Commission of the European Communities
Joint Research Centre
Karlsruhe Establishment

The European Institute for Transuranium Elements


Released by
Reg.Präs. Stuttgart
Nr. 2/55461 c

The European Institute
for Transuranium Elements

Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES
Directorate-General
Information Market and Innovation
Bâtiment Jean Monnet
LUXEMBOURG

Cataloguing data can be found at the end of this publication

Luxembourg, Office for Official Publications of the European Communities
1986

ISBN 92-825-6100-3 Catalogue number CD-NE-86-018-EN-C

Printed in the Federal Republic of Germany

THE EUROPEAN INSTITUTE FOR TRANSURANIUM ELEMENTS

Commission of the European Communities
Joint Research Centre (JRC)
Karlsruhe Establishment

Directorate-General

Science, Research and Development

1986 **EUR 10480 EN**

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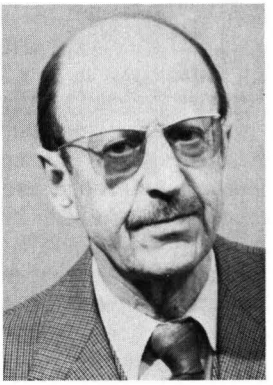


Prof. Dr. R. Lindner
1969—1986

The European Institute for Transuranium Elements (which I had the privilege to serve more than 16 years) constitutes a unique experience. Unique through the combination of the following factors:
A true European Institute with a multi-national working force, cooperating on a permanent basis on intricate research problems, branching out into industrial application and fundamental research at the same time.
Although the optimistic views of the founding fathers in the late 50s in the field of nuclear energy have yielded to realistic appreciation, taking into account developments on the technical, political and mass-psychological scene, this Institute is going strong and — I hope — will do so in the future.
This was and will be possible on the basis of the following efforts:
Quality of work, based on competence and experience of the staff and adequate equipment; continuous exchange of ideas with the scientific community on an official as well as a personal basis; continuity where it is necessary in spite of fluctuations of the public interest and support; flexibility where it is indicated to adjust to real needs, those of our customer: the European taxpayer.
In brief outline, the development has been as follows:
In the 1960s: Planning, construction, basic organisation, and entry into scientific-technological work by, amongst others, a major campaign of production of fuel elements for the first zero-power fast breeder. All under the responsibility of Jean BLIN, the first director (1963—68), and H. M. MATTHYS (acting director 1968—69).
In the 1970s: Tightening of international cooperation by active work of an Advisory Committee on Programme Management (1970—1984). Apart from nuclear fuels research, establishment of the second major line, namely safety of the nuclear fuel cycle. And then, of course, fundamental research on actinides. The contribution to fundamental knowledge of their solid state and electronic structure has increased over the years and is now a solid basis for the Institute's international reputation.

In the 1980s: Fuel research regained momentum which seems paradoxical because of the reduced activities in the national organisations, but which can be explained by just this fact, namely that a concentration of advanced high risk research within Europe naturally falls on the Community's institutions.
In recent years, the interlinkage between the various Joint Research Centre Establishments (apart from Karlsruhe, located in Ispra, Geel and Petten, respectively) has increased: partly by a stronger participation of the Transuranium Institute in research on nuclear waste and its disposal, partly by the utilisation of the Karlsruhe competence for urgent problems in the field of toxic aerosols, atmospheric reactions, and monitoring of workers in hostile environments.
Like in most nuclear research organisations, a change of the guard is taking place. At this date, a new edition of our information brochure (the 1975 version being outdated) might be useful.

Karlsruhe, February 1986 R. Lindner

Address from the Incoming Director

Dr. J. van Geel
Present Director

Research on properties and applications of Transuranium Elements on a European scale is a challenge to be met with unique expertise and equipment, which is assembled at the European Institute for Transuranium Elements, the Karlsruhe Establishment of the Joint Research Centre of the Commission of the European Communities. The problems to be covered range from the growth of — radioactive — actinide single crystals to the post-irradiation analysis of reactor-tested fuel rods, from the development and optimisation of 21st century reactor fuel materials to the investigation of the generation and dispersion of nuclear aerosols, from the study of material properties under simulated accident situations at temperatures of several thousand degrees to improvements in fuel reprocessing and radioactive waste conditioning.
There is, to my knowledge, no other academic or industrial institution in western Europe where all these activities — and many more — can be, and are being, pursued under one roof.

