realistic estimates of the consequences of relocation decisions. The three sites are representative of a site close to an industrial and highly urbanised area, a site in a remote area, and a predominantly rural site, respectively.

Five releases are considered. These are based on the inventory of the PWR proposed for Hinkley Point[1], and comprise the design basis accident[2], multiples of 10, 100, and 1000 times the design basis accident and a hypothetical release of 1% of the core. These releases are chosen to cover a wide range of accident size and consequence rather than to be representative of the most likely accident scenarios. The releases are detailed in Table A2.1. The actinide component of these releases is small, and since the only significant long term pathway is external dose actinides were omitted from the study.

The direction in which the release occurs may markedly affect the consequences of the accident due, predominantly, to the uneven distribution of the population and land use surrounding a site. There are obviously a large number of potential release directions, and, in order to restrict the database to a manageable and useful size, consequences are calculated for accidental releases assumed to take place with the wind carrying the plume in a limited number of directions only. These are those in which the consequences would be nominally worst, most favourable, and an intermediate, approximately average, case. Although the accident consequence models were run in a number of directions for each site to facilitate selection of the three directions there was, of necessity, a degree of judgement entailed in the choice. Due to the patchy distribution of population downwind the worst direction at one intervention level might not necessarily be worst at another intervention level because of the different areas affected. The assessment of the magnitude of the consequences in any direction was therefore based, for simplicity, upon the size of the populated area affected by an intervention level of averting an external dose of 10 mSv in the first year.

Levels of ground contamination resulting from accidental releases of radioactivity are predicted using a straight line gaussian plume atmospheric dispersion model modified to take account of dry deposition, as recommended by a UK working group[3]. Results are included for Pasquill stability categories B, D and F. A more detailed analysis indicated that these generally give concentrations which cover the median and extremes of the full range of those in dry weather conditions. Precipitation is not included in the database since this would involve the addition of many more variables to the scenario description, with a corresponding increase in the size of the database. In evaluating the results, however, it should be recognised that rainfall would be expected to concentrate ground contamination, potentially leading to a more severe set of consequences than included in the database.

External doses are calculated from the predicted ground contamination using the EXPURT model[4]. This model takes account of different housing types depending on location, the amount of time individuals spend indoors and outdoors, and the reduction of radionuclide contamination with time as a result of rainfall, radioactive decay and other natural processes. Three different environments, urban, semi-urban and rural, are identified in the contaminated area, on the basis of population density, and these are assigned representative building densities, mix of building types and shielding factors. Definitions of the environments are given in Table A2.2. Worker doses are calculated collectively on the basis of the dose rate prior to decontamination and the manhours required to carry out the remedial measures considered (see Table A2.3).

Relocation strategies are assumed to be based on a combination of an intervention level expressed in terms of external dose received in 1 year and a decontamination strategy. Return from relocation is assumed to occur when external doses fall below the relocation dose criterion, although it is recognised that this would not necessarily be the case. The intervention levels included to characterise the likely range of values are averted external doses in one year of 1, 3, 5, 10, 20, 30, & 50 mSv, assuming indoor occupancy of 90%.

The decontamination strategies adopted in conjunction with relocation are no decontamination, and combinations of procedures which would achieve decontamination factors of 2, 5, and 10 in the three environments identified, as described by Robinson et al[5]. Decontamination is assumed to take place over a period of one year, and worker doses are calculated at the dose rate before decontamination, and may thus be overestimated. In order to avoid the assumption that all the sparsely inhabited land surrounding a particular site

would be decontaminated the population of rural areas is treated as living in villages, at a population density of 500 km^{-2}. An area thus derived from the population of the rural region concerned, the 'village', is assumed to be decontaminated, whilst the remaining area is not. Details of the decontamination options are given in Table A2.3.

Calculations of the economic costs of the countermeasures are made using site specific economic parameters where available, otherwise UK average values are adopted[6]. The parameters used in the calculation of the economic costs are given in Table A2.4. The economic consequences of the accident are calculated on the basis of the number of people affected, the area of land affected and the time for which the countermeasure is applied.

A number of consequences (attributes) are calculated:

a) Health factors;
i) collective dose averted by the countermeasure
ii) worker doses arising during decontamination

b) Monetary Cost factors;
iii) direct costs from transport of the relocated population and from any decontamination measures undertaken
iv) indirect costs, lost revenue due to the interdiction of land, depreciation of consumer durables, loss of production, the non-utilised capital value of stock, and non-utilisation of dwellings. Since these costs are manifested over a prolonged period they were discounted at the interest rate used by HM Treasury to represent the real rate of return on Government investment[6,7].

c) Social factors; stress and disruption are very difficult to quantify and so directly quantifiable factors were included in the database as indirect measures of the response of the population to allow the user to interpret as he wishes.
v) number of people initially relocated
vi) area of land affected
vii) maximum time for which people would be kept away from their homes
viii) maximum time land interdicted

Database Structure

The database has been developed to be as flexible as possible, allowing the user to insert his own information if required. The format chosen is a set of discrete ASCII files, each containing the information relating to a unique combination of site, release, wind direction and atmospheric conditions, or a scenario. The files are organised in directories, each containing those relating to a specific site. A naming convention is used such that the scenario to which a file is dedicated is indicated by the filename. This simple, open, structure facilitates the insertion of information concerning further scenarios at a later date, since all that is required is the creation of a new file.

Each file contains:

(i) elements describing the scenario under consideration.
(ii) a set of alternative countermeasure options for that scenario.
(iii) the set of attributes for which consequences have been calculated.
(iv) the scores of each option on each attribute.

A primary consideration in deciding on the file format was that it should be made as clear as possible to any potential user who might wish to edit it how to introduce scenario specific data. Thus the files were written containing sufficient information that their construction would be self-explanatory, leaving the user in no doubt as to how to edit the file, rather than in the most convenient format for being read by the main program. In addition, because each file defines the attributes and options within it, the user may specify any form or number of these which is considered relevant to the problem.

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Table A2.1

Releases used in the Database

Release A - the design basis accident
Release B - 10 x the design basis accident
Release C - 100 x the design basis accident
Release D - 1000 x the design basis accident
Release E - 1% of core

	RELEASE INVENTORY (BQ)						
RELEASE	CS-137	CS-134	I-131	BA-140	TE-132	RU-106	RU-103
A	1.44E11	2.44E11	1.81E12	2.66E9	2.03E11	8.88E7	3.44E8
B	1.44E12	2.44E12	1.81E13	2.66E10	2.03E12	8.88E8	3.44E9
C	1.44E13	2.44E13	1.81E14	2.66E11	2.03E13	8.88E9	3.44E10
D	1.44E14	2.44E14	1.81E15	2.66E12	2.03E14	8.88E10	3.44E11
E	2.29E17	3.85E15	3.39E16	6.14E16	4.85E16	1.30E16	5.25E16

Table A2.2

Definition of Rural, Semi-Urban and Urban Environments

ENVIRONMENT CATEGORY	POPULATION DENSITY	BUILDING COVERAGE (%)[1]	BUILDING TYPE (%)[2]		
			LIGHT	MEDIUM	HIGH
RURAL	<1000 km^{-2}	25	0.35	0.65	0.00
SEMI-URBAN	1000 - 5000 km^{-2}	40	0.05	0.85	0.10
URBAN	>5000 km^{-2}	55	0.00	0.15	0.85

Notes
1. Building coverage in the area the population is likely to be exposed
2. Shielding factors for the three building categories were calculated according to the methodology described in reference 8, and are 0.18, 0.04, and 0.0007 for the three building types respectively

Table A2.3

Decontamination Procedures and Resources

	Dose Reduction Factor	Cost £ km^{-2}	Rate man days km^{-2}
RURAL AREAS;			
Ploughing, scrubbing and scraping	2	$4.0\ 10^{5}$	$5.1\ 10^{3}$
Removal of 1 cm of soil, sandblasting	5	$9.0\ 10^{6}$	$7.1\ 10^{3}$
Removal of 5 cm of soil, sandblast and replace roofs	10	$1.0\ 10^{7}$	$2.6\ 10^{4}$
SEMI-URBAN AREAS;			
Ploughing scrubbing and scraping	2	$5.0\ 10^{5}$	$8.0\ 10^{3}$
Removal of 1 cm of soil, scrub, scrape and road planing	5	$3.0\ 10^{6}$	$8.2\ 10^{3}$
Removal of 5 cm of soil sandblast and roof replacement	10	$1.0\ 10^{7}$	$4.2\ 10^{4}$
URBAN AREAS;			
Scrub and scrape	2	$6.0\ 10^{5}$	$9.9\ 10^{3}$
Road plane and sandblast	5	$6.0\ 10^{6}$	$1.5\ 10^{4}$
Sandblast and roof replacement	10	$2.0\ 10^{7}$	$5.7\ 10^{4}$

Note
1. Robinson CA, Private communication

Table A2.4

Parameter Values for Economic Costs

CTP	Cost of evacuation transport (per person)
DWELP	Value of dwelling (per person)
CVSP	Capital value of stock (per person)
CDURP	Value of consumer durables (per person)
VLAND	Value of land (per km^2)
PRODLP	Production loss (per person a^{-1})
SDEPR	Stock depreciation rate (per annum)
RIR	Real interest rate (per annum)
DURDEPR	Durable depreciation rate (per annum)
DWELDEPR	Dwelling depreciation rate (per annum)

	URBAN SITE	RURAL SITE	REMOTE SITE
CTP	£3.00	£3.00	£3.00
DWELP	£11118	£17410	£11917
CVSP	£9500	£9200	£8600
CDURP	£1708	£1500	£1151
VLAND	£300,000	£300,000	£300,000
PRODLP	£5389	£6047	£4991
SDEPR	0.06	0.06	0.06
RIR	0.05	0.05	0.05
DURDEPR	0.1	0.1	0.1
DWELDEPR	0.02	0.02	0.02

INDOOR DEPOSITION AND RELATIONSHIP BETWEEN INDOOR AND OUTDOOR AIR CONCENTRATION

Contract Bi7-015 - Sector C24

1) *Roed*, Risø National Laboratory - 2) *Goddard*, ICSTM

Summary of project global objectives and achievements

Introduction

In order to assess the effect of staying indoors during an air pollution episode, including that caused by a nuclear accident, it is essential to quantify the deposition of pollutant matter on indoor surfaces, as well as the resulting reduction in inhalation dose.

Full-scale investigations of house filtration and indoor deposition have so far used polluted air from the Chernobyl case. A technique using labelled monodisperse silica particles have enabled full scale measurements of indoor deposition to be made with monodisperse particles in the range of interest for accidental releases and so give improved data for modelling purposes.

Protective measures that may be taken by the householder are relevant to seeking optimal strategy in protecting the individual. In relation to aerosol, one decontamination method, that will be investigated, is the use of vacuum cleaner as a tool for cleaning indoor air.

Global objectives

- to examine - and improve if necessary - the techniques for estimating the reduction of inhalation dose by staying indoors and the deposition on indoor surfaces.
- to examine the influence of the surface type, for instance the importance of furniture on the deposition process.
- to consider the range of measures that may be taken to alleviate indoor exposure and particular to examine a vacuum cleaner as a tool for reduction of the indoor air pollution.
- to thereby improve models for generic and risk assessment purposes in radiation protection.

Achievements

1. Indoor deposition measurements

Risø and Imperial College have in collaboration developed a method for dispersing monodisperse silica particles and collecting them on filter paper. The filter papers are then analyzed be neutron activation and the deposition constant has been determined for different rooms. Experiments have been performed in houses both at Risø and in England determining the deposition constant for various rooms with 2 and 4 micron particles.

Table 1. Deposition constant for room with and without furniture.

	Particle size	Deposition constant	Mean deposition velocity
Unfurnished	2 μm	0.84 h^{-1}	0.015 $cm \cdot s^{-1}$
-	4 μm	1.51 h^{-1}	0.027 $cm \cdot s^{-1}$
Furnished	2 μm	0.95 h^{-1}	0.017 $cm \cdot s^{-1}$
-	4 μm	2.10 h^{-1}	0.038 $cm \cdot s^{-1}$

As can be seen from Table 1, the deposition velocity is lower for the smaller particles than for the larger particles. It can also be seen that furnishing the room increases the mean deposition velocity; this is in good agreement with earlier findings.

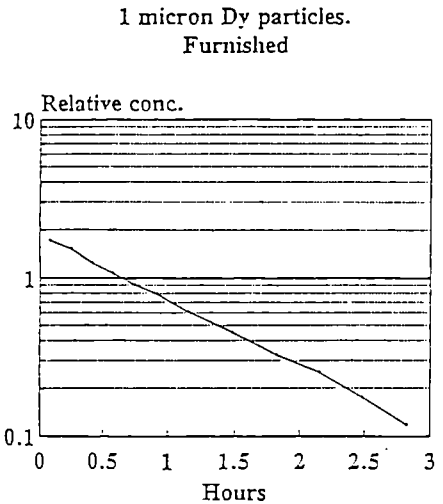

Fig. 1 Decay curve for dispersed silica particles

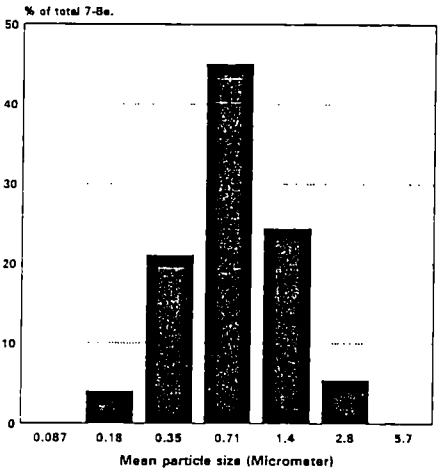

Fig 2. Size distribution of Be-7 in atmospheric air.

Taking into account the different particle sizes concerned, results for deposition velocity are broadly consistent with earlier measurements (1),(2), which indicate indoor deposition velocities of about 0.006 cms $^{-1}$ for volatiles attached to aerosols, about 0.07 cms^{-1} for refractory elements and 0.0011 $cm-s^{-1}$ (unfurnished) and 0.0021 cms^{-1} (furnished) for natural aerosol labelled with cosmogenic Beryllium-7.

2. Size distribution of Be-7

All atmospheric air contains Be-7 marked particles. Beryllium-7 is radioactive with a halflife of 51 days and is created in the stratosphere by spallation. To examine whetner these particles are suitable as tracers a cascade impactor

was run for 40 days. The filter from each stage was counted on a Li-detector and the result showed a nice log-normal distribution as shown in fig 2.

From a lognormal plot it follows that the Be-7 marked particles have a AMAD of 0.74 μm, which corresponds to the smaller of the two size groups measured after Chernobyl by Reineking et. al (3). They found that most of the isotopes had a AMAD in the range from 0.5 micron to 1 micron, apart from hot particles. Size distribution of aerosols from the Chernobyl accident has also been measured by P Rulik et. al. (4). They found an AMAD size of 0.4 μm for the volatile group containing particulate I, Cs and Ru. For the refractory group Ba, Ce and Zr and AMAD size of 1.2 μm has been measured. Typical filters have their minimum efficiency for particle sizes from o.1 μm to 1 μm (5). The filter efficiency for the refractory particles is therefore expected to be larger. For larger and smaller particles houses have a better filter capacity and a higher deposition rate, making the Be-7 marked particles a 'worst case' tracer, e.g. a particle with the highest penetration and lowest deposition when inside the house.

The Be-7 marked particles is therefore a well suited tracer simulating airborne particulate pollution.

3. Vacuum cleaner test

A typical householder has at his or her disposal an air cleaning device which may be capable of filtering airborne particles down to 0.2 micron, and which has a flow rate comparable to typical air exchange rates namely a domestic vacuum cleaner. The use of a vacuum cleaner as an indoor filtering device for protection against particulate air pollution originating from the outside has been investigated. The filter efficiency of four different vacuum cleaner has been determined.

The results were very constant, showing a marked increase when using a used bag. The mean value of the filter efficiency was found to be 81% for a new bag and 95% for a bag used once or twice. In the calculations on the overall effect of a vacuum cleaner we used a value of 0.83 for the filter efficiency in order to give a conservative estimation of the effect of using a vacuum cleaner.

4. Modelling

A model has been employed in this work as an aid in understanding experimentally observed aerosol behaviour. Described in detail in the Imperial College section of this report, the model predicts the indoor concentration of a contaminant aerosol of outdoor origin by using information about the rates

Table 2. Protection afforded when staying indoors.

Particle size (microns)	Air exchange rate (h^{-1})	Protection factor	Protection factor w. VC
2	0.2	0.20	0.08
2	1.0	0.54	0.29
2	2.0	0.70	0.46
4	0.2	0.12	0.06
4	1.0	0.39	0.23
4	2.0	0.57	0.39

at which various aerosol transfer processes transport particles to and from the building in question. The protection factor for that building(i.e. the ratio of the contaminant in the room to the outdoor concentration) is thus estimated.

Using experimentally determined aerosol deposition rates(see table. 1), the model has been used to predict the protection factor for a single room against particles of two sizes, for a ranges of room air exchanges rates. The results are given in Table 2.

Computational work has also been carried out to predict the additional protection afforded by running a vacuum cleaner in the occupied room. The equation for additional dose reduction when operating a vacuum cleaner is:

$$\frac{C_v}{C_i} = \frac{\lambda_r + \lambda_d}{\lambda_r + \lambda_d + \epsilon \frac{F}{V}} \qquad (1)$$

Where C_i is the aerosol concentration without using a vacuum cleaner and C_v with a running vacuum cleaner, ϵ is filter efficiency, F the flow rate of the vacuum cleaner, $_r$ is the air exchange-rate, V is the volume of the occupied room and $_d$ is the deposition constant. The last row of Table 2 gives the protection factor when operating a vacuum cleaner.

5. Conclusion

The two institutions have in collaboration developed an effective method for measuring aerosol deposition in real houses. This is a foundation for estimating the protective value of houses against radioactive particulates, which should be improved in future work at both Imperial College and Risoe. Modelling shows the important influence of the air exchange rate. Knowledge of typical exchange rates will be necessary, when estimating the protective value of the houses. Future work should also examine smaller particles, in the size range found after Chernobyl. The influence of indoor airflow patterns on deposition also merits investigation.

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Project 1

Head of project: *Dr. Roed*

Objectives for the reporting period

- To develop a method for dispersing monodisperse silica particles, collect it and analyze it, thus measuring deposition constants.

- To perform large scale experiments in a real house using this method combined with a chromatographic method for measuring the air exchange rate using SF_6 as tracer, and by combining the two measurements to find the indoor deposition in the house for two different particle sizes.

- in a test house using cosmogenic ^{7}Be-particulate as tracer to find indoor/outdoor air concentration and by varying the air exchange rate to find the filtering factor and the deposition constant.

- To investigate vacuum cleaners as a tool for reduction of indoor pollution and to test their performance under real conditions in a building.

Progress achieved including publications

1. Deposition experiments with monodisperse silica particles

In collaboration with visiting scientists from Imperial College an experimental technique was developed. In the first year of the project two full scale series of experiments were performed in the living room at 'Risø-huse 27', RH27.

The air exchange rate was measured using SF_6 as a tracer gas and its decay was monitored by chromatography. RH27 appeared to be a very tight construction with a maximum air exchange rate during our experiments below 0.05 h^{-1}. The decay caused by air exchange was thus of minor importance.

The dysprosium marked silica particles were dispersed from a Palas RBG 1000 powder disperser. To insure a uniform distribution of particles within the room a small fan was used during all the tests.

In the first experiment we dispersed 5 μm particles and collected them on Whatman 42 filter paper: 15 cm$^{\circ}$. The size of the paper was determined by the pumps ability to draw air through the filter. The filter samples were activated in Risøs research reactor and analyzed by gamma spectroscopy using a Germanium detector and a multi-channel analyzer. The result showed an unacceptable high background radiation caused by the sodium content of the filter paper.

In order to lower the background it was decided to used double punch pumps with a very rigid characteristics in future tests, to enable us to suck the same amount of air through a smaller filter paper . By activating a number of filters we found that Whatman 542 had the lowest background. This type of filter paper was used for the next tests.

Our second experiment was a great success we introduced the changes based on our experience from the first test. These results are presented in Table 2, section I of this report.

2. Deposition of cosmogenic Be-7 in house

In order to find the deposition velocity and filter factor for Be-7 marked particles indoor in a real house, we measured the reduction in Be-7 concentration indoors under three different conditions: (1) ducting air into the house creating an overpressure, (2) normal air exchange and (3) ducting air out of the house. In the first case the air is ducted directly into the house, so the reduction in Be-7 concentration is caused solely by deposition. In the next two tests both filtration and deposition plays a role. Using the deposition constant for the house found in the first test the filter factor can be calculated using data from the second and third test.

The air exchange in Vellerup was very, 0.25 - 1.5 h^{-1}, depending on wind speed and direction. This lead to a high uncertainty on our calculations of the deposition constant and the filter factor.

The results is shown in Table 1. The reduction in Be-7 concentration indoor is 0.8 both when ducting air into the house and when sucking air out of the house. This confirms the result found by Roed and Cannel[1] in 1986, that the filter factor is close to one.

Table 1. Levels of Be-7 in indoor air compared to outdoor.

Relationship when ducting air into the house.	Relationship when no ducting	Relationship when sucking air out of the house.
0.77	0.84	0.82
0.83	0.71	0.78
Avg: 0.80	Avg: 0.78	Avg: 0.80

3. Test of vacuum cleaners as an air cleaning device

A typical householder has at his or her disposal an air cleaning device which may be capable of filtering airborne particles down to 0.2 micron, and which has a flow rate comparable to typical air exchange rates namely a domestic vacuum cleaner. The use of a vacuum cleaner as indoor filtering device for protection against particulate air pollution originating from the outside has been investigated. The filter efficiency of four different vacuum cleaner has been determined and outdoor/indoor air transport model has been used to estimate the dose reduction factor for a vacuum cleaner.

The important step when estimating the usefulness of vacuum cleaners, is to determine their filter efficiency for small particles. Beryllium-7 was used as a tracer because of its suitable size distribution. The concentration of beryllium-7 in the air was measured before and after passing the vacuum cleaner. Each vacuum cleaner was placed in a barrel to screen the outlet air from the inlet air. A filter was placed in front of the outlet with an air flow half that of the vacuum cleaners. Unfiltered air samples were collected for reference purposes. All the vacuum cleaners tested had an outlet filter for absorbing the small particles. The four different vacuum cleaners were tested first for a three week period using new bags and then for three more weeks using bags, which had been used for a weekend cleaning at our homes. The vacuum cleaners were operated at maximum speed which was 60 m^3h^{-1}.

The results are very homogeneous, showing a markedly increase when using a used bag. The mean value of the filter efficiency was found to be 81% for a new bag and 95% for an used bag. In the calculations of the overall effect of a vacuum cleaner we

Table 2. Filter efficiency in % for four different vacuum cleaners.

Bag condition	New	New	New	Used	Used	Used
Brand \ Date	4/2	10/2	14/4	9/3	16/3	23/3
Electrolux	73	78	70	92	92	97
AEG Vampyr	82	82	62*	96	96	94
Hoover	87	87	69	92	95	100**
Nilfisk	85	90	87	94	94	97

*The AEG Vampyr broke down halfway, so this result is unreliable.
**Below detection limit.

used a value of 0.83 for the filter efficiency in order to give a conservative estimation of the effect of using a vacuum cleaner.

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Project 2

Head of project: *Prof. Goddard*

Objectives for the reporting period

-to obtain samples of monodisperse silica particles in the 1-10 micron size range and to use Imperial College facilities to confirm a technique by which those particles could be labelled with a neutron-activatable tracer.

-to carry out a size-analysis of the particles using the Imperial College APS analyser.

-to collaborate with Riso in carrying out full-scale indoor aerosol deposition experiments, using tracer-labelled surrogate aerosol.

-to develop models which could take into account the differences in behaviour between particles in the 1-10 micron size range

Progress achieved including publications

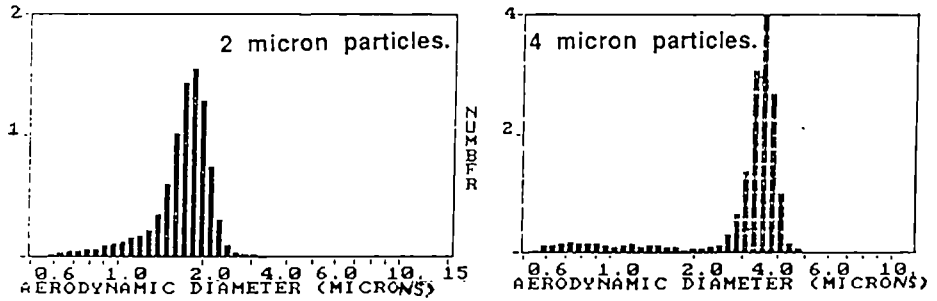
1. Aerosol generation and labelling

An effective particle labelling, dispersion and detection technique has been developed in collaboration with the Imperial College Centre for Analytical Research in the Environment. Silica particles are supplied by *Phase Separations Ltd.* in a variety of monodisperse size distributions. The particles are highly porous since they are manufactured for chromatographic purposes. By agitating the particles in a solution of a suitable tracer, tracer ions become bound to the particles' surfaces in a uniform manner. Typical labelling yields are of the order of 5 milligrams of tracer per gram of silica; there is a 100% improvement in labelling yield if the silica particles are pre-heated to expand their pores.

Neutron activatable tracers are used in this work; both Imperial College and Riso have nuclear reactor and gamma spectrometric facilities. Dysprosium-164 is the tracer used. Dysprosium has many advantages for use as an aerosol label; it has a very low natural background and a high activation sensitivity. Dysprosium-165m (metastable, half-life 1.26 minutes) and Dy-165 (half-life 2.3 hours) are the activation peaks analysed. The lowest detection limit of Dysprosium observed is 100 pg on filter paper.

The labelled particles are dispersed using a *Palas* RBG-1000 powder dispersion generator. Aerosolisation results when a rotating brush sweeps powder from a reservoir at a fixed rate, after which it is carried by an regulated airstream to the required site. In order to equilibrate charges which might build up on the particles during the aerosolisation process, a 75 MBq Kr-85 beta source is positioned at the generator's outlet.

In the experiments carried out to date, monodisperse particles of two sizes have been used; 2 micron and 4 micron AMAD. Figures 1 and 2 show the particle size distributions, as measured by a TSI Model 3310 Aerodynamic Particle Sizer.



Figures 1 & 2. Particle size data for 2 and 4 micron particles, respectively

2. Indoor deposition measurements

As discussed in the Riso contribution to this report, a technique for measuring indoor aerosol deposition rates using surrogate aerosol has been developed in collaboration between the two institutions and a series of experiments have been carried out in a Danish dwelling. This collaboration involved the participation of an Imperial College research assistant and the provision of labelled particles and aerosol-generating equipment by Imperial College. More recently, Imperial College has arranged the use of a test house at the Building Research Establishment's Garston site and a further series of deposition experiments were carried out

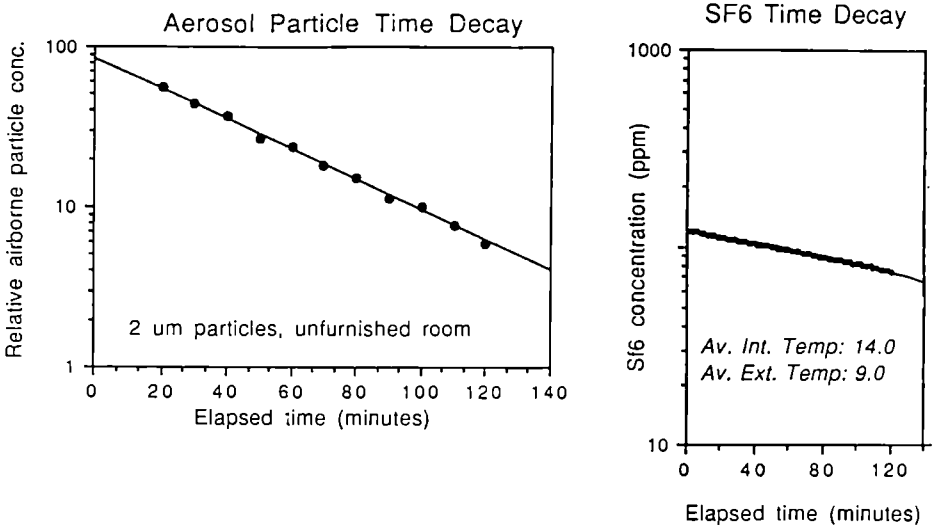


Figure 3 & 4. Time decay curves for 2 micron aerosol particles and SF_6 tracer gas, respectively, in an unfurnished room. The total decay rate constant, calculated from the aerosol time decay curve, is 1.23 per hour. The air exchange rate constant, calculated from the SF_6 decay curve, is 0.25 per hour. By subtraction, the rate constant for particle deposition is 0.98 per hour.

in this house. A research assistant from Riso, took part in these tests. Experiments were conducted in the living room and a small bedroom of the instrumented terraced house. Air exchange rates were determined from tracer gas monitoring while hot film anemometers were used to measure air velocity fluctuations. Meteorological data for the experimental period was collected.

A large number of experiments were carried out in this series; the tests in furnished and unfurnished rooms with two particle sizes, previously carried out at Riso, were repeated. The deposition results were consistent with the Riso findings and again, the enhancing effect of furnishings on aerosol deposition velocity was observed. A number of preliminary investigations were also carried out in this series with a view to examining the influence of various domestic features, such as enhanced human activity and enhanced air circulation, on aerosol deposition rates. The information provided by these investigations will be instructive for future experimental design. Figures 3 and 4 show the data obtained during an aerosol deposition measurement in an unfurnished room, using 2 micron particles.

3. Modelling

Imperial College has developed a model aimed at determining the degree of protection afforded by a building against a cloud of radioactive particles. The model, described in more detail by Roed and Goddard (1), is of the "compartment" type, where the building in question and each of the associated sources (such as the outdoor air which enters the building by infiltration) and sinks (such as the building surfaces on which particles are deposited, reducing the inhaled dose) of aerosol are represented by a compartment. The aerosol concentration in each compartment is assumed to be uniform and transfers between the compartments are determined by rate coefficients; using experimentally-determined aerosol deposition rates, the model thus takes into account the differences in behaviour between particles in the 1-10 um range. Figure 5 shows a compartment model which incorporates several aerosol transport processes.

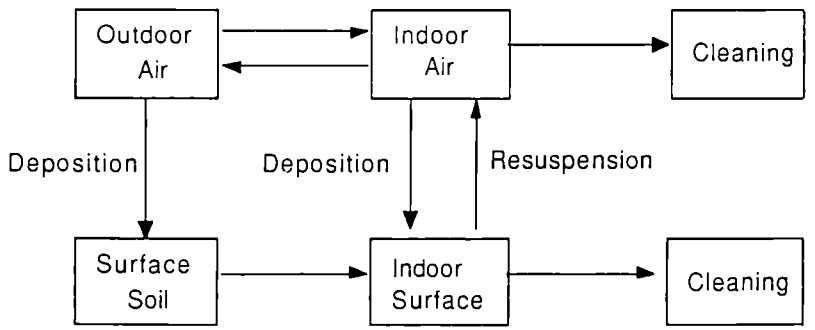
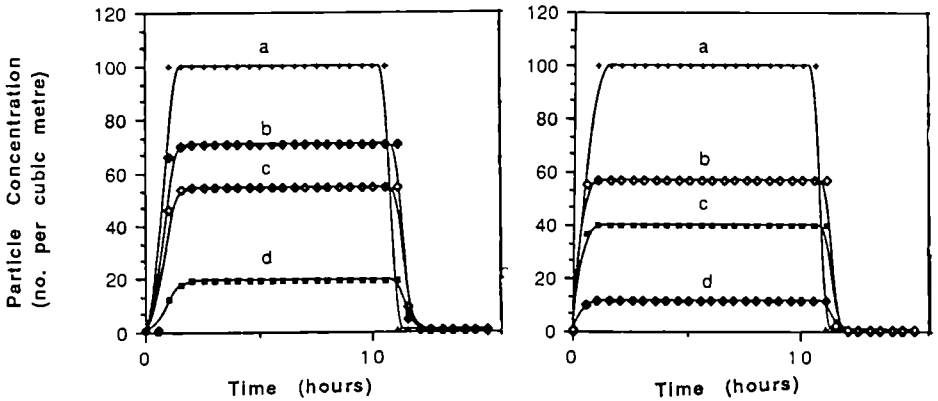


Figure 5. Multi-compartment model

Sensitivity calculations have been carried out to determine the relative importance of the various aerosol transfer processes, in particular , the building's air exchange rate (AER) and the aerosol deposition rate. The calculations show that, at high air exchange rates, the role of deposition in reducing inhalation dose is limited, whereas, at low air exchange rates,the role of deposition becomes dominant and the outdoor indoor concentration ratio can be significantly reduced.

The simplest situation which can be modelled is the case of a single room. Using

experimentally-determined aerosol deposition data, Figures 6 and 7 demonstrate the influence of air exchange rate on the degree of protection against inhalation dose afforded by a single-room building, as predicted by the model. The predicted protection factors are given in the combined section of this report. It should be noted that these significant protection factors are achieved through the deposition process alone; in practise they would need to be combined with the influence of building fabric filtration. Should an aerosol be gamma emitting, the influence upon direct gamma dose of indoor deposition would also need to be taken into account.



Figures 6 & 7. Predicted indoor particle concentrations in a single room for a step change in outdoor concentration for 2 micron (deposition rate constant = 0.84 /hr) and 4 micron particles (deposition rate constant = 1.51 /hr) ,respectively. Curve (a) shows the external concentration and curves (b), (c), and (d) show the internal concentration for air exchange rates of 2.0 per hour, 1.0 per hour and 0.2 per hour, respectively.

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VALIDATION-TRAINING AND UNCERTAINTY-STUDY EXPERIMENTS FOR REAL-TIME ATMOSPHERIC DISPERSION MODELS

Contract Bi7-017 - Sector C24

1) *Mikkelsen* , Risø National Laboratory - 2) *Werner*, Deutsche Forsch.anst.Luft Raumfart

Summary of project global objectives and achievements

Objectives

The objective of the project is to quantify the inherent and irreducible uncertainties influencing atmospheric dispersion assessment in the event of an nuclear accidental release, due to the random and stochastic variability that is always inherent in atmospheric turbulence.

This inherent and irreducible uncertainty arises from unmeasured or unresolved details about the atmospheric flow and leads, even under outer identical meteorological conditions, to random fluctuations in the concentration pattern from one diffusion scenario to another.

In modelling atmospheric dispersion scenarios where these random fluctuations are large, the mean concentration by itself is inadequate for risk assessment and decision making.

The natural fluctuations in concentration fields have consequently been studied through extensive and detailed experimental investigations of meandering and fluctuating plume behavior from full-scale near-range dispersion experiments.

Based on Lidar techniques for remote determination of the instantaneous plume concentration profiles, smoke diffusion experiments have been conducted over a variety of terrain types, and for a variety of different atmospheric conditions and source types - including, whenever possible, events during time-changing meteorology.

The resulting data base: "Reference and Validation Data Sets" contains both the detailed meteorology and the high-resolution, sequential concentration profile measurements obtained from the experiments listed in Table 1 below.

The data set are available for inclusion in RODOS, the joint-CEC real-time on-line decision support system, as a tool for hands-on emergency training and evaluation of local scale real-time dispersion models, Santabarbara (1992); Jørgensen, Santabarbara and Mikkelsen (1993).

Achievements

Table 1: List of conducted full scale dispersion experiments

Year	Location		Type of release	Terrain
86	Meppen	(D)	ground	Flat-homogeneous
88	Meppen	(D)	ground	Flat-homogeneous
89	Meppen	(D)	ground	Flat-homogeneous
90	Guardo	(E)	ground/elevated	Complex/Mount.
91	Ravlunda	(S)	elevated/puffs	Flat-homogeneous
92	Borris	(DK)	elevated/cont.	Flat-homogeneous
92	Porton	(UK)	ground/elevated puff/cont.	Non-Uniform

Real-time sequential data of plume dispersion, in the form of "movies" of instantaneous concentration profiles - measured at 3 second intervals - provides the raw-data on which the above diffusion data sets are constructed.

Each experiment is characterized by important statistical quantities such as mean- and mean-square concentration profiles of the horizontal or vertical plume spread, in addition to intermittency and concentration probability density functions.

Extensive meteorological mean and turbulence measurements are simultaneously recorded and analyzed for individual experiment in order to provide input-data for dispersion models to be used for simulation.

The Meppen '86, '88 and '89 data sets (Table 1) were already established during the previous Radiation Protection programme (1988-89). They consists of 29 multi-hour long lasting plume diffusion experiments, including surface and upper air meteorology, aerosol size distributions and aerial and ground level video recordings and photography. The data set has meanwhile been analyzed extensively: Mikkelsen (1990); Mikkelsen, Jørgensen and Thykier-Nielsen (1990); Mikkelsen, Jørgensen, Aufm Kampe, Weber and Borrmann (1990); Mikkelsen et al. (1991); Jørgensen and Mikkelsen (1993).

As to the data sets gathered under the present contract (Guardo, Ravlunda, Borris and Porton), participation and subsequent analysis and modelling of the complex terrain Guardo diffusion experiment is by far the most comprehensive, Ibarra (1991), Jørgensen and Mikkelsen (1992); Nielsen and Mikkelsen (1992).

The Guardo experiments were carried out as a joint research program with the Spanish Electricity Board (Project PIE-134.036) as an intensive 30 days field tracer study at and around the Guardo steam plant site in the Carrion river valley in Palencia (Northern Spain), Nov-Dec. 1990.

A total of 16 Lidar experiments of aerosol concentrations were here obtained from both the coal fired power plant stack emissions and of from artificial ground releases of smoke generated in the surrounding valleys, Jørgensen and Mikkelsen (1992).

Also, a total collection of fourteen 2-hour lasting meso-scale tracer-gas experiments using SO2/SF6 were conducted simultaneously and the results were found suitable for meteorological wind data analysis and model evaluation, see Nielsen and Mikkelsen (1992); Thykier-Nielsen et al. (1993).

The Guardo diffusion data set including the measured meteorology have meanwhile been transferred to the OECD/NEA Data Bank for general availability.

The swedish Ravlunda 1991 experiments consisted of both ground level and elevated (10 meter high) puff releases, which were tracked by lidar, in some cases out to several kilometers downwind.

The danish Borris'92 experiments were conducted as elevated (25 meter high) continuous releases over flat terrain. Five daytime and one nighttime reference experiments were obtained during a one week campaign in July, and lidar-measured plume statistics have been obtained at various downwind measurement points out to 1 km from the source point. Of particular interest from this data set is the "exeedance and duration" measurements of high ground-level concentrations. Also these experiment were accompanied by simultaneous conducted tracer-gas diffusion experiments (SF6) for mean-value determination and inter-calibration purposes.

The last experiment conducted under the present contract was the 3-week lasting MADONA (Meteorology And Diffusion Over Non-uniform Area) trials at Porton Down, UK. Here both ground and elevated puffs, tracer gas and ground level continuous smoke were released and measured by several Lidar systems, including both the Risø's and DLR's mini-Lidar systems (see DLR's contribution). With the Porton Down area being characterized by rolling and non-uniform terrain, extensive meteorological instrumentation (14 ten-meter high met towers, in addition to our 2 on-line sonic anemometers) were recorded around the clock. Interesting non-stationary dispersion scenarios were here encountered during transition zones and best visualized by the "S" real-time graphics display programme, a newly developed generic tool for fast sequential presentations (movie) of 2-D fields of scalars (concentrations) and vectors (winds), see Santabarbara, (1992) and Jørgensen et al., (1993).

Extensive data reduction and preparation is still needed before the MADONA trials will be finally analyzed.

Conclusions

Using lidars, we have for a variety of different atmospheric wind regimes, stability conditions and source configurations, obtained detailed "movies" of fluctuating plume dispersion measured with high spatial (1.5 m) and temporal (3-5 sec) resolution.

Statistics have subsequently been obtained of the mean and variance profiles, in addition to intermittency factors and entire probability density functions of the concentrations.

The resulting "Reference and Validation Data Sets" data base (Jørgensen et al., 1993) provides the Radiation Protection Programme with a series of near-site reference dispersion experiments in which the level of naturally occurring fluctuations in plume concentrations have been revealed. In addition, the data set establishes a reference for inter-comparison and evaluation of near-site atmospheric dispersion models, Mikkelsen and Desiato, (1993).

Project 1

Head of project: *Dr. Torben Mikkelsen*

Objectives for the reporting period

Analysis and publication of the Meppen experiments.
Conduction and analysis of the Guardo experiment.
Performing new diffusion experiments with puffs and continuous releases from elevated sources.
Data processing, quality assurance and corrections.
Add to the "uncertainty-knowledge and training data base" based on previous (flat terrain) and new (complex terrain) diffusion experiments.
Construction and testing of a new and improved mini-LIDAR system suitable for two-dimensional plume scanning and for plume measurements at longer ranges.

Progress achieved including publications

1. Introduction

With technological support and assistance from the German cooperators at DLR, we have in the reporting period participated in four full scale aerosol-plume dispersion experimental campaigns. They are:

I. Atmospheric dispersion experiments over complex terrain in a Spanish valley site (Guardo power plant, Nov.-Dec 1990, Palencia, Spain).

II. Elevated puff diffusion experiment over flat terrain (Ravlunda field test site, March 1991, Sweden).

III. Elevated (25 meter) continuous smoke release experiments over flat terrain at the Borris Moors in western Jutland, Denmark.

IV. MADONA (Meteorology And Diffusion Over Non-uniform Area) trials at the rolling and non-uniform terrain of Porton Down, UK. Sep 1992. Both ground and elevated puffs, tracer gas and ground level continuous smoke were released and measured by several Lidar systems, including both the Risø's and DLR's mini-Lidar systems.

The mini-LIDAR systems were the key instruments during these experiments, both for fast and high-resolution in-plume fluctuation measurements, and also for measuring the larger scale meander in the dispersion sceneries:

Real-time sequential data of plume dispersion, in the form of "movies" of instantaneous concentration profiles, were recorded for the compilation of a realistic diffusion data base. Subsequently, we establish plume-profile statistics of important statistical quantities such as

mean- and mean-square concentration profiles of the horizontal and vertical plume spread, in addition to the entire concentration probability functions (pdf's) at a variety of locations during each experiment.

Extensive meteorological mean- and turbulence measurements were simultaneously taken during each experiment in order to provide extensive input-data for the dispersion models to be evaluated and used for simulations, Jørgensen et al., (1993).

2. Atmospheric dispersion experiments over complex terrain in a Spanish valley site (Guardo power plant, Oct., Nov., Dec. 1990, Palencia, Spain)

An intensive experimental campaign, co-sponsored by the spanish companies of electricity, and organized by Iberdrola, Madrid (Project PIE-134.036) was conducted in the fall of 1990 with Risø participation in order to quantify atmospheric dispersion within a deep and steep valley located amid rough, mountainous terrain located in the southern foothills of Picos de Europa. The project was launched in the summer 1990 with the common goal to validate existing plume models and to provide an scientific basis for future model developments.

During the Guardo experiments the atmospheric transport and diffusion processes were studied over a 40 km by 40 km domain with emphasis on:

1) Evaluate smoke and continuous SO_2 and SF_6 emissions from a 185 meter tall power plant chimney,
2) Study dispersion from a ground level source located on a valley floor surrounded by complex terrain.

The five week experimental campaign resulted in a total of 14 successful tracer-gas experiments, and 16 local-scale diffusion experiments using artificially generated smoke that could be measured by our mini-lidar system, Jørgensen and Mikkelsen (1992).

The lidar experiments were supported by detailed meteorological mean flow and turbulence measurements based on a 25-meter high meteorological tower equipped with cups, wind-vanes, thermometers and a sonic anemometer, Nielsen and Mikkelsen (1992). We also contributed with measurements of the upper surface layer structure with profiles taken from a tethered balloon. Other participating experimental groups provided mean-flow measurements from a network of 10-meter towers distributed over the 40 km x 40 km terrain in addition to radio-sonde and SODAR-measurements, Ibarra (1991).

Our findings show that flow and dispersion in complex terrain is indeed very "site specific". The lidar experiments showed that the characteristic diurnal flow reversals significantly influenced the local dispersion climatology.

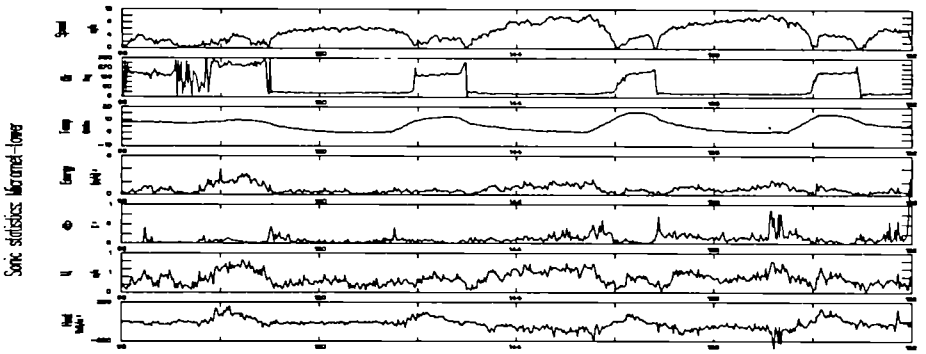

Figure 1 Four days of repetitive diurnal flow reversal in the valley.

Figure 1 shows the local flow and turbulence characteristics from the four day period (Nov. 5. through Nov. 8) as measured from our 25 meter meteorological tower located on the valley-floor in the upper end of the North-South oriented valley. The valley, 300 meter wide is here surrounded by high topography on both sides.

The three first traces show the 10-min mean wind speed, the mean wind direction, and the temperature. All do they exhibit a strong diurnal variation with strong (8-10 m/s) nocturnal drainage flow running down the valley (from north) and lasting till almost noon, then followed by a 5-6 hr period of much lighter up-valley (southerly) breeze. In the evening about 1800, the wind again returns to nocturnal drainage, ie., persisting strong local winds for the next approx. 18 hours. The remaining four traces show the corresponding measurements of turbulent kinetic energy (turbulence), the temperature variance, the friction velocity and the heatflux.

Fig. 2 below shows a "data versus model" inter-comparison based on the Guardo smoke experiment No. 14. This experiment was conducted on the flat valley floor amid strong morning drainage flow near the 25 meter meteorological mast.

At the 3000 second time mark into the experiment, corresponding to 1000 lidar shots, the figure compares the cross wind concentration profiles as measured (lidar) and simulated (Rimpuff) on a crosswind line 200 meters downwind of the ground level emission point.

Fig. 2 compares measured and modelled: a) instantaneous, b) mean, c) Root-mean-square, and d) intensity profiles of cross wind concentrations. Further details can be found in Jørgensen et al. (1993).

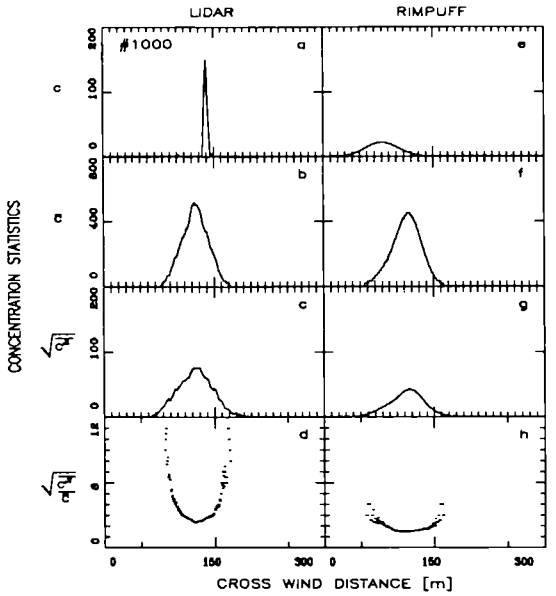

Fig. 2 Guardo "lidar vs. Rimpuff intercomparison

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Project 2

Head of project: *Dr. Werner*

Objectives for the reporting period

- participate in full-scale aerosol diffusion experiments with various types of lidar hardware available at DLR

- perform concentration profile measurements and to obtain raw data for subsequent calibration and statistical analysis

Progress achieved including publications

The participation in an additional full-scale aerosol diffusion experiment has been done in September 1992 with a trial called MADONA (Meteorology and Diffusion over non-uniform Areas, Chemical and Biological Defence Establishment, Porton Down, Salisbury, England).

The objective of this cooperative field study was to collect a comprehensive high-resolution meteorological and tracer data base in complex terrain using specialized high resolution sensors and trace generators.

One of these sensors was the DLR Lidar, an eye-safe infrared remote sensing laser radar. The technical description is listed in table 1.

Table 1: Specifications of the DLR lidar

Laser:	GaAs laser diode array
Wavelength:	906nm
Pulse energy:	1.6µJ
Pulse duration:	50ns
Pulse repetition rate:	2.5kHz
Optical diameter:	14cm
Laser safety:	conforms to IEC 825/VDE 0837 class 3A
Measurement range:	from 3m to 1536m
Data acquisition and control:	Commodore Amiga computer via RS232 serial interface
Output:	relative mass concentration

The laser matches the eye-safety criteria in two ways: it has the very low output power of 1.6µJ, and the laser beam is widened up to a diameter of 14cm. Caused by the low output

power the received signal is, for a single shot, highly afflicted with noise. Therefore one has to average over some hundreds of shots to get a representative information. This can be done very quickly with this system because of the high repetition rate of 2500 shots per second.
The averaging process has another positive effect, in addition to smoothing; the transient recorder (specially designed for this device) digitises every single shot with an 8bit A/D converter. The shots are then summed up in a 17bit sized array. The size of the digitising steps can be reduced from 1/256 (least significant bit of an 8bit converter) to 1/131072 (17bit), if the noise is greater than the least significant bit of the single-shot converter, i.e. noise level > 1/256. The total dynamic range of this fast (50MHz) transient recorder is therefore 17bit when averaging over many shots. This technique is called wide band noise dither (J. Vanderkooy and S.P. Lipshitz 1984).

The equipment for the measurement was installed in a car, the control unit (computer) at the back-seat and the measurement device (lidar) in the luggage boot. The startup time for a measurement is therefore very short (opening the luggage boot and power up the computer takes less than two minutes) and a measurement can even be done in moderate rain.

The placement of the lidar was always rectangular to the direction of propagation of the plume, some hundred meters apart from the artificial fog source. The direction and the elevation remained constant, so two-dimensional plots (mass concentration versus range) of the bypassing plume (versus time) have been taken.

A time series for a measurement in moderate rain is shown in figure 1.

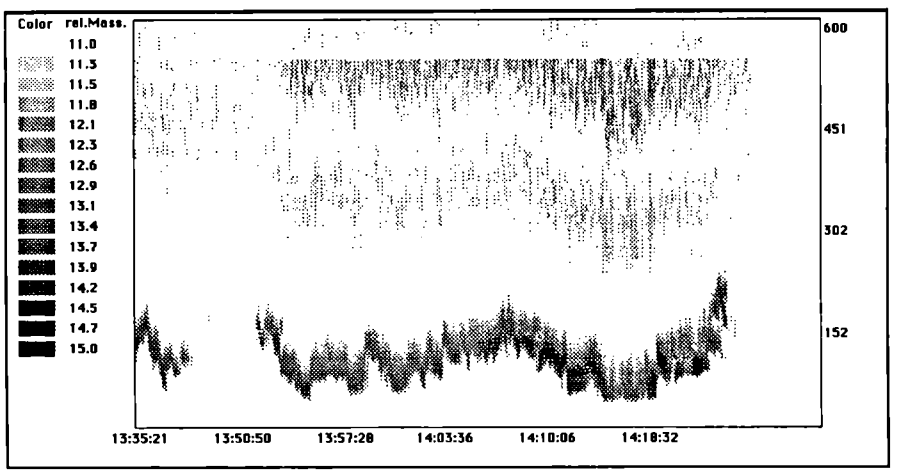

Figure 1: Artificial fog measurement in moderate rain (18. September).

The horizontal axis of these density plots represent the time at which the consecutive measurements were made with a time resolution of three seconds, the vertical axis the distance. The relative mass concentration is color coded, which means the received intensity P(R) is range corrected by the square of the distance and applied with the natural logarithm:

$$color = \ln(P(R)*R^2)$$

The total mass concentration (in g/m^3) can be found by taken further information into account, like the particle distribution function (amount of particles versus particle diameter for the wavelength of the laser).

In the situation of moderate rain, as shown in figure 1, the plume stays almost compact and meanders only slightly (the gap between 13:40 and 13:50 was caused by the shut down of the source). The ghost signal starting at 300m distance is composed out of noise and a leap over of the detector. It has no influence on the real signal.

Figure 2 shows in the contrast a measurement with no rain.

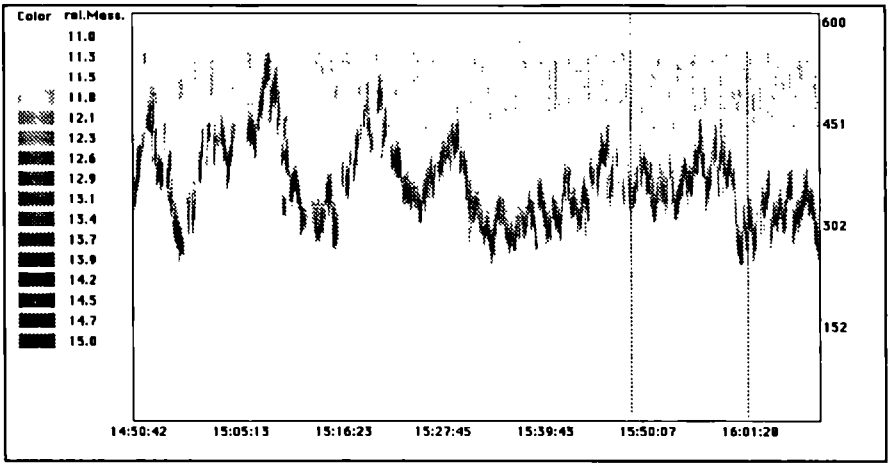

Figure 2: Artificial fog measurement, dry and windy (22. September).

The two dotted lines were caused by system errors.

In this case there are high fluctuations in the concentration as well as in the position of the plume (strong meandering). This picture reflects most of the measurements, which were taken in the complex terrain nearby Salisbury.

Beside this continuous smoke releases instantaneous "puff" releases have been recorded. In

the latter case small detonations distributed the artificial smoke into the atmosphere.

Releases of seven puffs are shown in figure 3.

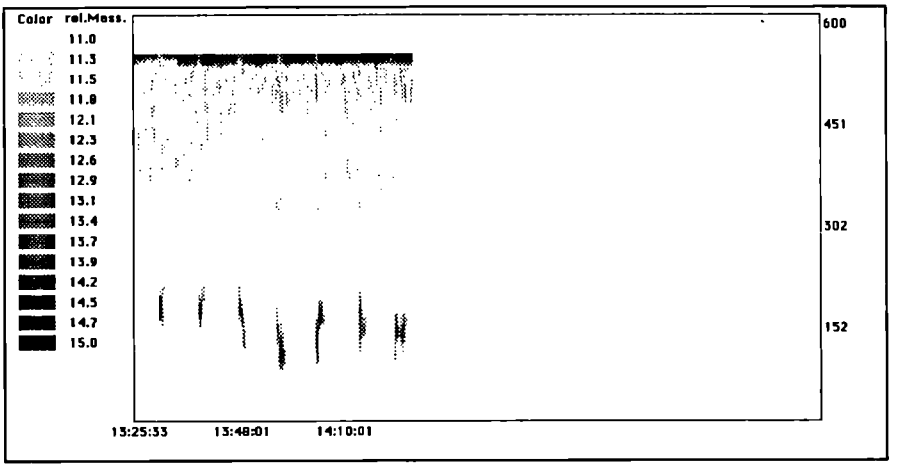

Figure 3: Artificial fog measurement, puff releases (15. September).

The strong and in the position constant signal is a hard target (slope of a hill).

The detection of the puffs was more difficult, because of the short bypass time and the strong variance of the center of the concentration.
All seven puffs show total different behavior in time:

- the first stays at the same location with decreasing concentration
- the second drifts away and then turns back
- the third one comes closer to the lidar with also decreasing concentration
- while the forth one comes closer with increasing concentration
- the sixth one drifts away very quickly with almost constant concentration
- the seventh stays at the same position with decreasing depth
- while the last puff stays in position and constant depth, but with a concentration gap.

All of the measurement of the trial MADONA have shown total different behavior, as it had been expected for a complex terrain.

With these datasets it is now possible to complete the database for an "uncertainty knowledge" based on the previous (sea and flat terrain, H. Herrmann et. al., J. Streicher et. al.) and the new (complex terrain) measurements.

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DEVELOPMENT OF A COMPREHENSIVE DECISION-AIDING SYSTEM FOR THE OFF-SITE EMERGENCY MANAGEMENT

1) *Ehrhardt* - KfK Karlsruhe 2) *Robeau* - CEA-FAR
3) *Bartzis* - NCSR "Demokritos" 4) *Caracciolo* - ENEA
5) *ApSimon* - ICSTM 6) *Thykier-Nielsen* - Risø National Laboratory
7) *Paretzke* - GSF Neuherberg 8) *Persson* - Inst. Meterological and Hydrolog.