The European Institute for Transuranium Elements has recently commemorated its twentieth anniversary. While the principal long-term guidelines for the work at the Institute are clearly defined, minor changes in the direction of the efforts undertaken become necessary from time to time.
During the years to come, the Institute will continue to make a contribution to nuclear safety. Its international status and the competence of its collaborators make it well suited to render a valuable service by acting as an authority on matters of the physics and chemistry of the transuranium elements, nuclear materials characterisation, standardisation, and regulations for the safety of workers in nuclear installations. Its rôle to provide the nuclear industry with information on the science and technology of the nuclear fuel cycle will be strengthened.

In this sense, the following pages invite you to get acquainted with our Laboratory. Additional information may be obtained from the Institute's documentation service.

Karlsruhe, June 1986 J. van Geel

1 At a Glance

Introduction

On March 25th, 1957, the plenipotentiaries of the Heads of State of Belgium, the Federal Republic of Germany, France, Italy, Luxembourg, and The Netherlands met in Rome to sign the Treaties establishing a European Economic Community and a European Atomic Energy Community (EURATOM). One of the provisions of the EURATOM Treaty was the creation of a Joint Nuclear Research Centre, to be operated in common by the six countries, dedicated to the peaceful development of nuclear energy.

On this basis, laboratories were set up for community research at Ispra (Italy), Petten (The Netherlands), Geel (Belgium), and Karlsruhe (FRG). Whereas the large Italian centre at Ispra was multidisciplinary in nature with laboratories for reactor physics, chemistry, materials research, and biology, the three smaller centres were more specialised; Petten was chosen to operate a high neutron flux research reactor; a Central Bureau for Nuclear Measurements was set up at Geel. Karlsruhe, following an agreement between the EURATOM Comission and the Government of the Federal Republic, was selected to host the European Institute for Transuranium Elements, built on the site of the German Nuclear Research Centre.

The original team that prepared the construction of the Institute comprised scientists and engineers who had worked in similar laboratories in Europe and in the United States. They were thus able to incorporate the experience gained in several earlier installations.

The costs for construction and initial equipment of the laboratory amounted to about 50 million Deutschmark. The first research teams moved into their laboratories in May 1964.

Today, the European Institute for Transuranium Elements numbers 210 staff from almost all countries of the Community.

The European Institute for Transuranium Elements is doing research on the utilisation of transuranium elements. The research programme is proposed by the Commission and agreed by the Council of Ministers for a period of four years. The European Parliament expresses its opinion on its contents, and the Economic and Social Committee is informed on the outlines of the research programme.

The Institute is almost entirely financed by the Commission of the European Communities. Its work is supervised by independent specialists from all Member States. The results of the research work carried out at the Institute are at the unrestricted disposal of the Member States.

What are Transuranium Elements?

Until 1942, physicists and chemists considered all matter of this world to be made from 92 elements, with hydrogen being the lightest and uranium the heaviest. For each element, atoms existed with slightly different weights, the isotopes, but they were chemically undistinguishable.

This view had to be changed when, at the beginning of the forties, physicists began to submit uranium and other heavy elements to bombardments with elementary particles in accelerators, or, later, in nuclear reactors. This led to complicated nuclear reactions which transformed, e. g., uranium into another, as yet unknown heavier element, plutonium. Today 15 artificial elements are known which lie beyond uranium, the so-called transuranium elements.

All transuranium elements are radioactive, which means, they decay after some time into "normal" lighter elements. Their lifespan ranges from several 100,000 years down to fractions of a second. For the technically interesting plutonium isotope 239, it takes 24,000 years until half of a given mass has decayed.

All transuranium atoms are - more or less - fissionable. They may disintegrate under bombardment with neutrons and during this process release energy. The energy set free per mass unit is, on the average, millions of times higher than in familiar chemical reactions, like combustion and explosion. To make use of this effect for peaceful purposes is the object of world-wide research. Contributing to this task is the principal mission of the European Institute for Transuranium Elements.