Summary of project global objectives and achievements

The main aim of the project is the development of RODOS, an integrated and comprehensive real-time on-line decision support system for nuclear emergencies in Europe. The system will be able to make predictions from the vicinity of the release in the early phase of an accident to far distant areas and at later stages unperturbed by national boundaries. It will integrate methods, models and data, which allow the continuously updated estimation of the present and future environmental distribution of activity concentrations in the environment, which offer the possibility to simulate different intervention strategies for all kinds of countermeasures in order to assess in advance their respective merits and disadvantages in terms of dose or health effects saved and the associated social and economic costs, and which enable intervention strategies to be ranked in terms of their effectiveness, practicability and acceptance.

An important task of the first phase of the project was the development of the overall structure and the hardware and software framework of RODOS as a transportable package, which supports the integration of external programs provided by the contractors. Therefore it has been designed in modular form allowing an easy exchange of models and data, and thus facilitating its adaptation to the accident situation. In particular, differing site and source term characteristics, differing amounts and quality of monitoring data, and differing national regulations and emergency plans can be considered. This operational fexibility together with a variety of access tools taylored to the different capabilities, knowledge and aims of potential users, will allow RODOS to be used not only in actual accidents, but also as a powerful tool for education and training of personnel involved in the decision-making process and in preparing and exercising emergency plans.

A first prototype version of RODOS has been realised, which integrates programs developed by contractors, in particular the complete software of the German real-time system RESY. They comprise models for near-range atmospheric dispersion, early emergency actions, dose calculations, food-bans, health effects and economic costs. The RODOS prototype was presented during the 3rd CEC workshop on real-time computing, Schloß Elmau, Bavaria, 25-30 October 1992.

Besides this work mainly performed at KfK, the global achievements of the other contractors are summarized as follows:

1. CEA and NCSR 'Demokritos'

The EURIDICE System Code has been developed, allowing reliable prediction of airborne radioactive pollutants dispersion under real conditions, i.e. topographies of any complexity, wet atmosphere, stable and unstable conditions.

The system is based on the existing ADREA-I and MC31 codes that have been interfaced. The DELTA code has been developed which simulates a given topography with a required precision, using adjacent triangular surfaces.

Further model developments have been achieved including new formulation for ground dependent dry deposition, water liquid distribution, orographically induced precipitation prediction, wet scavenging and wet deposition.

Two additional dispersion models have been developed, the Eulerian model ADREA-d and the puff model DIPCOT. Both have been included to the EURIDICE System Code. Furthermore, the graphics package GRIFFON has been developed, for illustrating the outputs of the system.

Various numerical simulations have been performed in selected sites, to test the system code capabilities.

2. ENEA

The ENEA-DISP contribution to the CEC contract "Development of a comprehensive decision-aiding system for the off-site emergency management" is the development of a software package for the assessment of meteorological parameters needed by real time atmospheric dispersion models. Firstly, the state of the art of the boundary layer parameterization and of the available methods for deriving the most important input parameters for the diffusion models has been reviewed; then, the input/output and the flow diagram of the preprocessor have been defined; a number of software routines to be included into the preprocessor have been developed, collected or modifyied; the technical specifications of the software package for the preprocessor have been written; finally, the software package has been developed and tested. PAD has been developed on a DEC RISC Workstation in UNIX environment, due to arguments the cost-effectiveness ratio and compatibility with other components of the comprehensive decision support system. The following parameters are evaluated: meteorological scaling parameters (friction velocity, Monin-Obukhov length, heat flux), mixing height, stability category, vertical profiles of wind fluctuations and Lagrangian time scale, plume rise, vertical profile of wind speed. Each parameter can be estimated using different methods, due to the physical assumptions and the primary meteorological data needed. The software structure is modular, so that new subroutines based on updated methods can be easily included, or replace old subroutines. Future developments concern the extension of the preprocessing for estimating input parameters and two- or three-dimensional fields of meteorological variables needed by medium range and complex terrain dispersion models.

3. ICSTM

It was evident from the earlier work on Chernobyl, and from the ATMES intercomparison of atmospheric dispersion models, that model forecasts are particularly sensitive to certain factors. In this project special attention has been paid accordingly to:

i) a sub-routine to prescribe the diurnal development of mixing layer depth, and vertical dispersion of material

ii) parametrization of wet deposition processes, in particular a sub-module for convective storms which includes vertical export aloft, and is based on work with our more detailed storm model, DROPS (*paper submitted to Atmospheric Environment*) and

iii) analysis of special problems in simulating transport within jets of faster moving air, as in frontal systems. Of particular concern is the correct indication of whether contaminated air will be drawn into a frontal system, and then carried aloft yielding wet deposition over areas where air at the surface appears clean. (*paper presented at NATO/CCMS meeting, October 1991; and a paper on frontal systems in preparation for Atmospheric Environment*).

We have also undertaken a validation study to test the model against the observated disposal of smoke from the Gulf War oil-well fires. The model performed well, and estimated the spreading and areas affected very successfully (*to be published in Atmospheric Environment*).

We have also been investigating the potential use of G.I.S for displaying and manipulating model results, and integrating them with measurements. The manner in which information is communicated to decision makers in an emergency situation, especially when there is conflicting data, is just as important as the data itself, and requires very careful design.

4. RISO

During the contract period high priority has been given to the interfacing of RIMPUFF with the RODOS system. Work has concentrated on topics which are important in connection with the local scale atmospheric dispersion modelling in the emergency response system. Emphasis has also been placed on visualization of model results and other aspects of user training.

A special version of RIMPUFF has been created and transferred to KfK for inclusion in the RODOS system. New and updated modules for the calculation of gamma-doses, plume rise, building wake and penetration of the inversion lid are being introduced in RIMPUFF. A procedure has been set up to calculate a windfield, which gives the best fit to a network of simultaneous observations at multiple stations. This procedure has been implemented in RIMPUFF.

The improvement of LINCOM continues by including non-neutral temperature forcing, so it becomes able to deal with both unstable and stable situations flow fields. The pre-processing subroutines for meteorological data developed in cooperation with ENEA are now being implemented in RIMPUFF.

Experimental evaluation of flow field and dispersion modelling has been performed, using data from complex terrain experiments in Spain and Switzerland. It has been found that RIMPUFF is able to realistically simulate short time concentration fluctuations.

Interfacing of RIMPUFF with regional scale models in the emergency response system is studied in cooperation with the Danish meteorological institute and the Swedish Meteorological and Hydrological Institute.

Computer programs displaying time series of calculated and measured dispersion data have been developed.

5. GSF

On the basis of the dynamic radioecological program system EURALERT developed in 1987-1990, the module package ECOAMOR (ECOSYS ASY Modules for RODOS) comprising a foodchain transport module and a dose module has been developed and integrated into the prototype 1 version of RODOS. The requirements for inclusion of external programs into the system have been taken into account: ECOAMOR has a modular structure, transfers data internally by common blocks and to other parts of the system via shared memory thus avoiding time consuming disk-I/O-operations, performs the calculations after complete data input without user interface, is easily adaptable to different data structures, regions considered and needs of users, supports an automatic and interactive mode of the system, is capable of making short term assessments down to 10 minutes as well as long term assessments for up to 70 years, and has a multitude of calculational endpoints the user may be interested in. The ECOAMOR modules are linked to the long term countermeasure module of the CSY of RODOS by data transfer interfaces and common submodules performing the same calculational steps in both subsystems of RODOS. The ECOAMOR modules were successfully integrated into RODOS prototype 1, the function of the input interface with the atmospheric dispersion module as well as the output interface with the graphical subsystem was demonstrated. The data base of radionuclides included in ECOAMOR has been extended to 33 nuclides of 19 elements including noble gases and short lived iodine isotopes.

6. SMHI

The SMHI 3-D Eulerian dispersion model for emergency applications on the European scale has been adapted to real time meteorological input data, both analyses and forecasts, from either HIRLAM (joint Nordic-Dutch-Irish high resolution weather forecast model) or from ECMWF (European Centre for Medium-range Weather Forecasts). Forecasts up to 48 h over Europe can be obtained from HIRLAM, while ECMWF-data can be used globally and for forecasts up to 7 days.

Real time applications were made in a nuclear emergency response exercise, on January 16, 1992, initiated by the Nordic Nuclear Security Research (NKS). Real time dispersion forecasts were also made in connection to the emission of radioactivity from Sosnovy Bor, St. Petersburg, March 21, 1992.

Some preliminary studies have been performed of introducing data assimilation of radiological data, connected to the European scale real time dispersion model.

Project 1

Head of project: *Dr. Ehrhardt*

Objectives for the reporting period

Main objective of the first phase of the project has been to develop and to demonstrate a first prototype version of RODOS reflecting its overall design and showing its key functions. To that purpose the hardware and software framework had to be developed allowing the integration of the software products provided by the contractors together with the modules from the German real-time decision support system RESY for near-range emergency actions such as evacuation and sheltering. The external programs had to be implemented in close cooperation with the developers, and both the user interface and the graphical software had to be extended correspondingly.

Progress achieved including publications

1. System development

With support of CEC, DG XI (Contract No. 89-ET-019), KfK prepared in 1990 a design study outlining in a modular approach the basic concept and content of a comprehensive decision support system for nuclear emergencies in Europe. It was based on the experience gained with the development of the German real-time system RESY for near range and early phase decision support. In the past two years, the document has been updated with ideas and contributions of all contractors. Finally, a broad agreement could be achieved on the objectives, overall structure and content of RODOS /1/. It comprises three main subsystems (Fig. 1):

(1) Analysing subsystem ASY:

Continuously updated estimation of the present and future environmental distributions of activity concentrations and derived dose/dose rates together with monitoring/measurement data and the associated uncertainties.

(2) Countermeasure subsystem CSY

Quantification of the benefits and drawbacks of alternative courses of actions, such as individual/collective doses and health effects saved, economic costs, areas and number of people affected, together with the technical and personnel aid required and the associated uncertainties.

(3) Evaluating subsystem ESY

Judgement of alternative courses of actions under the aspects of practicability in the actual situation, acceptance by and behaviour of the population, and socio-political implications.

The subsystems communicate with each other, the data base and the user via the operating system OSY, supported by a supervising subsystem SSY. OSY may be seen as an operator, whose main task is the management of data resources and communications, i.e. it has to organise the data needed, to preprocess them and to

make them available for the modules of the subsystems. It has to allow the user for local and remote interaction with modules and resources, and to manage correctly the execution of the system. The supervising subsystem SSY supports OSY in generating an appropriate logic of calling subsystems and modules based on the inner logic of the spatial and temporal sequence of physical processes and countermeasure actions.

The division of RODOS into the three subsystems ASY, CSY and ESY has to be considered as a conceptual design. To ensure an effective execution of the calculations, the actual software structure consists of a variety of submodules, each of them developed for a specific type of calculations. The development of each module can be performed for the most part independently, thus facilitating the specification of project structures and task descriptions.

From the beginning of the project, all partners considered it as highly beneficial to develop as soon as possible the hardware and software framework of RODOS based on the structure outlined in the design study. It should offer the possibility to implement and to test software products for application in real-time systems, which already exist or become available within the project. Accordingly, KfK laid down the structure of a detailed software framework and its internal logic in a document prepared with support of CEC, DG XI (contract No. 91-ET-0008). Open and lively debates led to a commonly accepted design /2/, which built the basis for the first prototype version of RODOS. Its operating system OSY has been developed in the programming language C as a transportable package to run with a UNIX operating system, and X-Window user interface with OSF/MOTIF extensions. The data management is based on the SQL standard. At present, OSY is implemented on workstations HP 9000 models 835 S and 720 CRX with several 700/X terminals and graphical stations.

The first prototype version of RODOS was demonstrated during the 3rd International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release to atmosphere from a Nuclear Installation, Schloß Elmau, Bavaria, 25-30 October 1992. It reflects the objectives, key features and software structures described above. In particular, OSY contains all elements for providing its basic services and functions. This allowed to integrate external programs, to operate the system, and to present the results obtained during the various stages of information processing in graphical and numerical forms.

As external programs, the modules ECOAMOR and FRODO from GSF and NRPB, respectively, and the complete RESY software from KfK have been implemented in RODOS. They comprise models for near-range atmospheric dispersion, early emergency actions, food-bans, dose calculations, health effects and economic costs assessments. They allow the following simulations and calculations to be performed /3/:

- different dispersion and deposition conditions, sites and source terms;
- early emergency actions, such as evacuation and sheltering;
- activity concentrations on surfaces and in foodstuffs; dose rates and doses from external and internal irradiation;
- time and duration of food-bans (milk, cheese);
- areas of land, numbers of cows, amounts of produce affected;
- doses, health effects and economic costs including countermeasures.

An expert system developed for ranking alternative countermeasure strategies is not yet implemented in RODOS, but can be used as a stand-alone program. Similarily, further software products, such as wind-field and supplementary atmospheric dispersion models, and hydrological models for river systems are ready for integration in RODOS.

2. Coordination

During the discussions about the structure and the functional specifications of a commonly agreed system, several areas were identified where additional research/investigation is necessary to complement the existing contracts in order to assure that all aspects of the system are being addressed and receiving appropriate attention. Those which were considered to have high priority are briefly described:

(1) Development of criteria for selecting meteorological and atmospheric dispersion models from a hierarchy of models according to the actual conditions.

(2) The use of model predictions and monitoring data in the optimisation of emergency response (data assimilation).

(3) The further development of atmospheric dispersion models, and their associated meteorological inputs (e.g. forecast, windfields) in order to provide probabilistic as well as deterministic estimates of relevant quantities.

Several meetings on these topics were organized by CEC, DG XI and DG XII, with input from KfK in the form of problem descriptions and proposals emerging from the needs of the various subsystems and their software realisation. Besides the existing close cooperation with the contractors and the associated institutions (JRC-ISPRA, S.C.K./C.E.N. Mol), new contacts have been established with the University of Leeds, UK, the Federal Office of Public Health, National Emergency Operations Centre, CH, the National Radiological Protection Board (NRPB), UK, the Nuclear Electric, UK, and the Electricité de France, F. A direct link exists to the collaborative research programme initiated within the framework of the agreement between the CEC and Byelorussia, Russia and Ukraine on investigations of the health and environmental effects of the Chernobyl accident; in its Joint Study Project 1, at present KfK is also acting as coordinator.

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/2/ Overall structure and content of a comprehensive decision-aiding system for nuclear emergencies in Europe following an accidental release of radioactive material - design study
Document prepared with support of the Commission of the European Communities, DG XI and DG XII, Kernforschungszentrum Karlsruhe GmbH, Juni 1992

/3/ J. Päsler-Sauer
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3rd International Workshop on Real-Time Computing of the Environmental Consequences of an Accidental Release to Atmosphere from a Nuclear Installation, Schloß Elmau, Bavaria, October 25-30, 1992

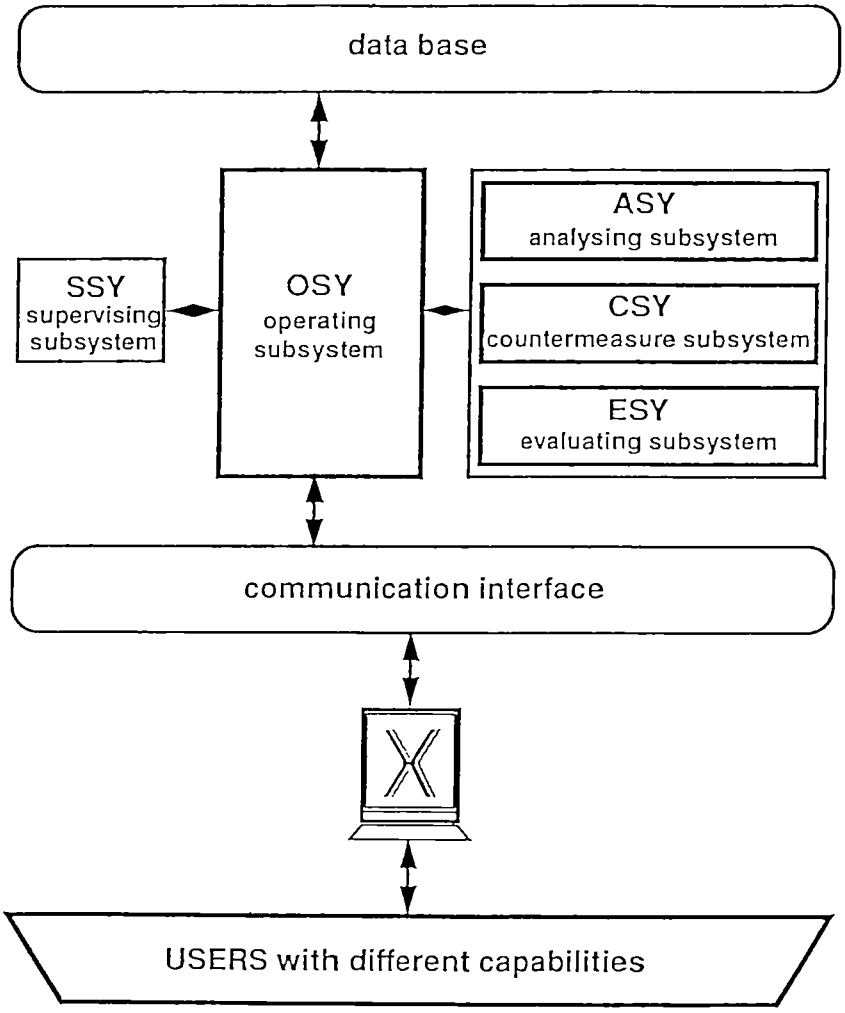

Fig. 1: Conceptual Structure of RODOS

Project 2

Head of project: *Dr. Robeau*

Objectives for the reporting period

The objectives of the reporting period was to develop four Codes respectively named DELTA, ADREA, MC31 and GRIFFON and include them in the System Codes EURIDICE. This System Codes permits to construct a relief using irregular triangular facets, then to compute a set of meteorological parameters as wind speed, wind direction, pressure, temperature, moisture and wash out in the region defined on DELTA from boundary initial conditions, and in the end, to follow the dispersion of a pollutant released from a point,a surface or a volume source. During the computation the input of data and the ouput of intermediate or final results can be displayed using cartographic representations.

Progress achieved including publications

The DELTA code permits to construct a relief from the definition of obstacles. Each obstacle is defined on a spray of points inside a polygon. Then the relief mesher DELTA build a relief with a great deal of triangular adjacent surfaces associated to a rectangular cartesian irregular grid. This grid has not only graphical utility because it has a particular topology. Indeed, each node of the triangular grid is also a node of the rectangular grid and at each facet of the triangular grid is associated a table permitting to define the physical properties (albedo of the surface, roughness, type and characteristics of soil etc...) and the mathematical properties of the facet (coordinates of the three points defining a triangle, components of the orthonormal vector to the surface,...). The rectangular meshes have classical properties of this type of grid. The medium associated at each rectangular mesh is defined on parameters, and the six surfaces limiting the mesh can be equiped with generalized boundary conditions as Dirichlet or Von Neuman conditions. The use of these twined grids permits to calculate the porosities of each rectangular mesh. The triangular facets cut off the rectangular meshes into two volumes whose the ratio is named "porosity". This quantity permits to calculate the ratio air volume on soil volume, air volume on water volume or air water on soil volume in each mesh limiting air and soil, air and water or water and soil.

The DELTA code permits to represent all type of orography either lightly or strongly undulating, coastal or continental.
The ADREA Code is a 3-D transient analytical tool, providing atmospheric boundary layer and dispersion analysis at the mesoscale and microscale levels, under any atmospheric stability conditions and with any ground complexity; it is particularly suitable for large topographical disturbances and consequently large atmospheric altitudes. The code, in response to the need to treat large topographical disturbances with the highest possible spatial and temporal resolution, introduces new features in the description of anomalous topography, turbulent diffusion coefficients and numerical approach.
The code MC31 is a 3D particles transport code solving dispersion advection equation. This code permits to solve in a moving cell, the dispersion advection equation and to select randomly the exit point on the frontier of the cell for a particle. The size of the moving cell depends on the physical characteristics of the medium inside the cell. The direction of the cell is parallel to the advection vector defined in the centre of the moving cell. The firing of a great deal of particles permits to obtain a distribution of particles on the domain initialy defined on DELTA. The particles are distributed in function of their location in the rectangular meshes. During the transport, a lot of particles strike triangular facets and deposit on, with a probability depending on the soil roughness. The balance of particles deposited on facets permits to calculate the deposition on soil.
The GRIFFON Code permits to display with a cartographical approach the design of the relief, the twined grids associated, the main meteorological parameters, the results of atmospheric and deposited radioactivity. The objective of this cartography is to offer to the decision makers a simple and overall view of the radiological situation. It is a classical bidimensional geographical cartography based on the colouring of the triangular surfaces of the relief. It is possible to inlayed several information sets into the map using different chromatic shades.

Three first numerical experiments of atmospheric dispersion in complex terrains were done:
-in the region of Attiki in Greece,
-in the Middle Rhone Valley in France
-in the Rocky Flats region in United States.

1. The region of Attiki

The Attiki region studied is divided by the presence of mountains and sea into differentregions; namely, the Athens basin, the Thriassio Field, the Messogia Plain, the Marathon area and the Islands of Salamina and Aegina. The Athens basin, where the City of Athens is located, is surrounded by mountains (Aegaleo, Parnitha, Penteli and Ymettos) on the three sides, while to the South there is sea (Saronikos gulf). The Thriassio Field, where most of the Greek Industry is concentrated, is separated from the Athens basin by the

Mountain Aegaleo (468 m hight). The greater Athens area covers a 70 km x 80 km x 6 km domain and is described by a 20 x 24 x 24 non-uniform calculational grid which is more dense in areas of important topographical disturbances; in the vertical direction the grid width increases geometrically with the altitude. The topography is described by using 7680 adjacent triangular surface elements generated by the DELTA code from a digitized map of about 43000 points. The pollutant point source at 100m altitude is assumed to be located at the Thriassio Field next to the western side of the Mountain Aegaleo. A simulated instantaneous release of 10^{16} Becquerels of a radionuclide having an infinite half-life starts at time zero. The atmospheric conditions are assumed to be neutral, while a geostrophic wind of 10 ms^{-1} is blowing from the West. The wind field obtained in low altitudes shows a distortion due to the presence of topographical irregularities and is shifted to the SW/NE direction. The deposition calculated shows the cloud moving along the SW/NE direction between the Parnitha and the Penteli mountains, towards the Marathon area, which is quite reasonable. The results indicate a cloud "narrowness" in the region of the Parnitha/Penteli passage, that might be attributed to that particular passage. The maximum deposition appeared also in this particular location.

2. The region of the Middle Rhône Valley

The region studied is a 100 km x 100 km x 6 km domain located in the Middle Rhône Valley in France. This domain is limited on the West side by a hilly region (200-400 m hight) and on the East side by the Bugey Mountains (900 m hight) and the Mountains of Jura (1000-1200m hight). This domain is described by a 20 x 20 x 35 non uniform calculational grid. The topography is described by using 6400 adjacent triangular surfaces elements generated by the DELTA code from a digitized map of about 2000 points. The ADREA code has been used to calculate wind field, dispersion coefficients and deposition velocities associated to a neutral atmospheric conditions and a geostrophic wind of 10 ms^{-1} from the North/West. Then, a transport of a radioactive pollutant has been simulating using the MC31 code. The pollutant point source at 100 m hight above ground is assumed to be located at the centre of the studied area.

3. The Rocky flats case

The analysis of the ASCOT-Rocky Flats experiments has been initiated at the end of the reporting period. These experiments from the Rocky Flats Plutonium Plant (Colorado U.S.A.) near the Rocky Mountains, on a particularly complex terrain with high mountains and canyons.

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Project 3

Head of project: *Dr. Bartzis*

Objectives for the reporting period

The general objective was to draw, expand and improve a complete set of calculation tools in the form of a System Code, permitting to do forecasting or real-time computations concerning airborne radioactive pollutant dispersion and deposition under any terrain complexity and atmospheric conditions.

The particular objectives were:

- to interface the ADREA-I code ("Demokritos" - Greece) and the MC31 code (CEA - France), the former performing transient 3D wind field calculations, the latter computing atmospheric dispersion
- to develop a code performing automatic and optimum discretization of the complex ground surface
- to introduce ground-dependent dry deposition velocities
- to model water liquid distribution, precipitation, wet scavenging and wet deposition
- to develop corresponding graphics output package and
- to test the Code System capabilities by performing case study calculations over selected sites

Progress achieved including publications

All the above objectives and requirements have been fulfilled and the corresponding models have been incorporated into the EURIDICE[1,2] Code System. EURIDICE allows reliable prediction of airborne radioactive pollutants dispersion under real conditions, i.e. topographies of any complexity, wet atmosphere, stable and unstable conditions, etc.

The current version of the EURIDICE Code System[3] is an ensemble of codes, namely DELTA, ADREA-I, MC31, ADREA-d, DIPCOT and GRIFFON. Within its framework:

- the DELTA[1] code, jointly developed by CEA and "Demokritos", provides the detailed topography description,
- the ADREA-I[4] code ("Demokritos") performs time-dependent 3-D wind field predictions under any stability condition,
- the MC31[1] (CEA), DIPCOT ("Demokritos"-CEA) and ADREA-d ("Demokritos") codes estimate airborne and deposited concentration patterns of radioactive pollutants and
- the GRIFFON[2] code (CEA) allows the graphical representation of the topography and the results of the calculations.

The interfaces between the various codes of the system are quasi-automatic, requiring minimum user intervention: each code produces output files which are directly used by another code of the system, according to the flow diagram of the system shown in Fig.1.
It should be pointed out that in a complete atmospheric dispersion calculation, most of the computation time is consumed to analyze the atmospheric boundary layer, creating the wind

field. Consequently and in order to keep the whole computation time and cost in reasonable levels, it is necessary to use relatively low resolution when treating the air domain. On the other hand, when the terrain happens to be complex, the model should be able to take into account particularities and details of the ground surface, in order to perform reliable air/ground interaction computations.

The Code System aims to meet the above requirements by following the so-called "high resolution ground - low resolution air" concept. This concept is translated in allowing on one hand the ground irregularities to "cross" the calculation cell and on the other hand the ground surface to be subdivided within the cell according to its orientation, land use, soil texture, albedo etc.

The Domain Description is performed by the DELTA code which simulates a given topography using adjacent triangular surfaces. The code starts from a digitized map containing the orographic data of the topography under treatment and requires additional data on the contours of the various topographical disturbances encountered and the cartesian output grid.

The external surface of the topographical disturbances is modelled using adjacent triangular surfaces in number and size depending on the accuracy requirements. Following the "high resolution ground - low resolution air" concept, each boundary calculation cell usually contains a large number (basically 16 but this may vary as 4^n following precision requirements) of triangular ground surface elements. Each triangular surface element is characterized by its own area, orientation, albedo and land use (21 soil types are taken into consideration), allowing reliable computations of important air/ground interaction parameters such as friction velocity, the ground heat flux or the deposition velocity.

The Wind Field Calculations are performed by the ADREA-I code, where the atmosphere is treated as an open multiphase system. The air is considered to be a two-component mixture of dry air and water in thermodynamic (but not in kinematic) equilibrium, the later component being in liquid or/and vapour phase.

The mixture is governed by mass, momentum and energy conservation equations. The energy equation is formulated in terms of internal energy, and full compressibility effects are taken into account. A one-equation model is used by default to deal with the turbulence closure modelling problem based on the eddy viscosity/diffusivity concept.

For the air/ground interaction modelling, an active ground layer of specified thickness is used and the heating/cooling rates due to the relaxation fluxes are computed using the broadband emittance method[5]. For simplicity and low computation cost requirements, only one prognostic equation for the water substance is used to predict orographically induced precipitation[6,7]. Dry deposition velocities have been introduced, taking into consideration the land use, the ground wetness, the atmospheric stability and the state of the pollutant (gas or particle)[8].

A variety of dispersion modes can be driven by the DELTA/ADREA-I ensemble of codes: eulerian models, puff models or Monte-Carlo models.

In the frame of the EURIDICE Code System and in case of an instantaneous pollutant release from a point, surface or volume source, the dispersion calculations are performed using the MC31 code, solving the stochastic form of the diffusion-advection equation. Dry and wet deposition are taken into account. The time-dependent concentration of radioactivity in the air is computed in each cartesian calculation cell whereas the ground deposited radioactivity is computed for each triangular ground surface element.

In case of a continuous release the pollutant concentration in the air is computed either by the ADREA-d module which is a eulerian model solving the concentration equation in the 3D cartesian grid or by the DIPCOT module, which is a Puff model, making use of particle trajectories over the simulated topography and summing gaussian probabilities of presence in given locations at given observation times. Both the ADREA-d and the DIPCOT modules are also able to deal with instantaneous pollutant releases.

The graphics representation of the results obtained by using the DELTA, ADREA-I and the dispersion codes, is performed using the GRIFFON code. GRIFFON generates geographic 2D maps and aims to offer to the decision maker a simple overall view of the radiological situation. The topography is represented by projecting on the horizontal plane the triangular ground surfaces and colouring them following their altitude. The airborne and the deposited radioactive concentration are represented using coloured isolines. The GRIFFON code uses the standard UNIX tools.

The Code System capabilities have been tested by using it for analyzing a SF_6-release experiment, in the region surrounding the Rocky Flats Plutonium Plant (Colorado, USA) near the Rocky Mountains. The terrain is particularly complex with high mountains and canyons. The study concerns a night release where thermally driven wind systems are dominant. The results obtained[3] show the reasonable trend on the dispersion pattern and the Code System capability to resolve small scale but important features such as the individual influence of the nearby narrow canyons.

An additional boundary layer analysis has been performed over the Greater athens Area, which is a typical case of complex terrain with relatively high mountains and plains surrounded by sea. The application leads to satisfactory simulation of the fate of pollutants in the area[3,9].

A third computation has been performed, aiming to demonstrate the capability of the EURIDICE Code System to predict an orographic rain and its effects on pollutant dispersion through a 2D steady state illustration example; the study is based on realistic meteorological cases which occurred in the Sierra Nevada mountains and are analyzed elsewhere. However, the pollutant dispersion example is purely imaginary and has been introduced only for illustration purposes. The results obtained show qualitatively the right trends[3,7,10].

Publications

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4. Bartzis J., Venetsanos A., Varvayanni M., Catsaros N., Megaritou A., *ADREA-I. A transient three dimensional transport code for complex terrain and other applications*, Nuclear Technology, 94, 135-148, (1991).
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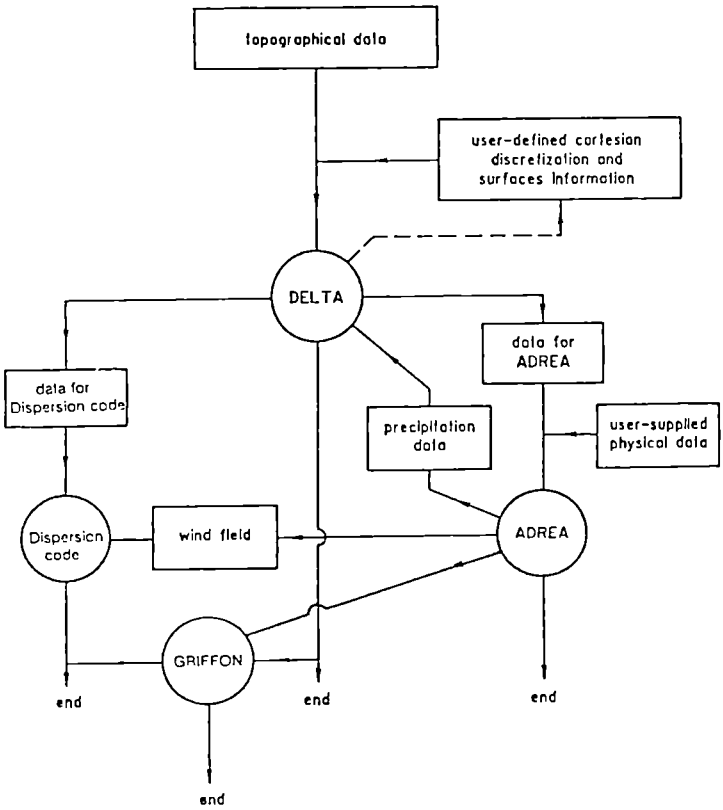

Fig.1 Flow-chart of the EURIDICE Code System
Dispersion code: MC31, DIPCOT, ADREA-d

Project 4

Head of project: *Dr. R. Caracciolo*

Objectives for the reporting period

The final objective was to develop a meteorological preprocessor for real-time atmospheric dispersion models (PAD: Preprocessor for Atmospheric Dispersion models) suitable to be incorporated into the Analysing Subsystem of the Comprehensive Decision Support System). For this purpose, the intermediate objectives were: to review the state of the art of the boundary layer parameterization and of the available methods for deriving the most important input parameters for the diffusion models; to define the input/output and the flow diagram of the preprocessor; to collect, modify or develop the routines which can be included into the preprocessor; to write the technical specifications of the software package for the preprocessor; to develop the software package; to test the software package.

Progress achieved

The ENEA-DISP contribution to the CEC contract "Development of a comprehensive decision-aiding system for the off-site emergency management" is the development of a software package for the assessment of meteorological parameters needed by real time atmospheric dispersion models.

During the first phase of the contract, the general structure and characterics of the meteorological preprocessor have been defined. The first requirement was to design the preprocessor as a independent module that can easily fit into the general architecture of a comprehensive decision support system, in particular into the Analysing Subsystem (ASY) of the CEC project. For this purpose, the preprocessor is independent on the atmospheric dispersion model(s) included into the system, and is flexible with respect to the meteorological data that can be available on site, which can range from a single wind measurement and cloud cover observation to vertical profiles of wind and temperature.

As far as the hardware and software environments are concerned, the applied choice consists of a RISC Workstation with UNIX Operational System, due to arguments the cost-effectiveness ratio and compatibility with other components of the comprehensive system. The user interface is driven by a user-friendly menu using X-Window, with the possibility of data entry through guided masks (fig. 1) and graphical display of the results (fig. 2).

PAD estimates the following parameters: scaling parameters (friction velocity, Monin-Obukhov length, heat flux), mixing height, stability category, vertical profiles of wind

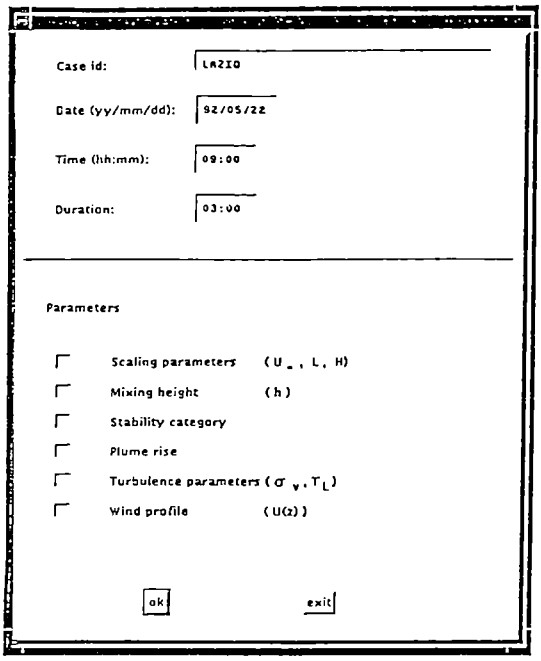

Figure 1 - An example of PAD menu

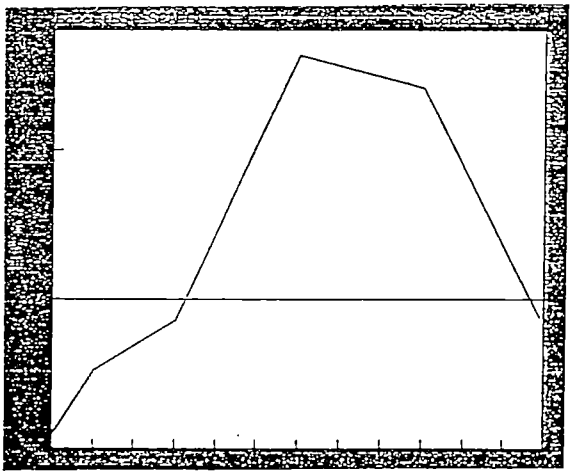

Figure 2 - An example of PAD output: the estimated heat flux as a function of time

fluctuations and Lagrangian time scale, plume rise, vertical profile of wind speed. Each parameter can be estimated using different methods, due to the physical assumptions and the primary meteorological data needed. The software structure is modular, so that new subroutines based on updated methods can be easily included, or replace old subroutines.
For example, scaling parameters can be evaluated using one of the following methods: the "profile" method, based on one wind speed and two temperature measurements near the surface; the "energy budget - first version" methos, based on wind speed and cloud cover; the "energy budget - second version" method, based on wind speed, cloud cover and incoming solar radiation. The convective mixing height for diurnal, unstable conditions, can be evaluated with the "slab" method based on scaling parameters, or with the "intersection" method, based on vertical profiles of temperature and humidity. A description of the methods included in PAD is in (Mikkelsen and Desiato, 1992).

The operations of input and output of the data concerning a specific dispersion episode are stored, allowing any successive analysis or modification for that particular "case". In the first window mask the user is requested to input a case-identifier, the date-hour of the initial time and the duration, and to choose the parameters to be evaluated.

For each group of parameters, the user can select the proper method of calculation based on the available data. He is then requested to set the data regarding the stations where primary meteorological variables are measured (coordinates, roughness height, anemometer height, etc.), and the values of the necessary primary meteorological data as a function of time, covering the period of the simulation. During this phase, the system performs a certain number of data checks and intercepts eventual inconsistencies between the data, and messages of errors are displayed.

The flow chart and the sequence of input masks are different for each group of parameters and depend on the selected method of evaluation. As an example, the scheme for calculating the mixing height is shown in fig. 3.

The modules of PAD can be easily introduced into the Analysing Subsystem of the Comprehensive Decision Support System by means of a decision tree for the adoption of the appropriate method based on on-line available data. Future developments concern the extension of the preprocessing for estimating input parameters and two- or three-dimensional fields of meteorological variables needed by medium range and complex terrain dispersion models.

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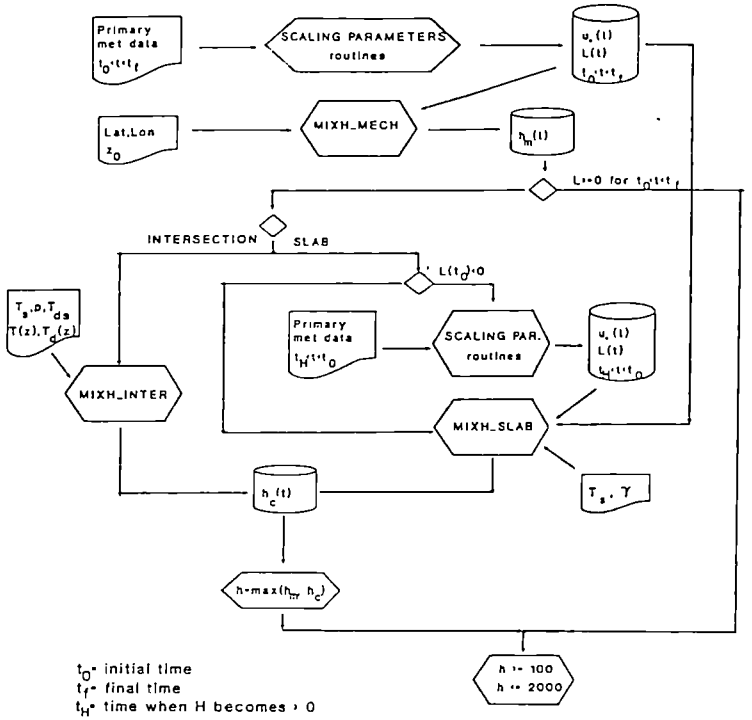

Fig. 3 – Flow chart for the calculation of mixing height. Meaning of symbols: u_*: friction velocity; L: Monin-Obukhov length; z_0: roughness height; h_m: mechanical mixing height; h_c: convective mixing height; T, T_d: temperature and dew point temperature; p: atmospheric pressure; γ: potential temperature lapse rate above the mixing height.

Project 5

Head of project: *Dr. ApSimon*

Objectives for the reporting period

Medium to long range dispersion of radionuclides from a nuclear accident

The objectives of this project have been to develop a computer model to analyse the transboundary spreading of radionuclides and contamination in the event of a nuclear accident. The 3DRAW (3-Dimensional RAndom Walk) model forms a module for use within the RODOS computer system to support emergency response and management. The model is designed for use with forecast data from weather prediction models, to estimate wich regions or countries are likely to be affected. Also, in conjunction with early radiological measurements during the passage of the cloud and simultaneous data on precipitation (e.g. from weather radar), it can assist in directing attention to areas where there may be enhanced deposition. It can also be used to help in interpreting measurements and, if necessary, to derive estimates of the quantities of radionuclides emitted.

A large part of the present project has been devoted to model validation and quality assurance, with improvement of particular aspects of the model, and identification of difficult meteorological situations when the model predictions are likely to be less accurate.

Progress achieved including publications

It was evident from the earlier work on Chernobyl, and from the ATMES intercomparison of atmospheric dispersion models, that model forecast are particulary sensitive to certain factors. In this project special attention has been paid accordingly to:

i) a sub-routine to prescribe the diurnal development of mixing layer depth, and vertical dispersion of material;

ii) Parametrization of wet deposition processes, in particular a sub-module for convective storms which includes vertical export aloft, and is based on work with our more detailed storm model, DROPS *(paper submitted to Atmospheric Enviroment)* ;

iii) analysis of special problems in simulating transport within jets of faster moving air, as in frontal systems. Of particular concern is the correct indication of whether contaminated air will be drawn into a frontal system, and then carried aloft yielding wet deposition over areas where air at the surface appears clean *(paper presented at NATO/CCMS meeting, October 1991; and a paper on frontal systems in preparation for Atmospheric Environment).*

We have also undertaken a validation study to test the model against the observed dispersal of smoke from the Gulf War oil-well fires. The model performed well, and estimated the spreading and areas affected very successfully *(to be published in Atmospheric Environment).*

We have also been investigating the potential use of G.I.S. for displaying and manipulating model results, and integrating them with measurements. The manner in which information is communicated to decision makers in an emergency situation, especially when there is conflicting data, is just as important as the data itself, and requires very careful design.

Development of the 3DRAW model

The basis of the 3DRAW model had already been established in a previous contract. The model simulates an accidental relcase of radionuclides as an assembly of particles, each following an independent trajectory from its time of release according to the evolving wind-field with random displacements scaled to represent the magnitude of turbulent mixing. For a selection of nuclides, time-integrated air concentrations are accumulated over prescribed intervals in a grid of cells across the chosen map area together with the dry and wet deposition.

In this contract we have been concerned with the reliance which may be placed on the model in different situations. Many of the limitations on accuracy arise from meteorological data derived from a numerical weather prediction model, and its resolution in space and time. A particular example of this arises with prescriptions of mixing-layer depth, where temperature data at the limited number of levels in a forecasting model are inadequate to define the top of this layer directly. Accordingly a sub-model has been introduced to derive mixing layer development through the day, based on the model of Carson and Smith. In developing this it was recognised that some aspects of the model, such as heat fluxes and insolation, were parametrized according to N European latitudes; these have been adapted to make 3DRAW more widely applicable, even outside Europe.

Special attention has been given to frontal systems, because they lead to widespread wet deposition which is likely to be the major problem for severe accidents with long-range effects. A large proportion of air at mid-northern latitudes is drawn into such systems and scavenged, but it is often not easy to decide which air will be drawn into a particular system, and which will be left behind for a later warm front (Chernobyl provided a good demonstration of this when some of the contaminated air over the Baltic missed the frontal system over Scandinavia, and travelled west across Europe before being sucked into fronts over the UK and the North Sea).

Difficulties arise in the interpolation for winds in space and time, especially when fronts are fast moving or are associated with very deep depressions. In some cases fronts can move one or two hundred kilometres within a few hours, so that it is impossible to estimate windfields in this vicinity properly during such an interval. Hence we have recommended that hourly wind-fields are desirable from numerical weather prediction models, and have indicated how the errors grow if time and space resolution are decreased. We still wish to investigate further examples of transport through a frontal system to test our ideas, and data for some suitable mereorological situations has been promised to allow this as part of our collaboration with the UK Meteorological Office.

Convective shower systems are treated quite differently from frontal precipitation. They are important in two respects; first because they can produce very patchy wet deposition, and secondly they eject material aloft into the free troposphere where it can travel in different directions from the surface air. To gain understanding of convective systems we had developed a detailed model DROPS (Deposition of Radionuclides and Other Pollutants in Showers). This model simulates the various processes affecting radioactive aerosols as a convective updraught is reinforced in strength due to condesation on cloud droplets, with subsequent formation of rain and ice particles. It was evident from this that the efficiency of deposition depends crucially on the effectiveness of the aerosols as condensation nuclei, and may also vary greatly with the exact time they enter the updraught during evolution of the storm. However at long distances from the source we have assumed that the radioactive aerosols would have aged and would be well mixed in the boundary layer air before entering convective updraughts. We have therefore derived a simple sub-model for convective storms, based on our more detailed simulations. This includes estimation of the volume of air drawn into the storms, and hence the probability that particles will pass through them. The quantities of radionuclides associated with such a particle are depleted according to the probability that the particle is deposited with the precipitation, and the remainder lofted to the free troposphere

at some height below the cloud top. Wet deposition from convective systems is reported separately, to allow indication in forecasting mode that it will be very patchy.

In this contract we also wanted to test and validate our model. We had already a good understanding of the spread of the Chernobyl release, and wished to investigate a new situation which we had not already studied. The smoke from the oil wells in the Gulf War provided this opportunity, with observations made by the UK Meteorological Office's Hercules aircraft which flew through the plumes, and additional satellite imagery of the cloud from above. The period covered was the 27-29 March, 1991, when the fires were burning strongly and yielding 10,000 tons of carbon soot per day. Figure 1 shows the observed spread of the cloud on 29 March. By comparison figure 2 shows the results obtained with 3DRAW for the evening of the previous day. It can be seen that the model correctly predicts the plume of smoke moving down the Gulf, and edging east into Iran - which is very encouraging. Other spatial projections of the modelled plume reveal a lot of structure depending on the time of release and development of vertical mixing. This comparison was conducted in collaboration with the UK Meteorological Office, who also ran their own NAME model, which gave slightly different results but still represented the general characteristics. A puzzling problem was that neither model produced any material as high up in the atmosphere as was observed: this does not seem explicable by special self-lofting properties of the soot particles. A paper is being drafted for Atmospheric Environment on this validation study.

Since RODOS is a system designed for some years to come, it is desiderable to make full use of new developments in Geographical Information Systems, G.I.S. This is particularly helpful in overlaying model results with measurements, and evaluating their agreement. KFK have developed their own GIS system for use in RODOS, but in the meantime we are experimenting with the one available at Imperial College, ARC/INFO. We have some early ideas on indicating uncertainties in the modelling results, and have also been consulting with other modellers on this topic. This is the area we now wish to continue work on to complete integration of 3DRAW within RODOS.

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Lowles, I., ApSimon, H.M., Wilson, J.J.N.,*The validation and uncertainties of real-time modelling of atmospheric dispersion over medium and long-range distances.* CEC symposium on emergency response, Schloss Elmau, October 1992.

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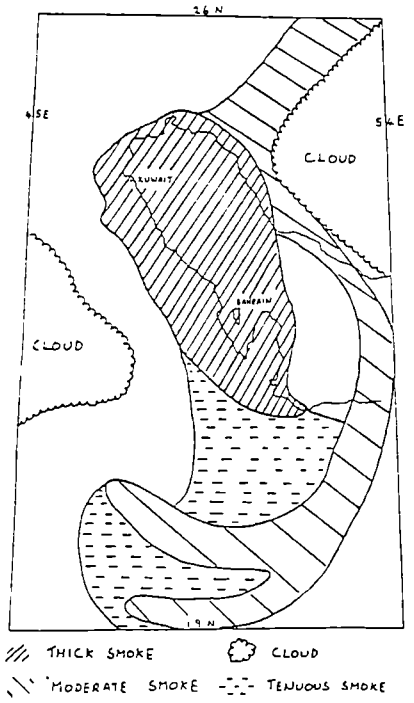

Fig. 1 Nephanalysis at 13:00 GMT 29/3/91

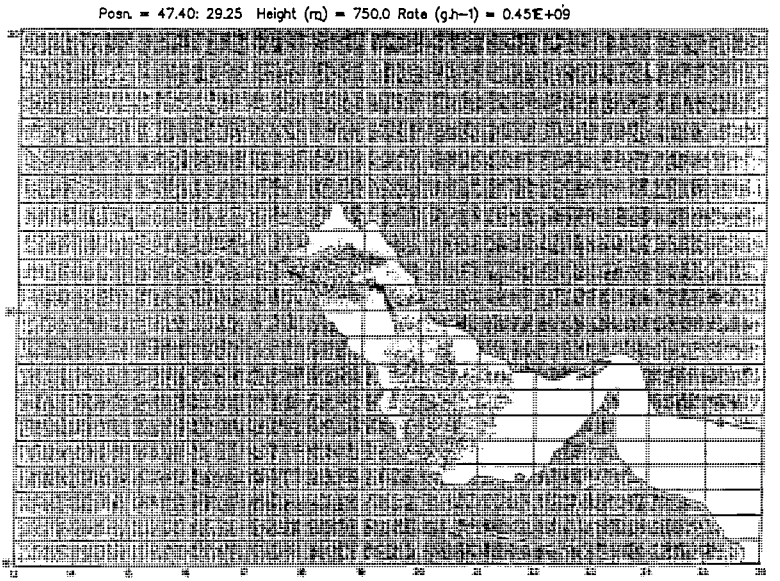

Fig. 2-3 DRAW Simulation of Kuwait oil fires 18:00 GMT 28/3/91

Project 6

Head of project: *Dr. Søren Thykier-Nielsen*

Objectives for the reporting period

Improvement of the modelling of plume rise, building wake, dry deposition and gamma-doses in RIMPUFF.

Interfacing with regional scale models in the emergency preparence system.

Interfacing atmospheric dispersion models with other modules in the RODOS emergency preparence system.

Interfacing with pre-processors for the RIMPUFF/LINCOM system.

Fitting of flow fields to wind observations.

Model evaluation over complex terrain.

Creation of a flexible user-interface for the RIMPUFF/LINCOM system.

Flow, modelling for unstable and stable meteorological situations.

Visualization system for display of temporal and spatial variations in meteorological data and in calculated concentration fields.

Progress achieved including publications

1. Introduction

During the contract period high priority has been given to the interfacing of RIMPUFF with the RODOS system. Work has concentrated on topics which are important in connection with the local scale atmospheric dispersion modelling in the emergency response system. Emphasis has also been placed on visualization of model results and other aspects of user training.

2. Interfacing with RODOS

All communication between the operating system in RODOS and the atmospheric dispersion module should take place through COMMON statements. Therefore a special version of RIMPUFF, RP4KFK5.FOR, has been created and transferred to KfK. RP4KFK5.FOR is without write and read statements. Further the updated modules for calculation of gamma-doses are included in this version.

3. Model development

New and updated models for plume rise, building wake and penetration of the inversion lid are being introduced in RIMPUFF. These sub-models are similar to the methods used in the OML-model (*OML=Operational Air Pollution Model*) developed by the danish environmental pollution laboratory.

A simple first order scheme for modelling of chemical reactions involving the materials released to the atmosphere have been tested in RIMPUFF.

4. Gamma dose modelling

In co-operation with CRIP, Budapest, we have started the development of a subroutine for the calculation of gamma doses from airborne and deposited radioactive isotopes, released to the atmosphere from a nuclear power plant during normal operation as well as during a hypothetical accident. We have completed the first stage of the project: *Calculation of gamma doses for spherical puffs by numerical integration for different values of* σ_p , E_γ *and puff center distances*. The second stage: *Development of a subroutine for* RIMPUFF *for calculation of gamma doses from airborne as well as deposited radioactivity*, will be finished during phase II.

5. Flow modelling

For complex terrain fluid-equation based windfield calculation is normally based on *one* upwind and terrain unperturbated observation. However, for neutral conditions, a procedure has been set up to calculate a windfield, which gives the best fit to a network of simultaneous observations at multiple stations. This fitting procedure has been implemented in RIMPUFF.

The improvement of LINCOM continues by including non-neutral temperature forcing, so it becomes able to deal with both unstable and stable situations flow fields.

6. Visualization of model results

Computer programs displaying time series of calculated and measured dispersion data has been developed. Most important is the program called S, designed as a tool for time-series

representation of a large number of data fields. Several kinds of data (vectors, scalars etc.) can be analyzed. The program is applied in the analysis of the 1990 Guardo trials.

7. Model evaluation

A series of 15 full-scale dispersion experiments from the 1990 Guardo trials, carried out over complex terrain in Northern Spain are being analyzed. Actual wind and turbulence measurements taken during the experiment are used as input data for a series of simulations made with Risø's combined flow and diffusion model (LINCOM/RIMPUFF). The results are analyzed for uncertainty by comparing with the actual observed concentration doses.

The sensitivity to different choices of stack heights has been evaluated in a study of buoyant power plant emissions at the Canary Islands (Gran Canaria and Tenerife).

Further an experimental evaluation of flow field and dispersion modelling has been performed, using data from the complex terrain SIESTA experiment (SF6 International Experiment in STagnant Air). Two alternative flow-field calculation methods were evaluated as "drivers" for the dispersion model RIMPUFF: One is the diagnostic mean-flow model LINCOM, the second is based on simple interpolation method using tower data (objective wind analysis).

Three of the SIESTA experiments were simulated, using RIMPUFF/LINCOM. In one of the experiments, wind direction and turbulence condition changed strongly with time. The comparison between measured and calculated values were quantified by the determination of Chi square, relative Chi square, correlation coefficient and mean error factor. In an orographically influenced dispersion scenario, like SIESTA, potential of improvements by use of the high-resolution mean wind model LINCOM was found.

Using data from our mini-LIDAR as obtained during several field-experiments, it has been shown that RIMPUFF is able to simulate short time concentration fluctuations very realistic .

In connection with forecasting of regional atmospheric dispersion a cooperation has been established between Risø, the Swedish Meteorological and Hydrological Institute (SMHI) and the Danish meteorological institute (DMI). Risø and SMHI are coupling the Risø mesoscale puff (RIMPUFF) to the SMHI regional scale dispersion model RAM. Methods for connecting the HIRLAM flow model to RIMPUFF are being investigated by DMI and

Risø. The aim of this work is to establish an integrated system for calculating the dispersion of toxic material over meso (100 km) and regional (1000 km) scales. In a case study HIRLAM and RAM were used for calculating the regional scale dispersion, while RIMPUFF, using the windfield data from HIRLAM, were used to calculate the dispersion on local/medium scale (100 km).

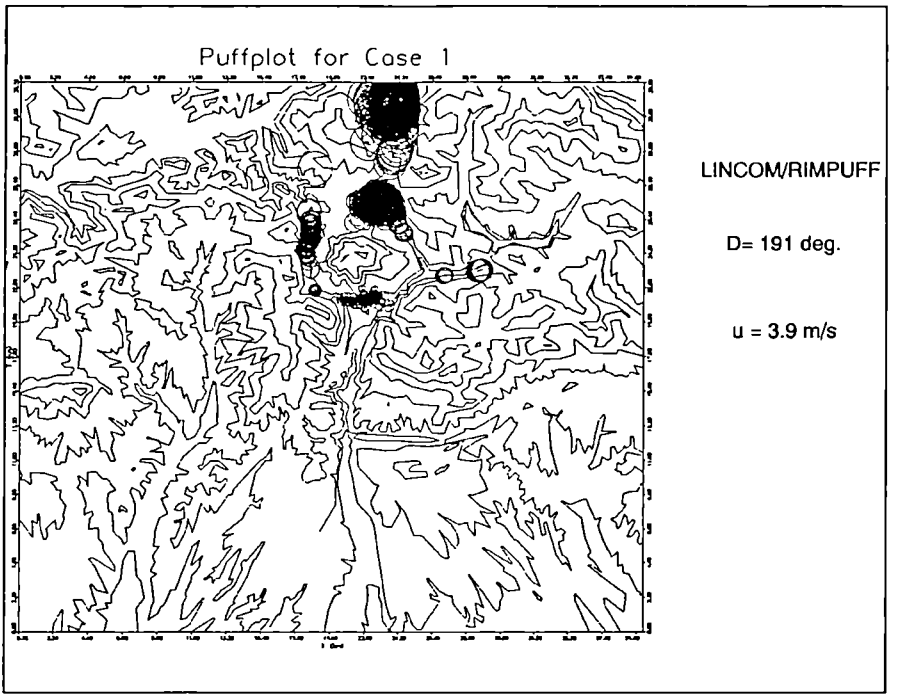

Figure 1 - Pentafurcation of Puffs after release from Guardo power plant

8. Preprocessing of input data

Preprocessing of meteorological data for dispersion models has been studied in cooperation with ENEA (*Project no. 7*). The resulting pre-processing subroutines are now being implemented in RIMPUFF.

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Project 7

Head of project: *Dr. Müller*

Objectives for the reporting period

Design and development of a foodchain transport module and a dose module for the European decision support system RODOS including

- adaptation of the modules of "EURALERT" developed in 1987-1990 according to the requirements of RODOS
- definition and implementation of interfaces and common submodules with other parts of RODOS
- integration of the foodchain transport module and the dose module into RODOS prototype 1
- extension of the data base of the code to some more
  - radionuclides including fission products of minor importance, corrosion products, actinides and noble gases,
  - products not yet taken into account, which are of some importance in parts of Europe
  - radioecological parameter sets for different regions in Europe
- implementation of results of other research programmes concerning external exposure

Progress achieved including publications

In the framework of the research programme "Radiological aspects of nuclear accident scenarios" the real-time emergency dose prediction system "EURALERT" has been developed during 1987-1990. This computer code has been designed to allow its adaptation to the different living habits, climatic and agricultural conditions in the different regions of the European Community.