Most nuclear power reactors which produce electricity - cheaper and cleaner than power stations fired with coal or oil - use a uranium isotope as fuel which constitutes only 0.7 % of natural uranium ore. However, the 99.3 % of non-fissile isotope U-238 can be transformed in a nuclear reactor by neutron capture into fissile fuel, namely, the plutonium isotope 239. It is even possible to design a reactor in such a way that more fissile material is produced than has been consumed. Since neutron capture by U-238 is most effective with high-energy neutrons, i.e. neutrons travelling very fast, the reactor is called a "fast breeder reactor", FBR. Current designs are fed with fissile plutonium and natural uranium and can breed new plutonium.

It has been shown that by making use of the breeding effect, the energy supply from natural uranium can be stretched by a factor of 60. Assuming that natural uranium supplies will be adequate for another hundred years, breeder technology could provide mankind with energy from nuclear fuels for the next 6,000 years.

This explains why transuranium elements in general and plutonium in particular are extremely interesting materials: they can be used to build reactors which exploit far more effectively the natural resources.

The development of safe and economic techniques for producing fuel elements which can be used in breeder reactors and the investigation of their in-pile behaviour are among the most important tasks of the European Institute for Transuranium Elements. The handling of plutonium and other transuranium elements, due to their high radioactivity, necessitates unusual safety precautions. Incorporation of even the smallest amounts of plutonium into the human body by inhalation, ingestion, or through wounds, may endanger the health of the individiual considerably.

Plutonium is therefore handled in so-called glove-boxes. Numerous safety measures are taken to prevent the spread of any contamination. These measures have been so effective that, in spite of the high hazard from plutonium, no serious accidents during plutonium handling have been reported over the past 40 years.

Wing C — port of call for administration problems

The Institute

The building of the European Institute for Transuranium Elements consists of an administration wing which is normally accessible and a "controlled" laboratory area. All rooms in the controlled area are kept slightly below atmospheric pressure in order to prevent the spreading of a possible contamination. In the controlled area, protective clothing is mandatory. Smoking in laboratories is prohibited. Before leaving the controlled area, all persons must check their hands and feet for radioactivity.