In the current research programme, the EURALERT program system was used as a basis for a foodchain transport module and a dose module for the analysing subsystem (ASY) of the proposed decision support system RODOS. According to the requirements of RODOS, the module package ECOAMOR (ECOSYS ASY Modules for RODOS) has been designed, developed and installed in the prototype 1 version of RODOS.

The main features of ECOAMOR being different from the basis EURALERT are:

- The ECOAMOR package consists of a number of subroutines (submodules) written in FORTRAN-77 which are integrated into the RODOS system. Data transfer between the submodules is performed via common blocks and interfaces to other parts of the analysing subsystem of RODOS are located in a shared memory area. The program parts

of EURALERT are main programs linked each other and to the atmospheric dispersion programs by external files. Due to this change time consuming disk-I/O-operations are avoided.

- In the course of the ECOAMOR programme, all input operations are done before the calculation starts. After these input operations, the user may select the further course of submodules and other calculational options according to his needs and interests. Then the actual calculations are performed without user interface. At the end of the calculations, all results are kept in common blocks and can be made available to the operating system by declaring them as shared common areas.

- For an easy adaptation to different data structures and calculational options, ECOAMOR is written in a very flexible structure. The programme comprising the foodchain transport module and the dose module consists of a number of submodules performing data input and calculational steps. Due to this structure, a stand-alone version of ECOAMOR and the version integrated into RODOS can be developed in parallel, since these versions differ from each other by linking different modules for data-I/O to the same main modules of ECOAMOR. All dimensions of arrays, input data, parameters, and results of the calculations are declared in include-files, therefore, changes of these data have to be made only once to take effect in all submodules. Structural parameters like foodstuffs considered or calculations to be made by default are initialized in a block data module, these data can also be changed quickly and, furthermore, may be set differently by the controlling system. As in EURALERT, the calculational parameters are kept in files allowing an easy adaptation to differing radioecological and agricultural regions in Europe.

- In addition to the timescale considered in EURALERT (from 1 day up to 70 years), the external exposure pathways due to radiation from radionuclides in the cloud and from radionuclides deposited on the ground and the internal exposure committed by inhaled radionuclides are assessed in a short term timescale according to the atmospheric dispersion data with a timestep down to 10 minutes.

- ECOAMOR is capable of supporting an automatic and an interactive operational mode. In the stand-alone program version, a number of menues is displayed after the input part of the program, in which the user may select the types of calculations to be performed, locations and products to be considered, and further options of the program. In the integrated version, up to now only the automatic mode is realized having a predefined course of modules and setting of options.

- The two modules of ECOAMOR have a multitude of calculational endpoints according to the selected options. In the foodchain transport module, presently the following data are resulting from a longterm calculation, which can be performed for a number of up to 121 locations:
  - specific activities in foodstuffs with detailed time resolution (up to 250 time steps) for up to 25 preselected pairs of nuclide and foodstuff (e.g. milk for all nuclides considered) and further pairs with high contribution to the dose
  - specific activities for some groups of nuclides (e.g. iodine isotopes) in a few foodstuffs with a time resolution as before
  - maximum specific activities in all foodstuffs for all nuclides considered
  - times at which these maximum specific activities occur and, if a certain level (e.g. the

EC intervention level) is exceeded,, the begin, duration and end of exceeding the level

In the dose module calculation, the corresponding results for again up to 121 locations are

- nuclide specific doses due to four exposure pathways and their sum
- intakes of radioactivity by ingestion for the nuclide foodstuff pairs considered
- ingestion doses for the nuclide foodstuff pairs considered
- ingestion doses due to groups of nuclides in groups of foodstuffs (e.g. iodine isotopes in milk and milk products)

Each of these results of a dose module calculation are given for two groups of individuals, e.g. effective doses of adults and thyroid doses of one year old children, and for up to 10 follow-up periods between 1 day and 70 years.

Since the development of the longterm countermeasure module in the countermeasure subsystem (CSY) of RODOS is performed by another contractor, the interfaces between the ECOAMOR modules and the longterm countermeasure module were defined and established. As a first step, these interfaces were realized by external files. For the purpose of consistency of calculations in ASY and CSY, some parts of ECOAMOR are used in both subsystem for the same calculational steps, namely, the calculation of activities in processed foodstuffs from the activities in primary products, the calculation of activity intakes and the calculation of ingestion doses.

The integration of the ECOAMOR modules into RODOS prototype 1 succeeded and was demonstrated at a Workshop in Elmau in October 1992. The interfaces between the atmospheric dispersion module and the transfer of the output data to the graphical subsystem of RODOS was found working correctly as well as the interface to the CSY-subsystem, so a graphical output of ECOAMOR module results was available. It was agreed to integrate in this demonstration system only a reduced set of output data including activity concentrations of iodine and cesium isotopes in milk and grain and ingestion doses due to these groups of nuclides and foodstuffs.

The data base of radionuclides has been extended to a number of 33 nuclides and 19 elements for which the radioecological data are assembled. The additional nuclides comprise the noble gases ^{88}Kr, ^{133}Xe and ^{135}Xe and short lived iodine isotopes (^{132}I, ^{133}I, ^{135}I) which were both included in the source term for the RODOS demonstration system.

A model for predicting activity concentrations in rice after deposition of radionuclides has been developed, but has not yet been implemented in the ECOAMOR foodchain transport module.

The work necessary for the development of the ECOAMOR modules according to the requirements of the system and their integration into RODOS exceeded by far the expected expenditure of work for optimization of computer programs according to the proposal. Therefore, the objectives concerning the compilation of radioecological parameter sets for different regions in Europe and implementation of results of other research programmes concerning external exposure could not be achieved in this funding period.

Publications

W. Friedland, H. Muller, G. Prohl, J. Brown, N.P. McColl, J.A. Jones and S M. Haywood: Modules for foodchain transport, dose assessment and long term countermeasures in RODOS, the European decision support system. Contribution to: "Third International Workshop on Real-time Computing of an Accidental Release to Atmosphere from a Nuclear Installation", Schloß Elmau, Bavaria, October 25-30, 1992. To be submitted to Radiation Protection Dosimetry

H. Muller, W. Friedland, G. Pröhl:
Uncertainty in the ingestion dose calculation. Contribution to: "Third International Workshop on Real-time Computing of an Accidental Release to Atmosphere from a Nuclear Installation", Schloß Elmau, Bavaria, October 25-30, 1992. To be submitted to Radiation Protection Dosimetry

G. Prohl, W. Friedland, H. Müller:
Potential Reduction of the Ingestion Dose after Nuclear Accidents due to the Application of Selected Countermeasures. Contribution to: "Third International Workshop on Real-time Computing of an Accidental Release to Atmosphere from a Nuclear Installation", Schloß Elmau, Bavaria, October 25-30, 1992. To be submitted to Radiation Protection Dosimetry

Project 8

Head of project: *Dr. Christer Persson*

Objectives for the reporting period

- Adaption of an Eulerian meso-scale dispersion model to emergency applications on the European scale, including development of a detailed description of the initial plume dispersion during the first 24 hours.

- Adaption of the dispersion model to different sets of real time meteorological input data, both analyses and forecasts, and improvement of the analyses of some essential dispersion parameters such as the boundary layer height and the eddy diffusivity.

- Recoding to improve the portability of the model code to different computer systems.

- Preparations for real time applications.

Progress achieved including publications

The SMHI meso-scale 3-D Eulerian dispersion model has been adapted to emergency applications and extended to the European scale. The basic feature of the model is a time and space variable vertical resolution. The advantage with this approach is that detailed information about the physical dispersion processes can be obtained within the frame of a limited computing volume. The model covers vertically the lowest 2-3 km of the atmosphere. A version of the model extending up to 7 km height in the atmosphere has also been tested. Wet and dry deposition of radionuclides as well as gravitational settling are included.

The horizontal advection is calculated using a fourth order flux correction scheme, while the vertical transports are determined from the similarity theory and the spatial and temporal variations of the mixing height. An operator split time integration scheme is used.

The further modelling work has been emphasized on the initial phase of an accidental release and on the first 24 hours of transport and dispersion of the plume. A careful description in this respect is a very important part of an emergency response system for large scale transport. A Gaussian puff model is used to describe the initial phase of the plume transport and dispersion. We have improved the technique of handling the puffs by implementing a puff-splitting technique taking the vertical wind shear more properly into account. Of specific concern is how to introduce the puffs into the Eulerian model. Improvements have also been achieved in terms of describing the initial spread of a released cloud. Progress in this respect has been made in cooperation with the Risø National Laboratory.

The dispersion model has been adapted to real time meteorological input data, both analyses and forecasts, from either HIRLAM (joint Nordic-Dutch-Irish high resolution weather forecast model) or from ECMWF (European Centre for Medium-range Weather Forecasts). Forecasts up to 48 h over Europe can be obtained from HIRLAM, while ECMWF-data can be used globally and for forecasts up to 7 days. The grid resolution is at present 40 km when using HIRLAM data and about 100 km with ECMWF data.

The Eulerian dispersion model was intentionally developed for a regular grid with equal grid spacing. When adapting to the European scale various map projections have to be considered. The system was therefore recoded to be independent of projection. However, the map projections used have to be specified, and at present the following projections are accounted for:

- regular equally spaced grid,
- latitude-longitude grid,
- rotated latitude-longitude grid.

Other projections are easily implemented in the system, and therefore the system has a great feasibility to use analysed or forecast meteorological input fields from various data bases. However, the interface to such data has to be carefully specified.

The model has been recoded giving a more general structure, and a large emphasis has been put on increasing the portability of the code. We have restricted the coding, as far as possible, to FORTRAN 77. The model is now applicable in VAX/VMS environment and UNIX environment.

Real time applications have been made in some situations. In terms of accidental releases a simplified version of the model was used at the advent of the Gulf war. The model was here extended to the continental scale with the use of weather data from the ECMWF (European Centre for Medium Range Forecasts) global database. We also participated in a nuclear emergency response exercise, on January 16, 1992, initiated by the Nordic Nuclear Security Research (NKS). Real time dispersion forecasts were also made in connection to the emission of radioactivity from Sosnovyy Bor, St. Petersburg, March 21, 1992.

Some preliminary studies have been made of introducing data assimilation of radiological data, connected to the European scale real time dispersion model. The underlying theory proposed is rather general in context, whilst the specific implementation is strongly model-dependent. Far more attention will be paid to this challenging task in the continuation of the programme.

Proceedings

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An operational Eulerian dispersion model applied to different scales - Applications possible on a subgrid level in the EMEP grid.
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Robertson, L., and Persson, C. (1992)
Attempts to apply four dimensional data assimilation of radiological data using the adjoint technique.
Proc., Third International Workshop on Decision-Making Support for Offsite Emergency Management, October 25 - 30, Schloss Elmau, Bavaria.

REAL-TIME UNCERTAINTY HANDLING AND DEVELOPMENT OF A COMPUTER BASED TRAINING SYSTEM FOR THE MANAGEMENT OF OFF-SITE NUCLEAR EMERGENCIES

Contract Bi6-106 - Sector C24

1) *Govaerts*, CEN -SCK

Summary of Project Global Objectives and Achievements

In case of an accidental release of radioactive materials to the atmosphere, it is a major task to make as soon as possible a realistic assessment of the environmental impact of the releases, in order to optimize interventions for the protection of the public. Past accidents have learned that the availability of data on source terms and transfer parameters might be rather weak. Reliable environmental monitoring data might be considerably delayed.

This project aimed to develop methods to reduce the initial uncertainty concerning the radiological situation in the early phase following an accidental radioactive release by considering near-field off-site environmental monitoring data as well as available on-plant data. The basic principle is to revise model input data and transfer parameters by comparison of model predictions with the early environmental monitoring results.

In addition to the further analysis of the advantages and disadvantages of proposed methods (numerical optimization, regression of environmental data) the opportunity of an alternative method, based on fuzzy logic, has been tested out on experimental tracer data. Independently of this, methods based on simple physical principles have been withheld.

In parallel with further reflexions and tests in order to find the most appropriate approach, work started to implement these methodologies into the European Decision Support System (DSS), under development by contract BI7-0045-C, coordinated by the Kernforschungszentrum Karlsruhe.

Project 1

Head of project: *Dr. Govaerts*

Objectives for the reporting period

1. To discuss the incorporation of a module to reduce the radiological uncertainty based on the inclusion of early near-field survey monitoring data in the "Comprehensive decision support system for Nuclear Emergencies in Europe", developed under contract BI7-0045-C.
2. To work out the previously developed methodology, based on a numerical optimization process for a realistic environmental monitoring system.
3. To discuss alternative methods to handle the differences between predicted and observed environmental data, in order to decide on the approach to be used in the European decision support system under development, such an approach should avoid the difficulties associated to the numerical method, developed up to now by the contract.
4. Preparation of a demonstration unit on PC, for presentation at the 3rd Real-Time Workshop at Schloss Elmau, 25-30 October 1992.

Progress achieved including publications

1. Incorporation of a "feedback" - module in the "Comprehensive Decision Support System for Nuclear Emergencies in Europe"

The incorporation of a module to correct predictions, based on a real-time dose assessment by considering some environmental data is discussed with the coordinator and the partners of the CEC-Radiation Protection Programme, contract BI7-0045-C during working sessions, organized at Neuherberg, Brussels and Karlsruhe. The main conclusions are :

- To develop an off-line module, with an input-output compatibility with the main system. The module can be inserted in the system under the control of the user. The module has to be considered as a tool for the user to explain and reduce differences between predictions and observations. It remains up to a users'decision to correct the predictions in the way proposed by the feedback module, and to associate weighing factors to the reliability of individual monitoring results.
- Regarding the complexity of the exercise a feedback exercise has to be based on a gaussian-like atmospheric dispersion model. Eventually it can be organized to confirm or correct in a first instance the trajectory of the center of mass of the releases, followed by a correction of source term, height of release and dispersion around the trajectory.
- Parameters optimized by the application of an optimization loop to a simple model, can then be introduced in a new assessment applying a more complex dispersion model.

2. Demonstration of the numerical optimization technique

The previously developed numerical optimization technique has been demonstrated on the measuring data collected by a set of gamma exposure rate monitors. The response of a gamma exposure rate meter can be predicted by :

$R(x,y) = f$ (S, H, stability, windspeed, wind direction)

where
- S is the source term, to be considered as a sum of release terms associated with consecutive gamma energy windows
- H is the effective height of release

A given response constraints the possible values of the arguments inside well-defined domains of the parameter space, defined by this physical relationship. The response of all monitors constraint those values to the intersections of the specific domains. In the ideal case this intersection will be a point giving the exact value for each argument, as soon as the number of monitors equals the number of arguments. In real cases this intersection will never be a single point.
A numerical optimization technique allows to choose a best value for each argument.
The most sensitive parameters will be the source term, the effective height of release and the wind direction.

3. Discussion of alternative methods

3.1. Fuzzy logic

An increasing number of practical optimization systems use the so-called fuzzy logic instead of numerical optimization techniques. Fuzzy logic is appropriate to translate a qualitative judgement into a degree of membership to a given group. A logic has been developed to derive a degree of "possibility" or "necessity" to conclusions, based on the combination of several fuzzy information.

Each environmental observation can in this way be appreciated and qualified as e.g. in very good agreement, good agreement, bad agreement, very bad agreement with the predictions, using an agreement membership function. An application of the fuzzy logic might allow to define boundaries to the possible values of the model input data or parameters. This approach has been combined with an analysis of spatial distribution of P/O-ratios.

A variation of a key-parameter of the prediction model will introduce a specific spatial distribution of the predicted to observed ratios. In a normal situation with a good fit between predictions and observations the P/O ratios are distributed symmetrically around 1. An artificial decrease of the source term, e.g. will decrease all the P/O ratios. A shift in wind direction will decrease the P/O values under the real wind direction and increase the ratios under the assumed wind direction. Analogous graphical transformations of the P/O distributions can be associated with variations of other parameters.
Following an analysis of typical P/O distributions an expert system is under development to propose variations to the input parameters, transforming the P/O ratio distribution to an acceptable distribution centered around 1, taking into account the limited validity of a model.

3.2. Methods based on physical methods

In the early phase of an accident the uncertainty about the radiological situation will be very important. All types of monitoring data, if obtained by following the monitoring procedures, will have an inherent information value and will help to reduce the uncertainty. One way to extract this information out of the data is the application of general physical princi-

ples on each specific data item as well as on a comparison between the monitoring data and model predictions, taking possible weaknesses of the model into account.
The first step is the acquisition of a raw data base of monitoring data (cloud, ground doses and dose rates, air concentrations, soil samples, gamma spectrometry, ...). This data has to be preprocessed with a data assimilation module, considering the geographical distribution of the data as well as the elementary updating cycle steps. A continuous comparison procedure between the monitoring data and model prediction will allow to reduce the radiological uncertainty about this release. Figure 1 gives a schematic representation. This methodology has to be further elaborated in view of the possible implementation, as shown in figure 1, in the European Decision Support System.

4. Preparation on a demonstration unit

A first off-line version of the uncertainty reduction module, using the methods mentioned in III.3.1. (fuzzy logics) is intended to be shown at the occasion of the demonstration of the European Decision Support System during the CEC-workshop on real-time systems in October 1992.

5. Publications

Govaerts P., Sohier A.
Optimization of real time dose assessment models, including the interface with environmental survey.
Seminar on methods and codes for assessing the off-site consequences of nuclear accidents.
Athens (Greece), 07-11.05.1990

Sohier A., Zeevaert Th., Govaerts P.
The use of an incomplete information data base for the assessments during the early phase of an accidental release of radioactive material.
8th International Conference of the International Radiation Protection Association, Montréal (Canada), 18-22.05.1992.

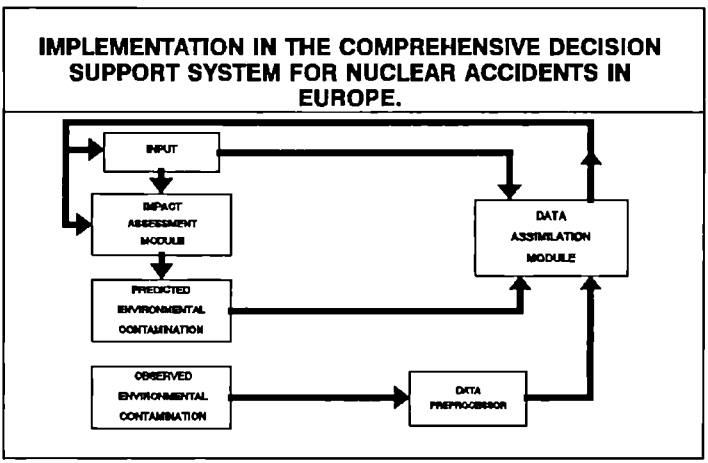

Fig. 1

EMPIRICAL AND FRACTAL DESCRIPTION OF RADIOLOGICAL DATA DETECTED AFTER CHERNOBYL ACCIDENT

Contract Bi7-062 - Sector C24

1) *Ratti* , Univ. Pavia

Summary of project global objectives and achievements

PART 1 - Fractal Model to describe the air radioactivity content in Northern Italy consequent to the Chernobyl accident.

During the work performed in the framework of Contract B16*-0241-I(A), it has been envisaged the possibility to develop an empirical fractal model able to take advantage of the experimental information available in campaign measurements performed immediately after the accident by different Laboratories and continued over a period of more than one month. Such information should provide the possibility of nearby extrapolation and hence the estimates in neighbourhood regions should be possible.

PART 2 - Fractal Analysis applied to the cumulative deposition of ^{137}Cs over various European Countries.

Deposition is very important as it represents the gate to the food chain contamination and has occurred in a very sparse and heterogeneous way, according to the path of precipitation and its intersection with the cloud. Therefore we feel it might be of great importance to undertake a study aimed at determining the general distribution features of the deposition and the frequencies of occurrence of the hottest spots.

The experimental information available in the Data bank REM consists not only of cumulative deposition data, but also of the daily values of precipitation, gathered over large part of Europe that represents an unique opportunity to describe the wet deposition phenomenon of the radionuclides. Fractal Models seem to be a new opportunity to do that. The number of precipitation data to be used is in order of half million, whilst the number of cumulative ^{137}Cs deposition data is few thousands. The study can therefore improve consistently the knowledge of the contamination of European soil. The distribution of intensities resulting from the Fractal Model application can be of great help in understanding future accident pathways.

Project 1

Head of project: *Prof. Ratti*

Objectives for the reporting period

The first preliminary fractal model of air pollution is based on the theory of Random Fractal Pulses. The input values are the fractal features of the atmospheric phenomenon (as used in meteorology) and the intensity of pollution estimated for each County, by means of an empirical decay function which fits the time-dependence of the pollution after the Chernobyl accident. This is done for each available radionuclide.

In the previous contract the parameters of that function for only four Counties of Northern Italy for ^{137}Cs, ^{134}Cs, ^{131}I, ^{132}I were determined. Now we are able to recover a larger data set by using additional measurements in different County. This will allow us to run the fractal model over all the Northern Italy.

The intermediate report is devoted to the elaboration and application of an original "recovery Method" based on the physical meaning of the parameters of the decay function. The method is checked against predictability and accurateness on the Counties analysed in the previous contract.

The results are rather good and provide an improved set of parameters (different curves describing the time dependence of the pollutant intensity in different counties) on which the fractal model can run.

Progress achieved

During the work done for the Radiation Protection Programme (Post-Chernobyl-Action 1) we set a mathematical function[1a,b] for the description of the air pollution for a given radionuclide (1):

$$y = K + e^{\{[-\frac{A}{\tau}t + B]\cdot[1 - e^{(\frac{C}{t} - t)}]\}} \qquad (1)$$

This function was applied to data sets collected in REM belonging to Italy and France and was good to properly describe the time dependence of radionuclide's concentration in air (starting from the instant of the Chernobyl accident).

In the first part of the present contract we try to recover information on ^{137}Cs by using the empirical parametrization applied to certified ^{137}Cs data available in nearby Counties as well as information from the data available on other nuclides in the same location.

The procedure is used to recover the numerical values of the parameters and the function provides "pseudomeasured values" of the nuclide' concentration.

The final goal is to use the total sample (measured plus pseudomeasured values) to describe a reasonable scenario of the air pollution due to ^{137}Cs in as many Counties as possible in Northern Italy. It is worth mentioning that it is not our principal aim to recover real measurements on the nuclide ^{137}Cs but rather to give at least an order of magnitude of the possible amount of ^{137}Cs and to avoid the dangerous situation in which any

predictive model is allowed to widely fluctuate without any constraint. *At this moment, in order to test a model, it is not important to have real data but rather to check how simulated fractal fluctuations might be able to reproduce a set of given data.* We will consider in the second part of the contract the sample of the real plus recovered data as a "field" of measurements in a fictious accident and try to reproduce the same field via a fractal procedure. Nonetheless *we will show that our recovery method is able to provide more than reasonable estimates for the missing nuclide.*

The left hand side of Table I shows the number of data available (^{134}Cs and ^{132}I nuclides are not reported since the presence of their values is irrelevant to our aim) and the four Counties where measurements on ^{137}Cs were missing. The right hand side the Table collect the amount of data usable in four different and possible "recovery methods" (e.g. use of data coming from other nuclides as specified in the first line of each column).

Tab. I - Analysis of the methods applicable to the available set of data.

County	Cs 137	I 131	Ru 103	Te 132	METHODS a=I-Ru	b=I+Te	c=I	d=Ru
AL	26	34	34	18	68	52	34	34
LT	47	73	51	33	124	106	73	51
MI	82	160	51	83	211	243	160	51
MT	66	68	68	-	136	-	68	68
PC	50	75	55	48	130	123	75	55
PV	76	58	76	47	134	105	58	76
RM	114	130	101	81	231	211	130	101
VC	58	78	37	27	115	105	78	37
PA	14	12	-	-	-	-	12	-
BO	32	41	43	21	84	62	41	43
CE	-	15	16	-	31	-	15	16
GE	-	10	-	10	-	20	10	-
PD	-	25	-	-	-	-	25	-
PI	-	25	-	-	-	-	25	-
TS	12	37	23	10	60	47	37	23

Each method, when possible, is separately applied to all Counties neglecting the data on ^{137}Cs. this allows us to check the predicted results with the neglected measurements.

Any method is applied in three consecutive steps.

In the first step we calculate parameters "A","B","C","K" of function 1 by using "single" and/or "global" fit[1a,b] and select among the two methods which is the best for each country and each nuclide.

In the second step the parameters are further processed in the following way:

- parameter "A" (time decay) is County-independent[1a,b] and unique for each nuclide;
- parameter "B" (power of the pollutant cloud) is evaluated, for a missing nuclides in a given County, by using the ratios between the B values of one (or two or three) different nuclides. Thus the ratio $B_{(i)}/B_{(j)}$ (for instance i =Cs, j =I,Ru,Te) is measured wherever possible and the overall average and dispersion are calculated by the following formulas:

$$R_{(i,j)} = \frac{B_i}{B_j} \qquad R_{\min(i,j)} = \frac{B_i - \sigma_{Bi}}{B_j + \sigma_{Bj}} \qquad R_{\max(i,j)} = \frac{B_i + \sigma_{Bi}}{B_j - \sigma_{Bj}} \qquad \sigma_{R(i,j)} = \frac{R_{\max(i,j)} - R_{\min(i,j)}}{2}$$

The value of "B" is then "weighted" by using the function:

$$B^{*}_{(Cs)} = \frac{B_I \cdot R_{(Cs/I)} \cdot n_I + B_{Ru} \cdot R_{(Cs/Ru)} \cdot n_{Ru} + B_{Te} \cdot R_{(Cs/Te)} \cdot n_{Te}}{n_I + n_{Ru} + n_{Te}} \qquad (2)$$

and the error is evaluated by:

$$\sigma_{B^{*}_{(Cs)}} = \frac{(\sigma_I \cdot R_{(\frac{Cs}{I})} + B_I \cdot \sigma_{R_{(\frac{Cs}{I})}})n_I + (\sigma_{Ru} \cdot R_{(\frac{Cs}{Ru})} + B_{Ru} \cdot \sigma_{R_{(\frac{Cs}{Ru})}})n_{Ru} + (\sigma_{Te} \cdot R_{(\frac{Cs}{Te})} + B_{Te} \cdot \sigma_{R_{(\frac{Cs}{Te})}})n_{Te}}{n_I + n_{Ru} + n_{Te}} \qquad (3)$$

- parameter "C", assuming that all nuclides have, in the same County, the same time arrival of the pollutant cloud, is assumed to be the time arrival of the one measured nuclide or calculated as the weighted average of the two (or three) measured nuclides:

$$C^{*}_{(Cs)} = \frac{C_I \cdot n_I + C_{Ru} \cdot n_{Ru} + C_{Te} \cdot n_{Te}}{n_I + n_{Ru} + n_{Te}} \; ; \; \sigma_{C^{*}_{(Cs)}} = \frac{\sigma_I \cdot n_I + \sigma_{Ru} \cdot n_{Ru} + \sigma_{Te} \cdot n_{Te}}{n_I + n_{Ru} + n_{Te}}$$

- parameter "K" (background level of the nuclide) is not easy to calibrate. However it is not a relevant problem since the numerical value is fluctuating from values 10^{-3} to 10^{-5} so that we adopted for the specific nuclide the average values of "K" calculated on all available Counties.

The next step compares the recovered measurements obtained in the Counties were ^{137}Cs was known with the real data and choose the best recovery method. In Table II the numerical values of the original and the recovered parameters "B" and "C" (the two most important parameters in formula (1)), the best among the all applicable "methods" for each County the number of data used in the adopted method are collected.

Tab. II - Comparison of the (original-recovered) values of the parameters; best choice of the method and data used.

Counties	parameter B		parameter C		method	# of dat.
	RECOVERED	*ORIGINAL*	*RECOVERED*	*ORIGINAL*		
AL	3.842 ±0.099	3.580 ±0.134	49.468 ±1.104	47.062 ±0.970	c	34
LT	4.056 ±0.078	3.980 ±0.112	70.651 ±0.29	80.913 ±1.496	c	73
MI	3.648 ±0.079	3.547 ±0.794	28.069 ±0.933	30.741 ±0.438	c	160
MT	4.329 ±0.051	4.424 ±0.542	46.017 ±0.358	56.176 ±1.637	c	68
PC	4.403 ±0.081	3.496 ±0.736	65.647 ±0.539	81.026 ±2.115	c	75
PV	3.208 ±0.054	3.405 ±0.321	32.774 ±0.525	36.924 ±0.307	c	58
RM	3.619 ±1.002	4.002 ±0.794	41.087 ±0.902	39.322 ±0.558	a/c	231
VC	3.377 ±0.935	3.223 ±0.123	24.429 ±0.221	29.349 ±0.584	a/c	115
PA	3.839 ±0.103	1.001 ±1.341	26.685 ±45.059	33.934 ±77.301	c	12
BO	3.105 ±1.188	2.644 ±0.750	67.996 ±0.658	46.347 ±1.664	b	62
TS	4.736 ±0.093	4.396 ±0.179	46.338 ±59.929	99.998 ±74.009	d	23

Figure 1 shows, as an example, the comparison by using function 1 in Matera between bands (determined by the errors) of the curves fitted on the real data (continuous lines) and the bands (determined by the errors) of the curves recovered by the method (dotted lines). The experimental measurements (points with error bars) are also reported for comparison. They lies well within the estimated bands.

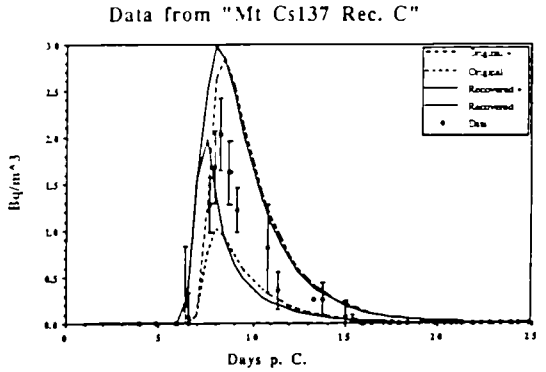

Fig. 1 - Comparison of the behaviour of functions (1) and analytical measurements for Matera

In the last step we apply the "best" recovery method to the Counties where ^{137}Cs measurements are missing, the behaviour of the pollution in air by using the parameters calculated with recovering function (1). Figure 2 shows as an example the highest and the lowest curves recovered for the County of Genova.

The complete set of real data (Alessandria, Milano, Piacenza, Pavia, Vercelli, Bologna, Trieste) and of recovered data (Genova, Padova, Pisa) is then now available to be the input of the fractal simulation in Northern Italy.

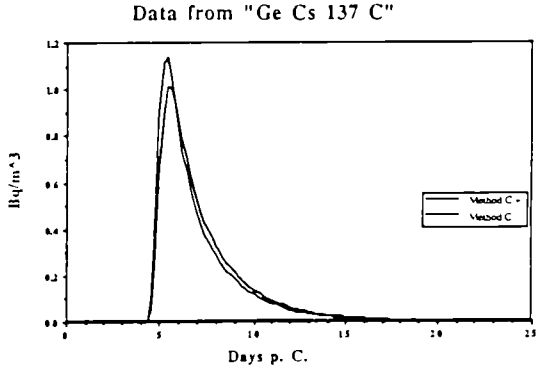

Fig. 2 - Behaviour of function (1) by using recovered parameters for ^{137}Cs in Genova.

COORDINATION ACTIVITIES

Coordination

Study Group meetings, Workshops, Seminars and Symposia have proved to be a most effective means of coordination because they are naturally adapted to scientific work and easily accepted by scientists. These meetings, focusing on the evaluation of particular subjects areas of the Radiation Protection Programme, are attended by research workers involved in the contract programme, as well as scientists from non-participating laboratories or organizations and by scientific staff members of the Commission.

On the following pages the various meetings held in the period from 1 June 1991 - 31 December 1992 are listed:

A: Meetings of Study Groups, where scientists involved in the contract programme, independent experts and Staff Members of the Commission discuss specific subject areas of the programme.

B: Meetings organized, coorganized or cosponsored by the Commission of the European Communities on special subject areas of interest for radiation protection and where contacts among scientists from a wider range of discipline and countries might be established.

C: Meetings of experts appointed for the purpose of coordinating and stimulating efforts toward practical measures of radiation protection as foreseen in Chapter III of the EURATOM Treaty or convened by the Commission for special tasks.

A

Meetings of study groups

Study Group on "Memorandum of Understanding CEC-US DOE"

Niagara Falls (CND), 14 - 17 July 1991
17 participants from US-DOE and the Commission

Principal subjects:

- Organizational changes at DOE and programme development
- Chernobyl activities
- Radon research
- Patient dose reduction
- Radioecology
- Health effects research
- Microdosimetry and biophysical modelling
- Expert judgement in uncertainty analysis
- EC radiation protection standards
- Training (ERPET)
- CEC/DOE Collaborative research activities

Study Group on "Memorandum of Understanding CEC - AEC Ltd."

Chalk River (CND), 18 - 19 July 1991
40 participants from Canada (Control Board, Health and Welfare Canada, Advisory Committee on Radiation Protection) and the Commission

Principal subjects:

- Amendments of regulations of directives to the new ICRP recommendations
- Chernobyl actions of the CEC Radiation Protection Programme
- Radiation biology
- Dosimetry
- Environmental research
- Radioecology and environmental risk assessment
- Radiation protection of the patient
- EC radiation protection standards

Study Group on "Quality Control of the Technical Aspects of Mammography Screening"

Nijmegen (NL), 9 - 10 September 1991
6 participants from 3 countries and the Commission

Principal subjects:

- Guidance to the establishment of quality control of the technical aspects of mammography screening;
- List of physical and technical parameters to be checked, frequencies and limiting values, measurement methods and tolerances;
- List of quality control equipment;
- Project of a protocol for quality control measurements.

Study Group on Decision Analysis Methods for use in establishing Intervention Levels

Chilton (GB), 16 - 17 September 1991
8 participants from 2 countries and the Commission

Principal subjects:

- Software for decision analysis
- Accident scenarios
- Technical input to Art. 31 WG on relocation

Study Group on Decision Support System for Off-site Emergency Management

Athens (GR), 26 - 27 September 1991
28 participants from 9 countries and the Commission

Principal subjects:

- Decision support systems for off-site emergency management
- Uncertainty estimation
- System and software structure
- Environmental modelling
- Decision aiding techniques

Study Group on CEC/NEA Intercomparison of Probabilistic Accident Consequence Assessment Codes (meeting of Project Management and Ad-hoc Group)

Paris (F), 2 - 4 October 1991
44 participants from 14 countries, IAEA, OECD and the Commission

Principal subjects:

- Intercomparison of probabilistic accident consequence models
- Specification of the intercomparison
- Evaluation of pilot exercise

Study Group on "Technical Requirements of X-Ray Equipment used in Paediatric Radiology"

Luxembourg (L), 16 October 1991
17 participants from 4 countries and the Commission

Principal subjects:

- Specification of X-ray equipment for paediatric diagnostic examinations with a view to image quality and dose reduction;
- Perspectives and future needs of paediatric radiology equipment;
- Improvement of paediatric radiology by more specific training.

EULEP Radon Task Group Meeting on the effects of inhaled radon and radon progeny.

Oxon (GB), 21 - 22 October 1991
8 participants from 3 countries and the Commission

Principal subjects:

- To organize an interlaboratory comparison of radon and radon daughter metrology in the exposure chambers used by the participating laboratories;
- To relate the concentration of radon and radon daughters to their deposition in the respiratory tract of rodents and the effects of different attached fractions;
- To explore the use of in vivo biological indicators of dose such as the induction of chromosome and nuclear aberrations in the lung and airway cells.

Study Group on Review of Pilot Study on Expert Judgement Elicitation

Chilton (GB), 22 October 1991
6 participants from 3 countries and the Commission

Principal subjects:

- Atmospheric dispersion and deposition
- Expert judgement elicitation
- Evaluation of pilot uncertainty analysis

Study Group on CHECIR project (JSP-1) to finalise the scope and content of this joint project

Obninsk, Moscow, Kiev and Zeleny Mys (CIS), 28 October - 1 November 1991
25 participants from 6 countries and the Commission

Principal subjects:

- Decision support systems for off-site emergency management
- Specification of CEC/CIS joint project
- Chernobyl data base
- Atmospheric, terrestrial and aquatic models

Study Group on "Quality Assurance and Radiation Protection in Digital Radiography - Restricted Programme, Committee of the Workshop (Mannheim 7-9 May 1992)"

Leuven (B), 20 November 1991
8 participants from 2 countries and the Commission

Principal subjects:

- Selection and limitation of subject areas;
- Organization and structure of planned discussions;
- Definition of terms of reference for comparison of analogue and digital radiography;
- Draft of Scientific Programme;
- List of potential participants to be invited to the Workshop.

Medical Physicist

Luxembourg (L), 13 December 1991
33 experts from 14 countries and the Commission

Principal subjects:

- Status and training of the medical physicist
- Job description of the medical physicist
- Discussion on article 5 of the Patient Directive

Joint meeting of EULEP Task Groups.

Chilton (GB), 16 - 17 December 1991
20 participants from 5 countries and the Commission

Principal subjects:

- To achieve a closer collaboration and a more co-ordinated approach between the Task Groups, particularly with regard to the sharing of material and ideas;
- The main topic areas were retroviruses-irradiation and osteosarcomas, cytogenetic and molecular studies on myeloid leukomogenesis, osteogenic and haemopoietic responses of bone marrow cells after X-irradiation, cell biology and lymphomagenesis.

Study Group on Methods for Assessing the Radiological Impact of Accidents (MARIA)

Chilton (GB), 20 - 21 January 1992
12 participants from 6 countries and the Commission

Principal subjects:

- Methods for assessing accident consequences
- PC version of COSYMA software
- Models for dispersion, health effects, economics, urban transfer
- Grids of population and agriculture

Study Group on proposed CEC/USNRC Joint Project on Uncertainty Analysis

Chilton (GB), 20 January 1992
6 participants from 3 countries and the Commission

Principal subjects:

- Uncertainty analysis of COSYMA
- Expert judgement methods
- Specification of joint project with USNRC

Study Group on Decision Support System Structure

Chilton (GB), 22 January 1992
8 participants from 3 countries and the Commission

Principal subjects:

- Decision support system for off-site emergency management
- System structure
- Software and graphics

Study Group on CHECIR project ECP-1 - resuspension and redistribution of radionuclides deposited in an accident

Neuherberg (D), 23 - 24 January 1992
12 participants from 6 countries and the Commission

Principal subjects:

- Resuspension and recontamination
- Resuspension during agricultural activities
- Resuspension by traffic
- Intercomparison of resuspension measurement techniques
- Specification of field campaign for 1992
- Equipment needs and exchange of scientists

Study Group on "Evaluation of the 1991 Trial on Quality Criteria for Diagnostic Radiographic Images"

Jouy-en-Josas (F), 24 - 30 January 1992
21 participants from 8 countries and the Commission

Principal subjects:

- Discussion of evaluation procedure and improvement of questionnaires;
- Evaluation of the image quality of 2000 radiographs from 74 radiological departments from 16 European countries;
- Evaluation of physical-technical parameters.

Study Group on "Test Phantoms and Optimisation in Diagnostic Radiology and Nuclear Medicine", Restricted Programme Committeeof the Workshop (Würzburg, 15-17 June 1992)"

Neuherberg (D), 3 - 4 February 1992
8 participants from 3 countries and the Commission

Principal subjects:

- State of the art of the design and performance of test objects and phantoms and computational models used for quality control in diagnostic radiology and nuclear medicine;
- Perspectives for standardisation of acceptance and constancy testings as a basis for optimisation of diagnostic radiology and nuclear medicine concerning image quality and patient dose.

Study Group on "The behavior of radionuclides in natural and semi-natural ecosystems"

Rome (I), 9 - 11 February 1992
10 participants from 6 countries and the Commission

Principal subjects:

- Results achieved by each participating Institution to ECP5 project on the fate and behaviour of Chernobyl fallout.
- Planning of field and laboratory exercises in EC-countries for intercomparison of methods and procedures used in radioecological studies.
- Planning of CIS scientists visits in EC laboratories in 1992.
- Planning of field activities in the Chernobyl area during 1992.

Study Group on "The transfer of radionuclides through the terrestrial environment to agricultural products, including thein fluence of agro-chemical practices".

Stockholm (S), 11 - 13 February 1992
11 participants from 6 countries and the Commission

Principal subjects:

- Results achieved by each participating Institution to ECP2 project on the fate and behaviour of Chernobyl fallout.
- Planning of field and laboratory exercises in EC-countries for intercomparison of methods and procedures used in radioecological studies.
- Planning of CIS scientists visits in EC laboratories in 1992.
- Planning of field activities in the Chernobyl area during 1992.

EULEP General Assembly and Annual Meeting

Gunzburg (D), 24 - 27 February 1992
90 participants from 15 countries and the Commission

Principal subjects:

- Two different one-day symposia were organised : -Pathology of Transgenic Mice and -Late effects after Total Body Irradiation. The topics were in general the lessons learned from studying transgenic mice, and the different pathology of transgenic mice carrying and expressing activated oncogenes. This symposium was to establish the state-of-art of this animal model. The symposium on the late effects after BMT were new malignancies after BMT, growth and development of children after transplantation, clinical performance of patients after 5-year survival.
- Several Task groups presented a report of their activities. Decorporation Task Group; Leukaemia Task Group; Fetal dosimetry;
- A session was devoted to the Training activity of EULEP;
- The preliminary draft of the EC Radiobiological Archive of Animal Experiments was presented.
- The necessity for EULEP to adapt to avoid duplication between its activities and the Commission's management responsibilities. For instance, EULEP Task groups should be set up with a very well defined objective fitting the priorities of the Radiation Protection Research Action and with a fixed dead line.

Study Group on CHECIR projects, JSP-1 and JSP-2

Moscow, (Russia) (CIS), 25 - 27 February 1992
30 participants from 10 countries and the Commission

Principal subjects:

- Decision support systems for off-site emergency management
- Historical portrayal of countermeasures taken after Chernobyl accident
- Social surveys in contaminated territories around Chernobyl
- Intervention levels for relocation
- Model validation
- Aquatic models

Study group on IAEA/CEC Coordinated research programme on Validation Models for Predicting Radionuclide Transfer in Terrestrial, Urban and Aquatic Environments (VAMP)

Vienna (A), 2 - 6 March 1992
100 participants from 25 countries and the Commission

Principal subjects:

- Model validation and performance
- Models for urban, terrestrial and aquatic environments
- Multiple pathways models

Study group on Transfer of Deposited Material through the Urban Environment and Exposure Pathways

Vienna (A), 4 March 1992
8 participants from 4 countries and the Commission

Principal subjects:

- Transfer through the urban environment
- Deposition on indoor surfaces
- Exposure indoors
- Deposition in fog

Study Group on CEC/NEA Intercomparison of Probabilistic Accident Consequence Assessment Codes (meeting of Project Management and Ad-hoc Group)

Paris (F), 2 - 5 June 1992
17 participants from 9 countries, OECD and the Commission

Principal subjects:

- Intercomparison of probabilistic accident consequence models
- Specification of the intercomparison
- Evaluation of pilot exercise

Study Group on Decision Support System Structure: Contractors meeting

Karlsruhe (D), 9 - 10 June 1992
31 participants from 10 countries and the Commission

Principal subjects:

- Decision support system for off-site emergency management
- System structure
- Software and graphics

Study Group on "Data Analysis in Quality Control and Radiation Protection of the Patient in Diagnostic Radiology and Nuclear Medicine, Restricted Programme Committee of the Workshop (Grado, 29 September-1 October 1993)"

Würzburg (D), 16 June 1992
6 participants from 4 countries and the Commission.

Principal subjects:

- Draft of first announcement;
- Organisational tasks.

Study Group on "Cooperation in the Radiation Protection Research and Training Action 1992-1993"

Würzburg (D), 17 June 1992
10 participants from 8 countries and the Commission

Principal subjects:

- Cooperation between the various multinational contractors' groups on quality assurance in paediatric radiology, dose related factors in the management of diagnostic radiology and quality assurance in computed tomography;
- Possible cooperation with research workers from Eastern and Central Europe.

CEC Thyroid Panel Meeting

Dublin (IRL), 22 - 23 June 1992
9 participants from 8 countries and the Commission

Principal subjects:

- To discuss a joint CEC/WHO mission by an international panel of thyroid experts to Belarus;
- To examine, in collaboration with Belarussian physicians, the childhood thyroid cancer excess following the Chernobyl accident;

Study Group on "The mobility of radionuclides in fresh water ecosystems".

Petten (NL), 14 - 15 July 1992
6 participants from 4 countries and the Commission.

Principal subjects:

- Study of the chemical forms of radionuclides in soils and sediments
- Transport models describing sediment processses
- Estimation of run-off from catchments
- Planning of field activities in the Chernobyl area during 1992.

Meeting for the implementation of the collaboration between the Radiation Protection Research Action and the CIS countries on the Health Consequences of the Chernobyl Accident

Zeleny Mys, Ukraine (CIS), 10 - 12 September 1992
25 participants from 7 countries and the Commission

Principal subjects:

- To initiate the studies of the health consequences of the accident via two ECP's and one JSP and implementation through multi-partner contracts with participation of scientists from the Member States and from the three Republics of the Commonwealth of Independent States (CIS);
- To identify the relevant scientists and institutes from the three Republics of the CIS, and also to define a scientific-technical annex for contractual purposes;
- What the benefits of a joint collaboration with the Europeans are, as for example the exchange and training of scientists.

Study Group on "Quality Control of the Technical Parameters of Diagnostic Radiology Equipment"

Luxembourg (L), 18 September 1992
25 participants from 10 countries and the Commission

Principal subjects:

- Discussion of the indicative values and tolerances of the technical parameters for quality control of medical radiological equipment;
- New parameters to be added to the list considered up to now in the Member States;
- Specific radiological procedures to be dealt with in detail;
- Implementation of Article 3 of the CEC Patient Directive (EURATOM 844/84) in the Member States.

Study Group on CHECIR project

Kiev (Ukraine) (CIS), 21 - 25 September 1992
18 participants from 8 countries and the Commission

Principal subjects:

- Resuspension by wind, agriculture, man's activities, fires, etc.
- Redistribution of deposited material

Study Group ECP 3 (CHECIR)

Leuven (B), 30 September 1992
14 participants from 5 countries and the Commission

Principal subjects:

- Progress in the subgroups during the year
- Results achieved
- Final report for the Commission
- Budget allocations for the partners research

24th Annual Meeting of the European Society for Radiation Biology

Erfurt (D), 4 - 8 October 1992
200 participants from different parts of Europe, with a few from USA and Japan and the Commission

Principal subjects:

- DNA damage and Repair; High LET; Cellular Effects and Tissue Effects of Radiation; Embryology; Carcinogenesis; Combined Effects of exposure to ionizing radiation and chemicals; Radiotherapy and Hyperthermia; Cytogenetic Effects; Lymphocytes, Immunology; Mutagenesis; Epidemiology;
- Three symposia were organised: 1. A EULEP Symposium on "Acute and Late Effects on the Lungs Caused by Inhaled Radioactive Materials and External Radiation", organised in cooperation with our programme. 2. A symposium on "Radon" organised in cooperation with the Bundesministerium für Umwelt. 3. A Symposium on "Mechanisms of Radiation-Induced Cancer" organised in cooperation with our programme.
- Plenary Lectures by Prof. L.N. Astakhova from Minsk, Belarus, on "Hypophysis and thyroid system state in children of Belarus after the Chernobyl accident"; and by Prof Chr. Reiners, Essen, Germany, on "Thyroid cancer in children exposed to radiation after the Chernobyl accident as compared to the literature and clinical experiences".
- The next ESRB meeting will take place in Stockholm, Sweden, June 10-14, 1992.

Study Group JSP2 on "Intervention Levels for use in Nuclear Accidents"

Paris (F), 12 - 16 October 1992
18 participants from 7 countries and the Commission

Principal subjects:

- Intervention levels
- Surveys of stress and risk perception in population around Chernobyl
- Historical portrayal of emergency response to Chernobyl accident

Study Group on "Deposition of Radionuclides"

Neuherberg (D), 15 - 16 October 1992
10 participants from 5 countries and the Commission

Principal subjects:

- Deposition on skin
- Indoor relative to outdoor concentrations of nuclides
- Long term migration of caesium from surfaces
- Resuspension of deposited material
- Urban exposure pathways modelling

EULEP Task Group/CEC NRPB Association Meeting on "Reduction of Risk of Late Effects from Incorporated Radionuclides".

Pierrelatte (F), 21 - 22 October 1992
25 Members of the Task Group including 4 Contractors and the Commission

Principal subjects:

- To assess the reduction of risk resulting from incorporated radionuclides;
- To provide guidance to those involved in the treatment of accidental overexposure to ingested radionuclides;
- Comparative studies between DTPA and LIHOPO;
- Toxicity studies of LIHOPO;
- Future relationships between EULEP Task Groups and CEC.

Panel Meeting "CEC Panel on Thyroid Cancer in Ex-Soviet Children Meeting"

Minsk, (Belarus) (CIS), 25 - 31 October 1992
6 Members of the Panel and 6 observers

Principal subjects:

- To examine the data and the children who present thyroid cancer;
- To examine the possibility of keeping material i.e. tissue samples, for research purposes;
- To compare treatment protocols in Belarus, Ukraine and Russia and the West;
- To define future plans and actions that will be of aid to these children and to ameliorate the situation;
- To prepare a comprehensive report of the situation as an official CEC report.

EURADOS General Meeting

Paris (F), 2 - 6 November 1992
105 participants from 14 countries and the Commission

Principal subjects:

- Working Group meetings on:
  - -numerical dosimetry
  - -assessment of internal dose
  - -radiation spectrometry in working environments
  - -individual dosemeters for external penetrating radiations
  - -criticality accident dosimetry
  - -basic physical data and characteristics of gas ionisation devices
- New Working Groups initiated: Civil aviation dosimetry
- General Assembly
- Council Meetings

Study Group on CEC/USNRC Project on "Uncertainty Analysis of Accident Consequence Codes"

Delft (NL), 9 - 11 November 1992
6 participants from 3 countries and the Commission

Principal subjects:

- Uncertainty analysis
- Probabilistic accident consequence codes
- Expert judgement elicitation
- Project plan and implementation

Study Group ECP 2 (CHECIR)

Barcelona (E) and Lisboa (P), 12 - 15 November 1992
24 participants from EC associated countries, Belarus, Ukraine, Russia and the Commission

Principal subjects:

- Working plan for 1993
- The progress of an intercalibration exercise
- Purchase and distribution of equipment
- Organisation and rules for exchange of scientists
- Data base for experimental plots established in 1992
- Description of the site characteristics and soil methodology

Study Group on "The transfer of radionuclides through the terrestrial environment to agricultural products, including thein fluence of agro-chemical practices".

Barcelona (E), 12 - 15 November 1992
20 participants from 10 countries and the Commission.

Principal subjects:

- Results achieved by each participating Institution to ECP2 project on the fate and behaviour of Chernobyl fallout.
- Results of intercomparison of methods and procedures used in radioecological studies.
- Planning of CIS scientists visits in EC laboratories in 1993.
- Planning of field activities in the Chernobyl area during 1993.

CEC - ERPET Training Course on Modern Methods in Radiation Measurements and Dosimetry

Bad Honnef (D), 23 - 26 November 1992
44 participants from 14 countries and the Commission

Principal subjects:

- Concepts and quantities in radiation protection
- Modern methods in photon, electron and neutron detection and dosimetry
- Area and individual monitoring
- Methods of internal dosimetry
- Calibration of radiation detectors

Study Group "Three Contracts on Stochastic Effects of Radiation"

Neuherberg (D), 8 - 10 December 1992
15 participants from 9 countries and the Commission

Principal subjects:

- Discussion of results of each group separately
- Presentation of an overview of each contract to the three groups
- Future plans, future collaboration between groups
- Development of new ideas and possibilities for the fourth framework programme

Study Group "CEC Thyroid Experts' Panel Meeting"

Brussels (B), 21 - 22 December 1992
8 participants from 7 countries and the Commission

Principal subjects:

- Follow-up of the Panel mission to Minsk, Belarus
- Finalize the Consensus Opinion on Childhood thyroid cancer in Belarus
- Semi-finalize the CEC report on Post-Chernobyl Thyroid Cancer in Children: a CEC Thyroid Expert Panel Report
- Development of experimental collaboration projects on thyroid cancer

B

Meetings organised or co-organised by the Commission

Conference on the International Chernobyl Project - Assessment of Radiological Consequences and Evaluation of Protective Measures

Vienna (A), 21 - 24 May 1991
250 participants from most IAEA member states and the Commission

Principal subjects:

- Corroboration of the Soviet measurements of contamination
- Corroboration of the Soviet dose estimate
- Evaluation of the health status of the population living in contaminated settlements
- Evaluation of the protective measures taken since the accident and of the Soviet and other concepts proposed to assure "safe" living conditions for those in affected areas.

Seminar on Planning for Nuclear Emergencies
Co-organised with the Technical University of Prague (CS) and the University of Surrey (UK)

Prague (CS), 25 - 29 June 1991
25 participants from 2 countries and the Commission

Principal subjects:

- Review of the accident at Three Mile Island
- Nuclear Emergency Planning in European Community
- Chernobyl Review
- Emergency arrangements for Nuclear Electric Power Stations
- Local Emergency Planning in the UK

Workshop on "Radiation Exposure of Civil Aircrew"

Luxembourg (L), 25 - 27 June 1991
64 participants from 17 countries, IAEA and the Commission

Principal subjects:

- Scientific background of radiation exposure
- Possible further activities

Fifth International Symposium on the Natural Radiation Environment
Co-organised with the US DOE (Washington DC), the International Atomic Energy Agency (Vienna) and University of Salzburg

Salzburg (A), 22 - 28 September 1991
300 participants from 25 countries and the Commission

Principal subjects:

- Measurement techniques and methodology
- Radionuclides in the earth, atmosphere, marine and aquatic systems
- Transfer pathways
- Radioactivity and radiation in the indoor environment
- Surveys, their methodology, population exposure and dosimetry of natural radiation
- Technologically enhanced levels of radiation exposure
- Relative importance of natural versus artificial radioactivity with respect to dose and risk assessment
- Remedial actions for reducing exposure
- National and international control policies and recommendations

Workshop: Biophysical Modelling of Radiation Effects

Co-organised with US Department of Energy (Washington DC) and the Istituto Nazionale di Fisica Nucleare - Legnaro- (I)

Padua (I), 2 - 5 September 1991

Principal subjects:

- Interaction of Mixed Radiations
- Track Structure Calculations
- Low Dose/ Low Dose Rate Modelling
- Aberrations, Mutation, Transformation
- Development of Models
- New Data for Models

Workshop: Effectiveness and quantification of agricultural techniques for countermeasures

Brussels (B), 1 - 4 October 1991
33 participants from 11 countries and the Commission

Principal subjects:

- Introduction: general approaches to countermeasures
- Countermeasures to limit contamination of plant products
- Countermeasures to limit contamination of animal products
- Countermeasures for reducing radiation doses arising from forest ecosystems
- General conclusion

International Seminar on Intervention Levels and Countermeasures for Nuclear Accidents
Co-organised with the Commissariat à l'Energie Atomique (CEA) and the International Union of Radioecologists and sponsored by the Regional Council Provence - Alpes-Côte d'Azur

Cadarache (F), 7 - 11 October 1991
138 participants from 19 countries, international organizations and the Commission

Principal subjects:

- Principles of intervention
- Short term countermeasures
- Intervention in the food chain
- Decontamination and rehabilitation
- Intervention in the USSR following the Chernobyl accident
- Justification and optimisation of intervention

Seventh Symposium on Neutron Dosimetry
Co-organised with Physikalisch-Technische Bundesanstalt (PTB), Braunschweig (Berlin) and the US Department of Energy (Washington DC)

Berlin (D), 14 - 18 October 1991
183 participants from 21 countries and the Commission

Principal subjects:

- Advancement in basic physical data for neutron and high-CET radiation dosimetry
- Radiation effectiveness and radiation quality
- Dose quantities and concepts
- Neutron radiation protection dosimetry and metrology
- Individual dosimetry methods
- Dosimetry for radiation therapy

Technical Requirements of X-ray Equipment used in Pediatric Radiology

Luxembourg (L), 15 October 1991
18 participants from 7 countries and the Commission

Principal subjects:

- Deliver scientific background for a study
- Laying down recommendations for X-ray manufacturers
- Establish dose reduction techniques for pediatric patients

International Symposium "Medical aspects of Radiation Protection in Europe"

Venice (I), 28 - 31 October 1991

Principal subjects:

- Medical supervision of exposed workers
- Professional illness by radioactivity

International Conference on "Implications of the New ICRP Recommendations on Radiation Protection Practices and Interventions"

Salamanca (E), 26 - 29 November 1991

Principal subjects:

- ICRP 60 and the International Perspectives
- Implications of ICRP 60 for Practices
- Implications of ICRP 60 for Interventions
- Technical and managerial aspects

Seminar on Decision-Aiding Techniques applied to Radiation Protection and Nuclear Safety

Luxembourg (L), 31 March - 1 April 1992
54 participants from 9 countries and the Commission

Principal subjects:

- Introduction to discussion analysis techniques
- Application to nuclear waste management
- Group decision support and decision conferencing
- The International Chernobyl Project on relocation
- Uncertainties and risks

Workshop on Objectives for Next Generation of Practical Short Range Atmospheric Dispersion Models

Roskilde (DK), 6 - 8 May 1992
110 participants from 20 countries and the Commission

Principal subjects:

- Short range atmospheric dispersion models
- Data bases for model validation
- Requirements for regulatory models

Discussion Workshop: Quality Assurance and Radiation Protection in Digital Radiography

Mannheim (D), 7 - 9 May 1992
80 participants from 15 countries (including the USA and Japan) and the Commission. Jointly organised by CEC, Institut für Klinische Radiologie and the European Association of Radiology

Principal subjects:

- Digital Projection Radiography - a new horizon in diagnostic imaging;
- Imaging capabilities of digital radiography;
- Quality assurance and radiation protection;
- Clinical value of analogue and digital imaging methods;
- Elaboration of a statement, "State and Perspectives of Digital Mammography and Potentials for Mammography Screening".