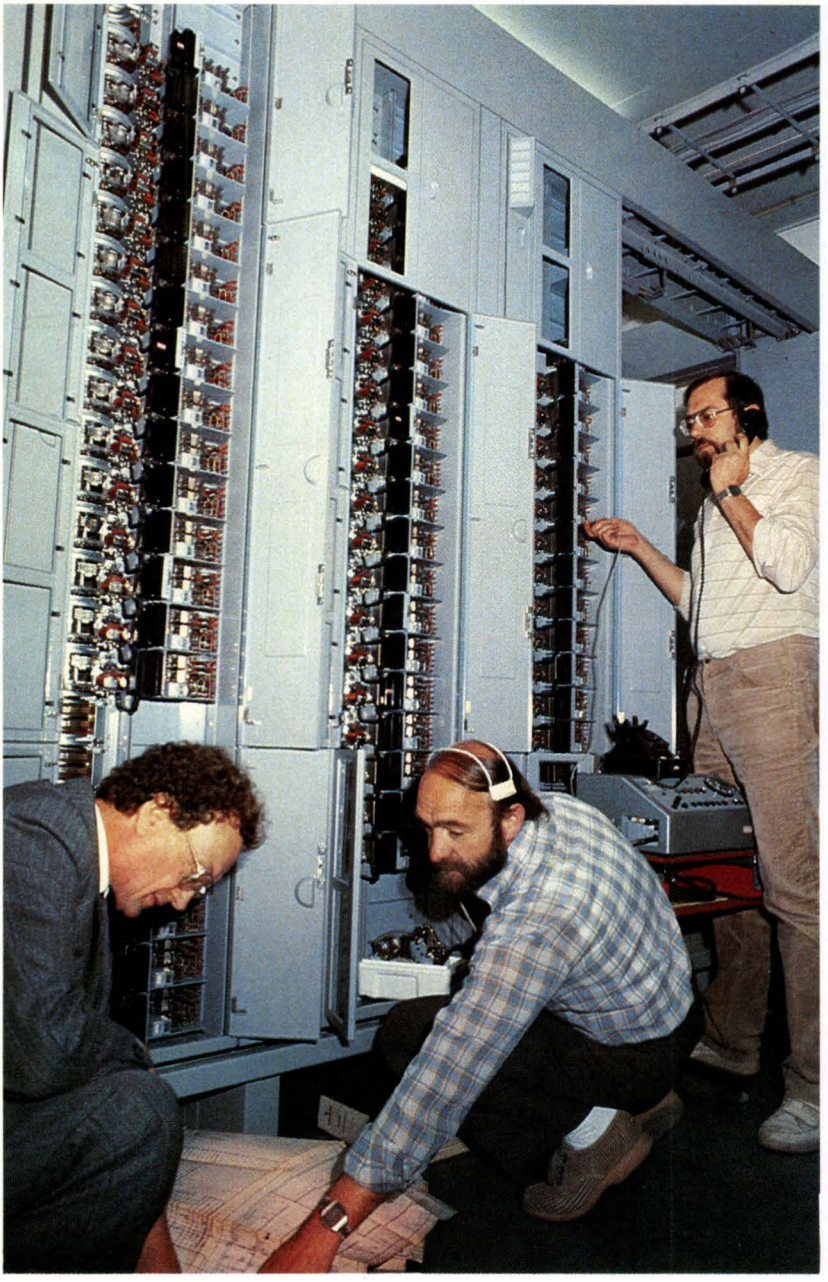
The controlled area, accessible via change rooms, houses offices, workshops, "hot" and "cold" laboratories. Cold laboratories serve for setting up and testing equipment and for working with non-radioactive materials. Plutonium and other highly radioactive transuranium elements are handled exclusively in so-called alpha-laboratories, always in glove-boxes which completely protect from the alpha-radiation.

Fuel specimens, which have been irradiated in a reactor, apart from α-particles, emit β- and γ-rays. Such specimens can be stored and manipulated only in thick-walled concrete cells, of which a total of 20 exist at the Institute.

We have a problem

We have to build a machine

We have to do it carefully



We have to listen to the outer world

The scientific staff of the Institute is organized in 16 groups/laboratories:

Hot Cell Laboratory
Fuel Fabrication Technology
High-Temperature Thermodynamics
Metallography and Thermal Treatment
X-Ray Analysis
Electron-Probe Microanalysis
Aerosol Research
Electron Microscopy
Thermophysics and Irradiation Experiments
Mechanical Properties Studies
Modelling of Fuel Behaviour
Analytical Chemistry
Isotope Analysis
Radio-Chemistry
Actinide Research
Molecular Spectroscopy

These laboratories are supported in their work by the technical division (workshops) and the health physics group.

The Programme

About 80 % of the activity of the Institute concerns the programme "Nuclear Fuels and Actinide Research". The aim of this programme is

- to develop and improve fuel materials for fast breeder reactors,
- to recognize, evaluate, and, if possible, reduce risks arising from the presence of transuranium elements in the nuclear fuel cycle,
- to study fundamental solid-state properties of transuranium elements and their compounds,
- to collect all information concerning the technical potential, the health hazards, and the availibility of transuranium elements.

A potentially life-limiting feature of "advanced" fuels under consideration for the second generation of fast breeder reactors is swelling due to the accumulating fission products. The microscopic phenomena responsible for volume changes during irradiation have been investigated in great detail to facilitate the optimum design of such fuels.

Knowledge is required of the conditions which could prevail in the fuel in the case of the worst conceivable accident which could occur if all built-in safety systems were to fail. Therefore, studies are made on material properties at extremely high temperatures. Such data are necessary to evaluate the consequences of the accident.

Also, processes which occur in the fuel during change of power of a reactor and which may induce strains leading to failure of the fuel cladding are investigated. The results should help to improve the economy of reactor operation.