Seminar on the Dynamic Behaviour of Radionuclides in Forests
Co-organised with the Swedish Radiation Protection Institute

Stockholm (S), 19 - 22 May 1992
89 participants from several countries including the CIS and the Commission

Principal subjects:

- Forest ecology
- Deposition and Interception
- Monitoring and mapping
- Distribution and cycling of radionuclides between soil and vegetation
- Behaviour of radionuclides in soils
- Contamination of wildlife
- Impact of contamined forests on man and the environment
- Countermeasures

Discussion Workshop on "Test Phantoms and Optimisation in Diagnostic Radiology and Nuclear Medicine"

Würzburg (D), 15 - 17 June 1992
172 participants from 28 countries (including USA, Japan, South Africa, New Zealand) and the Commission

Principal subjects:

- State of the art of the design and performance of test objects and phantoms and computational models used for quality control in diagnostic radiology and nuclear medicine;
- Perspectives for standardisation of acceptance and constancy testings as a basis for optimisation of diagnostic radiology and nuclear medicine concerning image quality and patient dose.

11th Symposium on Microdosimetry
Co-organised with US DOE, Washington, DC and Oak Ridge National Laboratory (ORNL), USA

Gatlinburg (USA), 13 - 18 September 1992
200 participants from 20 countries and the Commission

Principal subjects:

- Biological effects modelling
- Microdosimetry measurements and calculations
- Physical data and processes
- From track structure to radiation signature
- Radiation physics and chemistry in aqueous solutions
- Radiation quality and carcinogenesis
- Radiation chemistry of DNA in aqueous solution
- Biological measurements
- New microdosimetric experimental techniques
- Applications of microdosimetry
- Radiation carcinogenesis

Workshop on Future Research Needs and Priorities in Microdosimetry
Co-organised with US DOE, Washington, DC

Gatlinburg (USA), 18 September 1992
45 participants from 12 countries and the Commission

Principal subjects:

- Physics of energy depositions in condensed media
- Track structure calculations
- New experimental techniques in microdosimetry
- Radiation quality and radiation chemistry
- Molecular and cellular radiobiology relevant for biophysical modelling
- Biophysical modelling

International Symposium on Radioecology (Chemical speciation - Hot particles)
Co-organised with the International Union of Radioecologists and the Society of Czechoslovak Radioecologists

Znojmo (CS), 12 - 16 October 1992
105 participants from 20 countries and the Commission

Principal subjects:

- Chemical forms of radionuclides in aerosols and in hot particles
- Speciation in the hydrosphere
- Speciation and hot particles in soils
- Consequences of speciation on the transfer of radionuclides in biological materials and in the food chain
- Application of the results of studies on speciation and on the behaviour of hot particles for environmental modelling and dosimetry

Symposium on Radioecology and General Assembly of the IUR

Znojmo (CS), 12 - 14 October 1992
103 participants from 20 European and Central and Eastern European countries + 2 from the Commission

Principal subjects:

- IUR: New CEC policy with respect to the IUR tasks
- Speciation of radionuclides in air
- Speciation of radionuclides in natural waters and soils
- The role and changes of speciation of radionuclides in their uptake by organisms.

Third International Workshop on "Decision Making Support for Off-site Emergency Management"
Co-organised with the GSF-Forschungszentrum für Umwelt und Gesundheit GmbH, Neuherberg (D) and the United States Department of Energy, Washington DC (USA)

Schloss Elmau (D), 25 - 30 October 1992
130 participants from 21 countries and the Commission

Principal subjects:

- Information requirements of decision-makers and the public
- Local scale decision support systems
- RODOS, the EC Real-time On-line DecisiOn Support system
- Meteorology and atmospheric dispersion
- Monitoring
- Integration of monitoring data and model prediction
- Pathways and countermeasures

Technical Requirements of X-ray Equipment used in Pediatric Radiology

Leeds (GB), 29 - 30 October 1992
19 participants from 8 countries, IAEA and the Commission

Principal subjects:

- Technical criterions of instruments
- Criterions in education in pediatric radiology

C

Meetings of experts

Art. 31 Working Party on Relocation

Brussels (B), 3 June 1991
8 participants from 6 countries and the Commission

Principal subjects:

- Accident scenarios
- Radiological and economic consequences
- Relocation strategies

Group of experts referred to in article 31 of the Euratom Treaty

Brussels (B), 4 - 5 June 1991
30 participants from 12 countries and the Commission

Principal subject:

- Revision of the basic safety standards

Radiation Protection and the Single Market

Luxembourg (L), 6 June 1991
32 participants from 12 countries and the Commission

Principal subject:

- Radiation protection in the Single Market after 1.1.93

Group of Experts referred to in Articles 35 and 36 of the Euratom Treaty

Luxembourg (L), 19 - 20 June 1991
20 participants from 12 countries and the Commission

Principal subjects:

- Reporting and production of the next monitoring report (Working group I)
- Establishment and harmonization of an european network of highly sensitive radioactivity measurements in the environment

Training in radiation protection in primary and secondary education

Luxembourg (L), 24 June 1991
15 representatives of the competent authorities from 12 countries and the Commission

Principal subject:

- Production of a teachers manual on radiation protection

Group of Experts on the radiological protection criteria for the recycling of materials from the dismantling of nuclear installations
Recommendation from the Group of Experts set up under the terms of Article 31 of the Euratom Treaty

Luxembourg (L), 1 - 2 July 1991
22 participants from 10 countries and the Commission

Principal subject:

- Updating and extension of radiation protection N° 43

Protection of outside workers exposed to ionising radiation

Luxembourg (L), 11 July 1991
25 participants from 12 countries and the Commission

Principal subjects:

- Provisions of Council Directive 90/641/EURATOM on the operational protection of outside workers
- Member States' obligations under Article 33 of the Euratom Treaty

Implementation of Council Decision 87/600/EURATOM of 14 December 1987 on Community arrangements for the early exchange of information in the event of a radiological emergency (ECURIE)

Luxembourg (L), 18 - 19 July 1991
24 participants from 10 countries and the Commission
(meeting of Member States Representatives)

Principal subjects:

- Development of the ECURIE system
- Level-1 and level-2 exercises - experience to date
- Level-3 exercises:
  - evolution of the revised Convention Information Structure (CIS),
  - associated software,
- Outline plan for the first level-3 exercise

Information meeting in Radiation Protection for the European Trade Union Confederation

Luxembourg (L), 13 September 1991
18 participants from 6 countries, ETUC and the Commission

Principal subjects:

- Directive 90/641/EURATOM
- Directive 89/618/EURATOM

Assistance in the Event of a Nuclear Accident or a Radiological Emergency

Luxembourg (L), 16 September 1991
28 participants from 12 countries and the Commission

Principal subjects:

- Bilateral agreements in case of an emergency
- Presentation of the ECURIE system
- Community cooperation in civil protection
- Cooperation with International organizations

Technical experts in dosimetry

Luxembourg (L), 30 September 1991
14 participants from 12 countries and the Commission

Principal subjects:

- Revision of the technical recommendations
- Workshop radiation exposure of civil aircrew
- Directive on outside workers
- Radioactive substances in consumer goods - intercomparison programme accident dosemeters

Group of Experts referred in Article 31 of the EURATOM Treaty

Luxembourg (L), 1 - 3 October 1991
29 participants from 11 countries and the Commission

Principal subject:

- Revision of the basic safety standards

Ad hoc Committee to establish a list of products excluded from the application Council Regulation (EEC) N° 737/90 of 22 March 1990

Luxembourg (L), 14 October 1991
15 participants from 9 countries and the Commission

Principal subject:

- Adoption of the revised list of products excluded from the application of Council Regulation (EEC) N° 737/90 of 22 March 1990 on the conditions governing imports of agricultural products originating in third countries following the accident at the Chernobyl nuclear power station.

Implementation of Council Decision 87/600/EURATOM of 14 December 1987 on Community arrangements for the early exchange of information in the event of a radiological emergency (ECURIE)

Brussels (B), 4 - 5 November 1991
9 participants from 7 countries and the Commission
(meeting of the ECURIE exercises Working Group)

Principal subjects:

- Problems encountered by Member States in the preparation of level-3 exercise
- Update and experience of CIS software

Group of experts referred to in Article 31 of the EURATOM Treaty

Luxembourg (L), 18 - 19 December 1991
28 participants from 11 countries and the Commission

Principal subject:

- Revision of the basic safety standards

Radiation protection in Nuclear Power Plants

Luxembourg (L), 18 - 19 December 1991
25 participants from 10 countries and the Commission

Principal subjects:

- Analysis of 1990 data on collective doses
- Presentation of 7 experiences in radiation protection

Art. 31 Working Party on Relocation

Brussels (B), 28 - 29 January 1992
7 participants from 3 countries and the Commission

Principal subjects:

- Economic modelling
- Evaluation of scenarios
- Practical application of "optimum" intervention levels
- Decision conference

Group of experts referred to in Article 37 of the EURATOM Treaty

Windermere (GB), 3 - 5 February 1992
43 participants from 10 countries and the Commission

Principal subject:

- Examination of the General Data related to the plan for the disposal of radioactive waste from the THORP plant at the Sellafield Establishment (UK).

Art. 31 Working Party on exemption levels

Brussels (B), 11 February 1992
8 participants from 6 countries and the Commission

Principal subject:

- Preparation of the annex 1 (exemption levels) of the new Basic Safety Standards

Group of Experts referred to in Article 31 of the EURATOM Treaty

Brussels (B), 11 - 13 March 1992
28 participants from 11 countries and the Commission

Principal subject:

- Revision of the Basic Safety Standards

Working Party on the radiological protection criteria for the recycling of materials from the dismantling of nuclear installations
Recommendation from the Group of Experts set up under the terms of Article 31 of the EURATOM Treaty

Chilton (GB), 8 - 9 April 1992
6 participants from 4 countries and the Commission

Principal subject:

- Updating and extension of Radiation Protection Nº 43

Implementation of Council Decision 87/600/EURATOM of 14 December 1987 on Community arrangements for the early exchange of information in the event of a radiological emergency (ECURIE)

Luxembourg (L), 14 - 15 April 1992
9 participants from 7 countries and the Commission

Principal subjects:

- Level-1 / level-2 exercises
- Other exercises involving ECURIE
- Software development
- Preparations for first level-3 exercise
- Draft "Users' Guide"

Qualified experts in radiation protection

Luxembourg (L), 7 May 1992
19 participants from 12 countries and the Commission

Principal subject:

- Community harmonization of qualification criterions

Group of experts "MARINA-MED"

Luxembourg (L), 8 May 1992
12 participants from 7 countries and the Commission

Principal subject:

- Radiological impact on the population of the Member States of natural and man-made radionuclides present in the Mediterranean

Art. 31 Working Party on Relocation

Brussels (B), 14 May 1992
12 participants from 6 countries and the Commission

Principal subjects:

- Intervention levels for relocation
- Relocation/Return criteria
- Constraints
- Group at risk
- Accident scenarios

Ad hoc committee to establish a list of products excluded from the application of Council Regulation (EEC) Nº 737/90 of 22 March 1990

Luxembourg (L), 3 June 1992
19 participants from 10 countries and the Commission

Principal subject:

- Revision of Commission Regulation 598/92 (EEC) of 9 March, 1992, establishing a list of products excluded from the application of Council Regulation (EEC) Nº 737/90 on the conditions governing imports of agricultural products originating in third countries following the accident at the Chernobyl nuclear power station.

Implementation of Council Decision 87/600/EURATOM of 14 December 1987 on Community arrangements for the early exchange of information in the event of a radiological emergency (ECURIE)

Luxembourg (L), 24 - 26 June 1992
22 participants from 12 countries and the Commission
(meeting of Member States Representatives)

Principal subjects:

- Level-1 and level-2 exercises
- The Convention Information Structure (CIS)
- ECURIE users' guide
- Preparation of the first level-3 exercise

Group of Experts on the radiological protection criteria for the recycling of materials from the dismantling of nuclear installations
Recommendation from the Group of Experts set up under the terms of Article 31 of the EURATOM Treaty

Luxembourg (L), 8 - 9 July 1992
22 participants from 11 countries and the Commission

Principal subject:

- Updating and extention of Radiation Protection Nº 43

First meeting of the advisory Committee established by Article 19 of Council Directive 92/3/EURATOM on the supervision and control of shipments of radioactive waste between Member States and into and out of the Community

Luxembourg (L), 15 - 16 July 1992
23 participants from 12 countries and the Commission

Principal subject:

- Standard documents referred to in the Directive

Directive 89/618/EURATOM on "Informing the Public about Health Protection Measures in a Radiological Emergency"

Luxembourg (L), 2 September 1992
19 participants from 9 countries and the Commission

Principal subjects:

- Presentation of a manual for off-site workers
- State of the art on Article 7 of the Directive

Group of Experts referred to in Article 37 of the EURATOM Treaty

Luxembourg (L), 15 - 16 September 1992
36 participants from 12 countries and the Commission

Principal subject:

- Examination of the General Data related to the plan for the disposal of radioactive waste from the Sizewell B Nuclear Power Station (UK)

Radiological protection of persons undergoping medical examination

Brussels (B), 5 October 1992
16 participants from 8 countries and the Commission

Principal subject:

- Possible subjects for the revision of the Patient Directive (84/466/EURATOM)

Group of Experts "MARINA-MED"

La Spezia (I), 5 - 10 October 1992
19 participants from 8 countries and the Commission

Principal subject:

- Radiological impact on the population of the Member Srates of natural and man-made radionuclides present in the Mediterranean
  - Sources of radioactivity
  - Environmental measurements
  - Survey on marine products
  - Dose calculation model

Working Party on the radiological protection criteria for the recycling of materials from the dismantling of nuclear installations
Recommendation from the Group of Experts set up under the terms of Article 31 of the EURATOM Treaty

Luxembourg (L), 12 - 13 November 1992
8 participants from 6 countries and the Commission

Principal subject:

- Updating and extension of Radiation Protection N¤ 43

Second meeting of the advisory Committee established by Article 19 of Council Directive 92/3/EURATOM on the supervision and control of shipments of radioactive waste between Member States and into and out of the Community

Luxembourg (L), 23 November 1992
25 participants from 12 countries and the Commission

Principal subject:

- Export of radioactive waste to third countries

Group of Experts referred to in Article 31 of the EURATOM Treaty

Luxembourg (L), 24 - 25 November 1992
28 participants from 12 countries and the Commission

Principal subjects:

- Recent Community activities in Radiation Protection
- Dose constraints
- Community strategy in the field of radioactive waste
- Industrial gamma radiography

Radiation protection in Nuclear Power Plants

Luxembourg (L), 30 November - 1 December 1992
23 participants from 8 countries and the Commission

Principal subjects:

- Analysis of 1991 data on collective doses
- Analysis of 1987-1991
- Presentation of 10 years of experience in the field of radiation protection

Group of Experts referred to in Articles 35 and 36 of the EURATOM Treaty

Luxembourg (L), 14 - 15 December 1992
22 participants from 11 countries and the Commission

Principal subjects:

- Discussion of the draft monitoring report 1987-1990
- CEC-WHO intercomparison exercises

Ad hoc Committee to establish a list of products excluded from the application of Council Regulation (EEC) N° 737/90 of 22 March 1990

Luxembourg (L), 16 December 1992
17 participants from 10 countries and the Commission

Principal subject:

- Adoption of a revised list of products excluded from the application of Council Regulation (EEC) N° 737/90 of 22 March 1990 on the conditions governing imports of agricultural products originating in third countries following the accident at the Chernobyl nuclear power station.

ERPET

EUROPEAN RADIATION PROTECTION EDUCATION AND TRAINING

V. ERPET - European Radiation Protective Education and Training - Activities, Period: June 1991 - End 1992

The CEC is promoting education and training activities in radiation protection in order to maintain and extend Community expertise in radiation protection, in particular in view of the forthcoming developments in the Community. These education and training activities are in compliance with Article 33 of the EURATOM Treaty.

Education and training activities are organised by the Commission's services in charge of Radiation Protection: DG XI, DG XII and, where appropriate, the service for EURO Courses of the JRC-ISPRA, together with competent institutions in the Member States, existing cooperative groups or other groups created for this purpose.

The education and training activities involve:

- Organisation of training courses;
- Development and provision of information and training packages;
- Exchange of scientists and promotion of participation in scientific conferences.

On the following pages, training courses and other activities, organised in the period from June 1991 to end 1992 are listed. The courses provided coordinated, up-to-date programmes on key problems in radiation protection, for which a consistent Community approach is crucial. Some of these courses will be repeated after evaluation and updating in order to ensure a larger number of interested persons to become acquainted with the most advanced knowledge in radiation protection.

Training Course: Quality assurance for image quality and dose reduction in medical diagnostic radiology

Jointly organised by CEC, CAATS/INSERM, Cachan, IRS, Liverpool and AFPPE, Paris; Course held in English and French

Paris (F), 3-7 June 1991

43 participants from 6 countries

Purpose:
To provide up-to-date operational aspects and measures of radiation protection practice in diagnostic radiology.

Main topics:
Background information to operational and legislative framework for radiation protection of the patient as well as the staff, quality assurance in diagnostic radiology: quality requirements with regard to radiographic images and patient dose; quality control programmes: organisation, implementation, measurements; role of technical developments, practical demonstration.

Target groups:
All those actively involved in the day-to-day practice of diagnostic radiology, as well as those responsible for education and training of radiographers and radiological technicians.

3rd Training Course: Optimisation of radiological protection in the design and operation of nuclear and industrial facilities

Jointly organised by the CEC, CEPN, Fontenay-aux-Roses and NRPB, Chilton

Saclay (F), 3-7 June 1991

23 participants from 9 countries

Purpose:
To present tools and structures to help implement ALARA-concepts at the practical level.

Main topics:
ALARA-principles and procedures. Occupation dose calculation and reduction. ALARA in operations.

Target group:
All those associated with designing and implementing radiation protection programmes in nuclear and industrial facilities.

Training Course: A summer school in radiophysics - Nuclear Medicine

Jointly organised by the CEC and EFOMP, York

Dublin (IRL), 30 June-6 July 1991

35 participants from 15 countries

Purpose:
To provide updated knowledge on the advanced part of the training relevant to nuclear medicine.

Main topics:

- Protection of the patient in diagnosis and therapy;
- Optimisation of exposure and alternative diagnostic methods;
- Quality control of nuclear medicine equipment and procedures;
- Design, construction and adaptation of premises;
- Production and purity of radionuclides and radiopharmaceuticals;
- Biokinetics of radioactive substances and dose calculations;
- Radioactive waste, storage and disposal.

Target group:
All professionals working in nuclear medicine.

Training Course: Emergency planning and response

Jointly organised by the CEC and CEN/SCK, Mol

Mol (B), 9-13 September 1991

55 participants from 19 countries

Purpose:
To provide a general overview of emergency planning and response procedures for technically involved professionals.

Main topics:

- Predictive methodologies;
- Accident scenarios;
- Derived emergency reference levels and intervention criteria;
- Evaluation of countermeasures.

Target group:
Professionals involved in emergency planning.

4th Training Course: Optimisation or radiological protection in the design and operation of nuclear and industrial facilities

Jointly organised by the CEC and CEPN, Fontenay-aux-Roses, and NRPB, Chilton. Course held in English and French.

Saclay (F), 4-8 November 1991

30 participants from 6 countries

Purpose:
To present tools and structures to help implement ALARA-concepts at the practical level.

Main topics:
ALARA principles and procedures. Occupational dose calculation and reduction. ALARA in operations.

Target group:
All those associated with designing and implementing radiation protection programmes in nuclear and industrial facilities.

Training Course: Radiation protection of the patient

Jointly organised by the CEC and ISH, Salzgitter/Neuherberg, CIR, Fontenay-aux-Roses/ISTN, Saclay and NRPB, Chilton

Neuherberg (D), 6-10 April 1992

24 participants from 14 countries

Purpose:
To provide a common level of understanding of radiation protection concepts applied in medicine.

Main topics:
Basic concepts and principles of radiation protection in diagnostic radiology, radiation Therapy and nuclear medicine; European protocols and projects; demonstrations.

Target group:
All those working in alliance with medical staff in hospitals, universities, research institutes or health care authorities.

Training Course: Radiation Protection in Radiation Therapy

Jointly organised by the CEC and EFOMP

Sevilla (E), 14-21 June 1992

29 participants from 11 countries

Purpose:
Training of the medical physicist as a qualified expert in radiophysics, protection of the patient in radiation therapy.

Main topics:
Physical principles, control of irradiation facilites and radioactive sources, biological fundamentals, clinical dosimetry, radiation treatment planning, quality assurance procedures, radiation protection of the patient, the staff and the environment, instructions in case of accidents, legal requirements, etc.

Target groups:
Medical physicists and medical staff involved.

2nd Training Course: Off-Site Emergency Planning for and Response to Nuclear Accidents

Jointly organised by the CEC and CEN/SCK, Mol

Mol (B), 29 June-3 July 1992

21 participants from 15 countries

Purpose:
To provide a general overview of emergency planning and response procedures for technically involved professionals.

Main topics:

- Predictive methodologies;
- Accident scenarios;
- Emergency plans and intervention criteria;
- Evaluation of countermeasures;
- Decision support systems.

Target groups:
Professionals involved in emergency planning.

Training Course: Cyclotron Production on Quality Control and Utilisation of Medical Radionuclides

Jointly organised by the CEC and JRC, Ispra

Ispra (I), 30 June-2 July 1992

24 participants from 7 countries

Purpose:
To improve the awareness of radiation protection problems and support the implementation of the corresponding Council Directives during the production and handling of radionuclides and radiopharmaceuticals.

Main topics:
Sources, production and use of medical radionuclides, cyclotron production of radionuclides, quality control and methods to measure purity, nuclear diagnosis PET and SPECT (Positron Emission Tomography, Single Photon Emission Computer Assisted Tomography), radiation protection problems, practicals.

Target groups:
Technicians and paramedics active in the production and use of mainly cycloton produced radionuclides and radiopharmaceuticals in research, industry and hospitals.

3rd Training Course: Off-Site Emergency Planning for and Response to Nuclear Accidents

Jointly organised by the CEC and Greek Atomic Energy Commission and CEN/SCK, Mol

Athens (GR), 13-16 October 1992

25 participants from 2 countries

Purpose:
To provide comprehensive understanding of all aspects of today's emergency planning and response.

Main topics:
Principles of intervention planning, organisation and decision making with respect to off-site intervention in the case of an accidental release of radioactive material to the environment.

Target groups:
The participants nominated by the Greek and Bulgarian Governments.

4th Training Course: Optimisation of Radiological Protection in the Design and Operation of Nuclear and Industrial Facilities

Jointly organised by the CEC and CEFN, Fontenay-aux-Roses and INSTN, Saclay and CETIC, Chalon and NRPB, Chilton. Course held in English and French.

Saclay (F), 16-20 November 1992

23 participants from 10 countries

Purpose:
To present tools and structures to hep implement ALARA (As Low as Reasonably Achievable) concepts at the practical level.

Main topics:
ALARA-principles and procedures; occupational dose calculation and reduction; ALARA in operation.

Target groups:
All those associated with designing and implementing radiation protection programmes in nuclear and industrial facilities.

2nd Training Course: Quality Assurance and Quality Control in Diagnostic Radiology

Jointly organised by the CEC and CIEMAT, Madrid and IRS, Liverpool. Course held in English and Spanish.

Madrid (E), 16-20 November 1992

66 participants

Purpose:
To provide up-to-date operational aspects and measures of radiation protection practice in diagnostic radiology.

Main topics:
Background information to operational and legislative framework for radiation protection of the patient as well as the staff, quality assurance in diagnostic radiology: quality requirements with regard to radiographic images and patient dose; quality control programmes: organisation, implementation, measurements; role of technical developments, practical demonstrations.

Target groups:
All those actively involved in the day to day practice of diagnostic radiology, as well as those responsible for education and training of radiographers and radiological technicians.

Training Course: Modern Methods in Radiation Measurements and Dosimetry

Jointly organised by the CEC, EURADOS, GSF and IARR
Bad Honnef (D), 23-26 November 1992

42 participants from 14 countries

Purpose:
To provide in-depth information on modern techniques and methods for detecting ionizing radiation and measuring dose quantities in radiation research, radiation protection, radiation biology and radiation medicine.

Main topics:
Principles and purposes of radiation measurement; concepts and quantities used in radiation protection; requirements in radiation protection dosimetry; modern methods of electron and photon measurements; modern methods of neutron measurement; cosmic rays and heavy charged particle measurements; measurements of radon; advanced measurement methods in specific application (in medicine, environment and at work places); modern methods in area and individual monitoring; dosimetry for irradiation experiments (e.g. in radiobiology); measurement methods of internal dosimetry; calibration of radiation detectors.

Target groups:
Students, young and senior scientists working in various areas of radiation research. Basic knowledge of radiation physics required.

Training Course: Radiation Protection in Dental Practice

Jointly organised by the CEC, University of Amsterdam, University of Newcastle and Fed. Vol. Hosp., Dublin
Amsterdam (NL), 26-27 November 1992

35 participants from 10 countries

Purpose:
Sensitizing of the dental profession to radiation protection aspects regarding patients and medical staff.

Main topics:
Definition of radiation protection problems, national and international regulations, organisation and administration of radiation protection, quality assurance and quality control, dose evaluation for the patient and staff, monitoring, special radiation protection problems, etc.; practical evaluation of equipment by post-package system will be offered in advance to the participants.

Target groups:
Medical and auxiliary staff involved in dental practice and oral surgery.

Training Course: Modern Techniques in Radiation Cytology and DNA Repair

Jointly organised by the CEC and University Leiden (NL)

Leiden (NL), 23 November-4 December 1992

12 participants from 9 countries

Purpose:
Training in molecular biology techniques currently being developed for cytogenetics and DNA damage and repair studies.

Main topics:
Prematurely condensed chromosomes; chromosome painting; restriction enzymes; DNA mapping; PCR.

Target groups:
Young post-doctorates working in cytology and DNA repair.

SELECTION OF PUBLICATIONS ISSUED ON THE INITIATIVE OF THE COMMISSION

VI. Publications, Period: 1 June 1991 - 31 December 1992

The scientific research results of the Commission's Radiation Protection Programme are presented in articles published in scientific journals. References to these are given in the corresponding Progress Reports. In certain cases, the Commission initiated surveys of detailed results of specific activities in the field of radiation protection and published them as monographs or proceedings. Short descriptions of those publications, published or prepared in the period from 1 June 1991 - 31 December 1992 are given on the following pages.

PROCEEDINGS

Medical Radiation Protection Practice in the CEC

Proceedings of a meeting jointly organised by The British Institute of Radiology (BIR), London and the CEC.

London (UK), 5 December 1990

Edited by M. Fitzgerald and J. M. Courades

The Member States of the European Community have made considerable progress in promoting health protection against ionizing radiation not only for the workers, but also for the patients. Despite the diverse historical, cultural and legal backgrounds of the Member States which have given rise to a number of notable differences in their approaches to radiation protection, there is a common pattern in the legislative systems.

The Proceedings of this meeting give a comparative overview of current legislation and practice in the Member States. This publication represents the most comprehensive collection of data on the legal and administrative aspects of medical radiation protection within the CEC.

Published by BIR, London, 1991
ISBN 0905749 26X, 53 pages

To be ordered through:
The British Journal of Radiology
36 Portland Place
GB-London WIN 4AT

Price: £.Stg. 13.50

Dosimetry in Diagnostic Radiology

Proceedings of a Seminar, jointly organised by the CEC, the PTB, Braunschweig, the WHO, Europe and the ICRU

Luxembourg (L), 19-21 March 1991

Edited by H.M. Kramer and K. Schnuer

The 1990 intercomparison programme of dosemeters used in diagnostic radiology, carried out by the CEC services, can be considered as an action of the Commission towards the requirements of the EURATOM Treaty.

The intercomparison programme was performed in 19 European countries. The results and findings formed the basis for this seminar on Dosimetry in Diagnostic Radiology.

The contributions presented during the seminar provided clear evidence that radiation protection of the patient plays an increasingly important role for manufacturers of radiological equipment and for regulatory bodies, as well as for radiologists, medical doctors and assistants.