A major problem in the disposal of radioactive waste is the very long half-life of actinides, such as neptunium and americium. It appears possible to incorporate these elements into new fuel rods with the added bonus of further energy production since they are fissile. Considerable efforts are being made at the Institute in this field, including the development of new fuel fabrication and handling techniques and the execution and evaluation of relevant irradiation experiments. Special attention is given to safety aspects of the reprocessing of spent fuel materials.

The generation and dispersion of radioactive dusts produced during plutonium handling in glove-boxes and in accident situations is being studied in detail in order to evaluate and, if possible, further reduce the risk of handling radioactive materials.

About 20 % of the scientific potential of the Institute is devoted to fundamental research. Techniques have been developed to prepare highly pure

We have to inform visitors

We have to present our results

samples of transuranium elements and transuranium compounds, mostly in the form of single crystals. These samples are used for the study of solid state properties at this laboratory and in cooperation with other European research institutions. The investigations aim at understanding in detail the electronic structure of these materials which determines their chemical and physical character. A good knowledge about the electronic properties makes it possible to predict their behaviour under a wide variety of conditions.

The highly modern research installations of the Institute and the techniques developed here have more recently been applied succesfully also to the study of questions related to (non-nuclear) safety at the working place and to ecological problems.

The results of the work performed at the European Institute for Transuranium Elements are described in semi-annual reports which have been issued regularly for 20 years. About 1500 articles have been published in journals, and more than 1000 contributions to conferences and symposia have been made. Almost 100 patents have been filed as a result of work performed at the Institute.

Research results, know-how and personnel are exchanged with almost 100 research establishments and universities in Europe and overseas. Several large international conferences have been organised by the Institute as well as numerous smaller meetings and workshops with the participation of specialists from all over the world.

2 The Mission

2.1 Background Information

The European Communities and their Treaties

The Treaties for the foundation of the European Economic Community and the European Atomic Energy Community were signed in Rome on March 25, 1957, by the six original Member States, i.e., Belgium, Germany, France, Italy, Luxembourg, and The Netherlands (these countries had already founded the European Coal and Steel Community in 1951).

On April 8, 1965, the Member States agreed that the three Communities should have one common Council of Ministers and one common Commission of the European Community, which started their work on January 1, 1968. The United Kingdom, Ireland and Denmark joined the European Communities on January 1, 1973. They were followed by Greece in 1981, and on January 1, 1986 with Portugal and Spain the number of Member States increased to twelve.

Signature of the Treaties of Rome, March 25, 1957

The EURATOM Treaty

The Preamble states that the Treaty was concluded

- "Recognising that nuclear energy represents an essential resource for the development and invigoration of industry and will permit the advancement of the cause of peace",
- "Resolved to create the conditions necessary for the development of a powerful nuclear industry which will provide extensive energy resources, lead to the modernisation of technical processes and contribute, through its many other applications, to the prosperity of their peoples."

According to Article 1, "it shall be the task of the Community to contribute to the raising of the standard of living in the Member States and to the development of relations with other countries by creating the conditions necessary for the speedy establishment and growth of nuclear industries." Article 2 stipulates that the Community shall, in order to perform its task as provided in the Treaty, "promote research and ensure the dissemination of technical information". According to Article 4, "the Commission shall be responsible for promoting and facilitating research in the Member States and for complementing it by carrying out a Community research and training programme". Article 8 provides for the creation of a Joint Nuclear Research Centre which "shall ensure that the research programmes and other tasks assigned to it by the Commission are carried out".

The European Institute for Transuranium Elements was established and is operated on this basis.

The Transuranium Elements

Formation of Transuranium Elements

A chemical element is characterized by its atomic number Z, i.e., the number of protons in the nucleus. The atomic mass is determined by the sum of the protons (Z) and neutrons (N) in the nucleus. To synthesize transuranium elements, proton numbers greater than 92 have to be attained by nuclear reactions.

The most important nuclear reactions used to build up transuranium elements are:

a) stepwise neutron capture and decay of β-unstable, heavy nuclides during irradiation in a nuclear reactor.

b) multiple neutron capture during nuclear explosions or during rapid nucleosynthesis in stars.
c) bombardment with heavy nuclei in particle accelerators.