The proceedings reflect the activities and work in the field of radiation protection of the patient and would initiate further action in order to harmonise dosimetric measurements and calculations, to ameliorate education and training, to improve the technical standards of the equipment and to give a push to a more effective use of ionising radiation in the medical sector.

It should furthermore help to implement Article 25 of the 1980 Directive on the Basic Safety Standards which stipulates that examination and testing or protective devices and measuring instruments shall comprise regular checking that measuring instruments are serviceable and correctly used. In addition, Article 3 of the Patient Directive of 3 September 1984 (EURATOM 84/466) obliges the Member States to establish criteria of acceptability for radiological and nuclear medical installations. Last, but not least the Commission must ensure that these provisions of the Directives are applied in a harmonised manner within the Member States.

Report EUR 14180 EN, published in Radiation Protection Dosimetry
Vol. 43, Nos. 1-4, 1992, 300 pages.

To be ordered through:
Nuclear Technology Publishing
P.O. Box No. 7
Ashford
GB-Kent TN25 4NW

Price: £.Stg. 80

Test Phantoms and Optimisation in Diagnostic Radiology and Nuclear Medicine

Proceedings of a Discussion-Workshop jointly organised by the CEC, GSF, Neuherberg, ICRU and EFOMP.

Edited by B.M. Moores, N. Petoussi, H. Schibilla and D. Teunen.

The workshop was perceived as a forum for discussions of test objects and phantoms, computational models and optimisation in diagnostic radiology and nuclear medicine. The current status of this field was presented by invited overview papers backed up by proffered papers in the form of posters and by discussions. They concentrated on requirements of design, implementation and the relevance of test objects, phantoms and computational models most suitable for quality control under different physical and clinically realistic conditions. The contributions should help to establish guidance for more standardisation of design and use of test objects, phantoms and computational models as well as the evaluation of the obtained data.

Nineteen overview papers and 60 proffered papers are reproduced, together with the summarised discussions and comments. They reflect the concepts and perspectives of some 170 participants coming from 28 countries.

The proceedings are subdivided into 9 chapters:

1. Requirements for test objects and phantoms;
2. Applications in conventional radiology and fluoroscopy;
3. Mammography;
4. Conventional and computed tomography;
5. Digital radiography;
6. Nuclear Medicine;
7. Computational models;
8. ICRU - Activities in Phantom Design and Application;
9. Conclusions.

In Chapter 8, 25 phantom specific sheets are published which complement the ICRU Report, 48 on phantoms and computational models in therapy, diagnosis and protection.

Report EUR 14767 EN, to be published in Radiation Protection Dosimetry, in press.

Biophysical Modelling of Radiation Effects

Proceedings of a meeting held in

Padua (I), 2-5 September 1991

Edited by K H Chadwick, G Moschini and M N Varma

Principal subjects:

Biophysical models in radiation biology
Interaction of mixed radiations
Track structure calculations
Low dose/low dose rate modelling
Biophysical modelling in radiation protection
Aberrations, mutations and transformation
Development of models
Cancer models
New data for models

Published by Adam Hilger (Bristol, Philadelphia and New York) 1992, (EUR 13848) 350 pages.)

ISBN 0 7503 0187 2

To be ordered through

IOP Publishing Ltd.
Techno House
Redcliffe Way
Bristol BS1 6NX
England

Price: £.Stg.40

The Natural Radiation Environment

Proceedings of the Fifth International Symposium on the Natural Radiation Environment, jointly organised by the CEC, the US Department of Energy, the IAEA Vienna and the University of Salzburg.

Salzburg (Austria) 22-28 September 1991

Edited by A. Janssens, W. Lowder, M. Olast, J. Sinnaeve and F. Steinhäusler

This symposium follows the one organised by the CEC and the US-DOE in Lisbon in 1987 and those organised by the US-DOE in Houston in 1963, 1972 and 1978. It also continues a series of meetings organised by the CEC on this subject (Paris, 1979, Anacapri, 1983, and Maastricht, 1985). These regular international symposia always generate great interest because of the rapid progress of knowledge and new development in this field.

In the opening session it was clearly stated that the radon issue is one of the major problems in radiation protection and underlined the need for international collaboration in order to optimise the research effort in different countries. One can refer to the latest UNSCEAR report and to the request to the IAEA from more than fifty-five countries for technical assistance, to illustrate the seriousness of the radon problem and its regulatory implications.

In the course of the symposium, it was also emphasised that there is an urgent need to develop research to reduce the uncertainties associated with our present knowledge about the health impact of exposure to radon. One can hope that the increase of data coming from measurements of radon in the human environment, from experimental investigations and from epidemiological studies will lead to a realistic assessment of the health impact. This would have the approval of the whole scientific community.

Fortunately this NRE V symposium was not only a radon symposium; many other important subjects, such as the radiological impact of non-nuclear industrial releases and the exposure of the public and of workers to natural sources of radiation in non-domestic environments, were also addressed in this symposium.

Report EUR 13892 EN, published in Radiation Protection Dosimetry
Vol. 45, Nos. 1-4,1992, (Supplement), 800 pages.

To be ordered through

Nuclear Technology Publishing
P.O.Box No.7
Ashford
GB-Kent TN25 4NW

Price:£.Stg. 150

Effectiveness and quantification of agricultural techniques for countermeasures

Proceedings of a workshop

Brussels (B), 1 - 4 October 1991

Principal subjects:

- Introduction: general approaches to countermeasures
- Countermeasures to limit contamination of plant products
- Countermeasures to limit contamination of animal products
- Countermeasures for reducing radiation doses arising from forest ecosystems
- General conclusion

Proceedings edited by G. Desmet and B. J. Howard.

Published by Science of the Total Environment

ISSN 0048-9697

To be ordered through

Elsevier Science Publishers B.V.
Journals Department
P.O. Box 211
NL-1000 AE Amsterdam

International Seminar on Intervention Levels and Countermeasures for Nuclear Accidents

Report edited by DG XI: Environment, Nuclear Safety and Civil Protection.

Proceedings of a seminar organized by the Commission, the Commissariat à l'Energie Atomique (CEA) and the International Union of Radioecologists (IUR) and sponsored by the Regional Council Provence-Alpes-Côte d'Azur.

Cadarache (F), 7-11 October 1991.

One of the main conclusions of the seminar, held in Luxembourg in October×1990 on the three nuclear accidents at Kyshtym, Windscale and Chernobyl, was that all countries, irrespective of whether they had nuclear installations on their territory, should make arrangements to deal with the consequences of the possible widescale dispersal of radioactive material in the event of a major nuclear accident. These arrangements should be prepared in advance, covering all countermeasures which may need to be implemented to control the potential consequences of an accident. Following the Chernobyl accident considerable experience has been gained in many countries, especially in the USSR, in establishing intervention levels for various countermeasures. The seminar gave the opportunity to review this experience and to draw the relevant conclusions for the future. The main objectives of this seminar were to present and discuss:

- characteristics of the different types of countermeasures, in particular their advantages and disadvantages,
- approaches used for establishing intervention levels for each type of countermeasures,
- experience gained in the practical implementation of countermeasures.

138 scientists from 19 different countries have attended the seminar. About 20 scientists, coming from different C.I.S. Republics, have presented the latest information available. From the 52 papers presented it may be concluded that the objectives of the seminar have largely been realized.

Report EUR 14469 in press.

To be published by:
Office for Official Publications
of the European Communities
Boîte Postale 1003
L - 2985 Luxembourg

Age-dependent Factors in the Biokinetics and Dosimetry of Radionuclides

Proceedings of a workshop jointly organised by US DOE, EULEP and the CEC.

Schloss Elmau (D) 5-8 November 1991

Edited by D.M. Taylor, G.B. Gerber and J.W. Stather

There is an increasing need to be able to assess radiation doses to members of the public following the entry of natural and artificial radionuclides into the environment and from the use of radio-pharmaceuticals in nuclear medicine. To obtain realistic estimates of doses to a population, information is required on the effect of age and chemical form on the uptake of radionuclides following ingestion and inhalation, on their distribution and excretion after entry into the blood, and on factors influencing their biokinetics in the skeleton and other tissues. Information is further required on the transfer of radionuclides to the developing embryo and fetus following intakes of radionuclides by the mother, either before or during gestation.

The invited or contributed papers presented at the Workshop and published in the proceeding, cover many areas including gastrointestinal uptake and inhalation of radionuclides by various age-groups in the population, the effect of age on the biokinetics models and the transfer of radionuclides from the mother to the developing embryo and fetus. Reviews of the activities of the ICRP Task Group on Age-dependent Dosimetry and of other collaborative international investigations are also included. The presentations provide a comprehensive overview of the current state of our knowledge on the age-related factors which are of importance for assessing radiation exposure of the population, indicating the progress which has been made since the previous Workshop on this topic held in Angers, France, in late 1986. A summary of a round-table discussion held at the conclusion of the Workshop assesses the possible implications for radiation protection and identifies areas where further research is needed.

Published by Nuclear Technology Publishing in Radiation Protection Dosimetry Vol 41 Nos. 2-4, 1992, (Report EUR 14460) 295 pages.

ISBN 1 870965 15 9

To be ordered from:

Nuclear Technology Publishing
P.O. Box No. 7
Ashford
GB-Kent TN25 4NW

Price: £.Stg. 20

Digital Radiography - Quality Assurance and Radiation Protection

Proceedings of a Discussion - Workshop, jointly organised by the CEC, the Institut für Klinische Radiologie, Mannheim, and the EAR.

Mannheim (D), 7-9 May, 1992.

Edited by H.P. Busch and M. Georgi

The discussions concentrated on the two new digital imaging methods: digital image intensifier radiography and storage phosphor radiography. Radiologists, physicists and representatives of the manufacturing companies discussed the image quality assurance parameters, quality control methods and the appropriate protection measures as well as reasonable patient exposure levels. Various working groups were looking into the imaging properties and potential applications of these new techniques. The Proceedings give an overview of the experiences of those working groups and summarise the discussions centred around the following aspects. It was emphasised that the introduction of new imaging techniques needs a permanent exchange of experiences, for the evaluation of diagnostic information, while at the same time minimising the burden to the patient arising from invasiveness, examination time and dose. It was pointed out that digital imaging provides a means of adjusting the dose and hence image quality for a wide range of clinical indications. Thus the imaging parameters can be tailored to the question being addressed. In addition, digital postprocessing opens up new imaging possibilities. The right choice of exposure parameters can enhance the diagnostic information and reduce radiation exposure, compared with conventional techniques. More efforts are needed to develop methods and procedures for regular quality control, which should draw on the extra potential offered by the new digital technology.

A working party established a statement on the state and perspectives of digital mammography and the potential for mammography screening.

Published by Schnetztor Verlag GmbH, Konstanz, 1992, 103 pages

ISBN 3-87018 - 094 - 3

Available on request from:

Prof. Dr. H.P. Busch
Institut für Klinische Radiologie
Theodor Kutzer Ufer
D-6800 Mannheim

The dynamic behaviour of radionuclides in forests

Proceedings of seminar

Stockholm (S), 18 - 22 May 1992

Principal subjects:

- Deposition and Interception of radionuclides
- Distribution and cycling of Radionuclides between Soil and Vegetation
- Behaviour of radionuclides in Soil
- Contamination of Wildlife
- Impact of Contaminated Forests on Man and Environment
- Countermeasures

Proceedings edited by G. Desmet and J. Melin, to be published in Science of the Total Environment

MONOGRAPHS

ALARA: From theory towards practice

Report prepared by P.J. Stokell and J.R. Croft, NRPB (UK) and J. Lochard and J. Lombard, CEPN (France) for the Commission of the European Communities.

The ALARA principle states that "all exposures shall be kept "as low as reasonably achievable", economic and social factors being taken into account". It is a simple concept - the idea behind it is widely used in nearly all spheres of life, i.e. to do the best one can under the given circumstances. This book aims to help define what is meant by "best" in the context of radiation protection. It describes a procedure that is useful in structuring one's approach to any particular situation where a decision as to the "best" course of action is required. It also provides practical guidance on how the concept can be incorporated into radiation programmes.

This book has been written as a reference manual on both the theoretical and practical aspects of the subject. But it is equally targeted at those involved in radiation protection at the practical level.

Report EUR 13796 EN, 1991, 220 pages

To be ordered through:
Office for Official Publications
of the European Communities
BP 1003
L-2985 Luxembourg

Price: ECU 18.75

International Chernobyl Project - input from the Commission of the European Communities to the evaluation of the relocation policy adopted by the former Soviet Union

Report prepared by J. Lochard and T. Schneider, CEPN (F), (Part A), and S. French, School of Computer Studies, University of Leeds (UK), (Part B) for the Commission of the European Communities.

In October 1989, the Government of the USSR formally requested the International Atomic Energy Agency (IAEA) to carry out: "an international experts' assessment of the concept which the USSR has evolved to enable the population to live safely in areas affected by radioactive contamination following the Chernobyl accident, and an evaluation of the effectiveness of the steps taken in those areas to safeguard the health of the population".

The CEC was represented in the International Advisory Committee and accepted responsibility for the funding and management of the evaluation that was made of the policy being adopted, or proposed, for the relocation of people still continuing to live in contaminated areas. This evaluation had two major technical inputs: firstly, an analysis of the costs and effectiveness, in terms of possible improvements in health among those affected, of the proposed policy; and, secondly, the holding of a series of Decision Conferences in each of the affected Republics and at the All Union level to ascertain the major factors or considerations that were influencing policy decisions in this area. The main findings of this evaluation are contained in the reports of the International Advisory Committee. Because of the importance of, and wide interest shown in this evaluation, a fuller account of the evaluation has been prepared and is published in this report. The results of each of the Decision Conferences held in the respective Republics and at the All Union level are summarised. The report also illustrates the relative merits of cost benefit and multi-analysis techniques (the latter applied in a decision conference mode) in identifying the key issues and their relative importance in determining relocation policy in the former USSR. The experience gained in the effective use of both types of technique in this evaluation will be useful in aiding the development of policy generally for intervention following an accident.

Report EUR 14543 EN, 1992, 151 pages

To be ordered through:
Official for Official Publications
of the European Communities
BP 1003
L-2985 Luxembourg

Price: ECU 15

Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers

Report prepared by G.B. Gerber (CEC) and R.G. Thomas (WDOE) for the Commission of the European Communities.

Edited by G.B. Gerber and R.G. Thomas.

Difficult decisions face physicians and health physicists when they are confronted with an accident involving radionuclide contamination of workers. These decisions must be made rapidly and usually without advice from outside experts. This book provides guidance in such situations.

The treatments and procedures recommended in this book were prepared as a join effort by six scientists in the field together with the editors. They come from the European Community and the United States. Their work was sponsored by the Radiation Protection Research Programme of the Commission of the European Communities and the Office of Health and Environment Research of the US Department of Energy. This guide offers an international consensus and is an example of the results that can be achieved by joining efforts on a problem that does not recognise national borders.

This book will be helpful to physicians, paramedics and emergency personnel who may face an accident involving radionuclide contamination of workers. Efficient management of such an accident requires meticulous planning; the personnel must be fully trained, and the lines of communications among all potentially responsible parties must be established beforehand.

The recommendations presented here are guidelines. The scientists who prepared the book and the agencies who sponsored the work are not responsible for any adverse consequences arising from using the information presented. Trade names and supplier of the different products are given as examples; official permission for use, the availability, and the composition of the drugs, may vary in different countries.

Published by Nuclear Technology Publishing in Radiation Protection Dosimetry Vol 41 No. 1, 1992, (Report EUR 14320) 50 pages.

ISBN 1 870965 22 1

To be ordered from:

Nuclear Technology Publishing
P.O. Box No. 7
Ashford
GB-Kent TN25 4NW

Price: £.Stg. 20

Community Radiation Protection Legislation

Report edited by DG XI: Environment, Nuclear Safety and Civil Protection

Composure of the provisions of the European Communities in the area of radiation protection. This document contains the full text of the provisions of the European Communities in the area of radiation protection. It is designed to help those who work in the area of radiation protection and those interested in these problems by providing them with an easily understood collection of the relevant texts which have been issued on the basis of the EURATOM Treaty.

The collection is arranged as follows:

I.Provisions of the EURATOM Treaty;
II.Regulations, Directives and Decisions of the Council or the Commission;
III.Recommendations and Communications of the Commission.

It has been prepared in English, French and German versions by the Radiation Protection Division of the Directorate-General for the Environment, Nuclear Safety and Civil Protection in Luxembourg. The third edition contains all official texts in force as of 1st August 1992.

Doc. XI/3539/92 EN, FR, DE, 1992; 119 pages.

To be ordered through:

Commission of the European Communities
Radiation Protection Division
Mr H. LELLIG
Centre Wagner
rue Alcide de Gasperi
L - 2920 Luxembourg

Radiocesium contamination of foodstuffs in Greece following the Chernobyl accident

This report has been prepared by G. APOSTOLATOS and A.A. KATSANOS, Ministry of Agriculture, Technical University of Crete, Chania, Greece, for the Commission of the European Communities, Directorate General Environment, Nuclear Safety and Civil Protection.

Data have been collected and presented in a comprehensive form on the consequences encountered in Greece as a result of the Chernobyl accident on the 26th of April 1986. The data refer to: (a) The radiocesium contamination levels in air, soil, rain, sea, drinking water, and in the various agricultural products. (b) The time evolution of the radiocesium contamination with respect to various products, production areas and to the environmental conditions prevailing at the time of the fail out, and (c) the recent contamination levels of the agricultural products, especially the new vegetation and those of long storage life. Finally, (d) the recommended and the implemented countermeasures in Greece and their effect are presented and discussed.

Radiation protection series: No 55 EN, 1992; 54 pages

To be ordered through:

Commission of the European Communities
Radiation Protection Division
Mr. M. HERZEELE
Centre Wagner
Rue Alcide de Gasperi
L - 2920 Luxembourg.

Introduction to radioecology of forest ecosystems and survey of radioactive contamination in food products from forests

This report has been prepared by A. FRAITURE, Laboratory of Systematic Botany and Phytogeography at Liège University (B), for the Commission of the European Communities, Directorate General Environment, Nuclear Safety and Civil Protection.

The first part of this report consists in a review of the various factors determining the contamination of forest ecosystems after an accident such as the one that occurred in Chernobyl. The second part encompasses a survey of the contamination levels observed in the main plants and animals growing in forest ecosystems and likely to be consumed as food by man. Three chapters deal with higher plants, game and wild fungi. A survey of the observed contamination levels is proposed thereafter, based both on literature data and on unpublished reports. It is followed by some comments and conclusions.

The third part of this report presents a set of preventive measures aimed at reducing doses ingested by the public when consuming products from forest ecosystems after a radioactive contamination. The fourth part is a quick presentation of the evolution of the contamination levels in forest ecosystems and, among others, of the plants and animals living there. A bibliographical list of 366 references is given at the end of the report.

Radiation protection series: No 57 EN, 1992; 103 pages

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Centre Wagner
Rue Alcide de Gasperi
L - 2920 Luxembourg

Impact radioécologique de l'accident de Tchernobyl sur les écosystèmes aquatiques

This report has been prepared by L. FOULQUIER and Y. BAUDIN-JAULENT, C.E.-Cadarache, IPSN/DPEI/SERE (F), for the Commission of the European Communities, Directorate General Environment, Nuclear Safety and Civil Protection.

Over three hundred reports containing data on the radioactive contamination resulting from the Chernobyl accident have been reviewed in respect of levels in water, sediments, aquatic plants and fish, levels which clearly demonstrate the wide spatial variations which occurred. This review allows a closer examination of the mechanisms in aquatic environments, which govern transfer of the nuclides concerned, viz., I-131, Te-132, Ru-103/106, Ag-110m, Cs-134/137 and to a lesser extent Sr-89/90.

Radiation protection series: No 58 FR, 1992, 392 pages

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OTHER PUBLICATIONS

CATALOGUE OF CONTRACTS OF THE COMMISSION'S

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(Publication EUR 13387 EN)

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To be obtained from:

CEC
DG XII/F/6
Rue de la Loi, 200
B - 1049 Brussels

LIST OF ACRONYMS AND ABBREVIATIONS

AECB	Atomic Energy Control Board, Ottawa (Canada)
AECL	Atomic Energy of Canada Limited (Canada)
AFPPE	Association Française du Personnel Paramédical d'Electrocardiologie, Paris (F)
AIRM	Associazione Italiana di Radioprotezione Medice (I)
AIRP	Associazione Italiana di Protezione contro le Radiazioni (I)
ALARA	As Low As Reasonably Achievable
CAATS/INSERM	Centre d'évaluation pour l'Assurance de qualité des Applications Technologiques dans le domaine de la Santé/Institut National de la Santé et de la Recherche Médicale, Cachan (F)
CEA	Commissariat à l'Energie Atomique, Fontenay-aux-Roses (F)
CEC	Commission of the European Communities, Brussels (B)
CEDHYS	Centre de Développement des Etudes et Applications en Hygiène et Sécurité, Paris (F)
CEN/SCK	Centre d'Energie Nucléaire/Studie Centrum voor Kernenergie, Mol (B)
CEPN	Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire, Fontenay-aux-Roses (F)
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Technológicas, Madrid (E)
CIR	Centre International de Radiopathologie, Fontenay-aux-Roses (F)
CNEN	Comitate Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Egnergie Alternative, Rome (I)
COSYMA	Code System Maria
CRSA	Centro Regionale per la Sperimentazione Agraria per il Friuli-Venezia-Guilia, Udine (I)
EAR	European Association of Radiology
EBMT	European Bone Marrow Transplant Group
ECURIE	Early Exchange of Information in the Event of Radiological Emergency
EFOMP	European Federation of Organisations of Medical Physics, York (UK)
ENEA/DISP	Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative, Direzione Sicurezza Nucleare e Protezione Sanitaria, Rome (I)
ENEL	Ente Nazional per l'Energia Elletrica, Roma (I)
ERPET	European Radiation Protection Education and Training CEC DG XI/A/1, Luxembourg (L) & DG XII/D/3, Brussels (B)
EULEP	European Late Effects Project Group
EURADOS/CENDOS	European Radiation Dosimetry Group/Collection and Evaluation of Neutron Dosimetry Data
EUROMET	European Metrology
DG	Directorate General of the CEC
GSF	Gesellschaft für Strahlen- und Umweltforschung, Neuherberg (D)
IAEA	International Atomic Energy Agency (A)
IARC	International Agency for Research on Cancer, Lyon (F)
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
ICSTM	Imperial College of Techn. and Medicine Science, London (UK)
IFE	Institute of Freshwater Ecology, Ambleside (UK)
INTECHMER-CNAM	Institut National des Techniques de la Mer - Conservatoire National des Arts et Métiers-Cherbourg (F)
INSTN	Institut National des Scienes et Techniques Nucléaires, Saclay (F)
IOMP	International Organisation of Medical Physicists
IRS	Integrated Radiological Services Ltd, Liverpool (UK)

ISH	Institut für Strahlenhygiene/Bundesamt für Strahlenschutz, Salzgitter/Neuherberg (D)
ITE	Institute of Terrestrial Ecology, Grange-over-Sands (UK)
ITRI	Inhalation Toxicology Research Institute, Albuquerque, NM (USA)
ITRI/TNO	Instituut voor Toegepaste Radiobiologie en Immunologie, TNO Rijswijk (NL)
IUR	International Union of Radioecologists
JRC	Joint Research Center of the CEC at ISPRA
KFA	Forschungsanlage, Jülich (D)
KfK	Kernforschungszentrum Karlsruhe (D)
KUL	Katholieke Universiteit Leuven (B)
LNETI	Laboratorio Nacional de Engenharia e Tecnologia Industrial, Lisboa (P)
MAFF	Ministry of Agriculture, Food and Fisheries, Lowestoft (UK)
MARIA	Methods for Assessing the Radiological Impact of Accidents
MLURI	McAulay Land Use Research Institute, Edinburgh (UK)
NEB	Nuclear Energy Board of Ireland, Dublin (IRL)
NIRP	National Institute of Radiation Protection, Stockholm (S)
NCSR	Democritos, National Centre for Scientific Research, Athens (GR)
NRPB	National Radiological Protection Board, Chilton (UK)
OECD/NEA	Organisation for Economic Cooperation and Development/Nuclear Energy Agency
ORNL	Oak Ridge National Laboratory, Knoxville, Tennessee (USA)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig (D)
RADE-AID	Radiological Accident Decision Aiding System
RBE	Relative Biological Effectiveness
REM	Radioactivity Environmental Monitoring
RERF	Radiation Effects Research Foundation, Hiroshima (Japan)
RIVM	Rijks Instituut voor Volksgezondheid en Milieu, Bilthoven (NL)
SCRPI	Service Central pour la Protection contre les Rayonnements Ionisants, Le Vésinet (F)
SEPR	Sociedad Española de Proteccion Radiologica (E)
SFEN	Société Française d'Energie Nucléaire, Paris (F)
SFRP	Sociedad Española de Proteccion Radiologica (E)
SRD	Safety and Reliability Directorate, Warrington (UK)
SUAS	Swedish University of Agricultural Sciences, Umea (S)
TEPC	Tissue-Equivalent Proportional Counter
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, Rijswijk (NL)
UKAEA	United Kingdom Atomic Energy Authority, Harwell (UK)
ULB	Université Libre de Bruxelles, Brussels (B)
US DOE	US Department of Energy, Washington DC (USA)
US EPA	US Environmental Protection Agency
US NCI	US National Cancer Institute, Bethesda (USA)
US NIES	US National Institute of Environmental Sciences
USL	Unità Sanitaria Locale, N° 7, Udine (I)
WHO	World Health Organisation

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The final report of the 1990-91 period of the radiation protection programme outlines the research work carried out during the whole contractual period under all contracts between the European Commission and research groups in the Member States. More than 450 scientists collaborated on this programme.

Results of more than 350 projects are reported. They are grouped into three sectors:

1. Human exposure to radiation and radioactivity, which includes:
1.1. Measurement of radiation dose and its interpretation.
1.2. Transfer and behaviour of radionuclides in the environment.
2. Consequences of radiation exposure to man: assessment, prevention and treatment, which includes:
2.1. Stochastic effects of radiation.
2.2. Non-stochastic effects of radiation.
2.3. Radiation effects on the developing organism.
3. Risks and management of exposure, which includes:
3.1. Assessment of human exposure and risks.
3.2. Optimization and management of radiation protection.

Within the framework programme, the aim of this scientific research is to improve the conditions of life with respect to work and protection of man and his environment and to assure safe production of energy, i.e.:

(i) to improve methods necessary to protect workers and the population by updating the scientific basis for appropriate standards;
(ii) to prevent and counteract harmful effects of radiation;
(iii) to assess radiation risks and provide methods to cope with the consequences of radiation accidents.

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Fordelingskoden er tilpasset strålingsbeskyttelsesprogrammets forskellige arbejdsområder. De rubrikker,.der svarer til Deres interessefelter, bedes forsynet med et X.

1 Radioaktiv miljøforurening

☐ 2 Genetiske virkninger af stråling

☐ 3 Strålingsvirkninger på kort sigt, akut strålingssyndrom og dets behandling

4 Strålingsvirkninger på lang sigt og inkorporerede radionukleiders toksikologi

☐ 5 Strålingsmåling og dens fortolkning, dosimetri

☐ 6 Vurdering af strålingsrisici

Såfremt De er interesseret i at blive optaget på vor forsendelsesliste, bedes De tilbagesende dette kort i udfyldt stand (maskinskrevet)

Falls Sie daran interessiert sind, in unsere Versandliste aufgenommen zu werden, schicken Sie uns bitte diese Karte vollstandig ausgefullt zuruck (Maschinenschrift)

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☐ 2 Genetische Strahlenwirkungen

☐ 3 Fruhwirkungen bei Bestrahlung, akutes Strahlensyndrom und seine Behandlung

☐ 4 Spatwirkungen bei Bestrahlung und Toxikologie inkorporierter Radionuklide

5 Strahlenmessung und ihre Interpretation, Dosimetrie

6 Abschatzung des Strahlenrisikos

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1 Contaminazione radioattiva dell'ambiente

2 Effetti ereditari delle radiazioni

3 Effetti a breve termine delle radiazioni, sindrome acuta da irradiazione e suo trattamento

4 Effetti a lungo termine delle radiazioni e tossicologia dei radionuclidi incorporati

5 Misura delle radiazioni e loro interpretazione, dosimetria

6 Valutazione dei rischi da radiazioni

Se desidera che il Suo nome figuri fra i destinatari delle nostre pubblicazioni, La preghiamo di restituirci il presente modulo debitamente compilato (a macchina)

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3 Effecten van straling op korte termijn, acuut bestralingssyndroom en behandeling

4 Effecten van straling op langere termijn en toxicologie van opgenomen radionucliden

5 Meting van straling en de interpretatie daar van, dosimetrie

6 Beoordeling van stralingsrisico's

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5 Mesures des rayonnements et leur interprétation, dosimétrie

6 Évaluation des risques d'irradiation

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