Most of the first transuranium nuclides were synthesized by the nuclear reaction:

$$^{238}_{92}U + {}^{1}_{0}n = {}^{239}_{92}U \xrightarrow{\beta^-} {}^{239}_{93}Np \xrightarrow{\beta^-} {}^{239}_{94}Pu$$

It is this reaction which results in the formation of fissile plutonium in nuclear fuel, increasing the life-time of fuel elements or, in breeder reactors, generating more fissile material in the blanket and the core than is consumed in the core.

Elements 99 (Einsteinium, Es) and 100 (Fermium, Fm) were discovered in the debris of the first thermonuclear explosion: they had been formed according to

$$^{238}_{92}U + 15\,{}^{1}_{0}n = {}^{253}_{92}U \xrightarrow{8\,\beta^-} {}^{253}_{100}Fm$$

Elements with atomic numbers higher than 100 can only be synthesized with accelerated particles:

$$^{244}_{94}Pu + {}^{16}_{8}O = {}^{255}_{102}No + 5\,{}^{1}_{0}n$$

Here, a plutonium target is bombarded with oxygen to produce element 102, nobelium.

For several years, groups working at Berkeley (USA) and at Dubna (USSR) have both claimed priority for the synthesis of the latest transuranium elements to be found. In 1974 both groups independently reported the discovery of element 106.

In 1982 a research team at the Gesellschaft für Schwerionen-Forschung (GSI, Darmstadt) succeeded in synthesizing and identifying element 107.

Nuclear Stability and Superelements

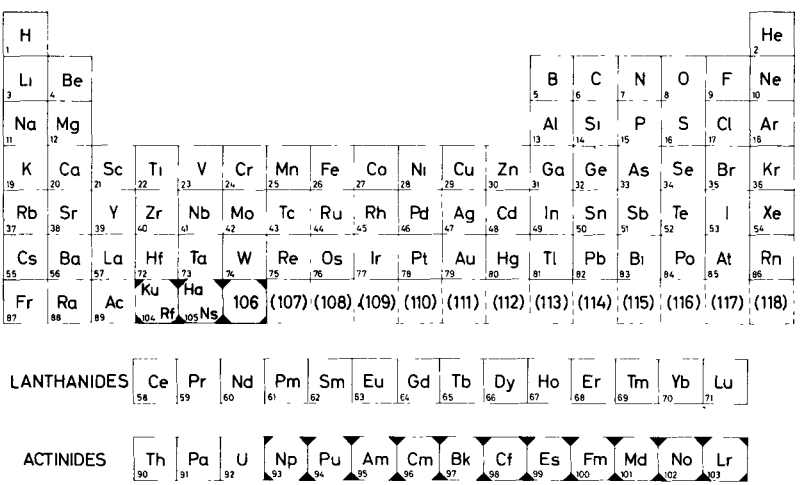
Up to element 106, the half-lives of the longest-lived nuclide of each of the transuranium elements decrease with increasing Z, from more than a million years for the most stable nuclide of Neptunium down to less than a year for Einsteinium. Heavier transuranium elements have a fleeting existence measurable only in fractions of a second. But recent calculations

(based on the nuclear shell model and the existence of magic numbers) suggest that elements with atomic numbers around 110 - 114 might be more stable again. So far, however, attempts to synthesize or to detect in nature these superelements on what SEABORG calls" islands of relative stability in a sea of instability" have failed.

The Actinide Concept of Transuranium Elements

Before their discovery, it was assumed that the transuranium elements would be homologues of the elements Re, Os, Ir in groups VII and VIII of the Periodic Table. This classification was put in doubt when the newly synthesised elements proved to be similar to the Rare Earth elements. The chemical similarity of the Rare Earths results from the similarity of the configuration of the outer electron: the 14 Rare Earth elements following lanthanum differ only by the number of electrons in the inner 4f shell. The lanthanides, therefore, are 4f elements. By analogy, SEABORG suggested that the transuranium elements belong to a family of 5f elements. The 14 elements following Ac (Actinium, $Z=89$) in the Periodic Table (up to $Z=103$) are characterised by increasing occupation of the 5f shell and are called actinides.

SEABORG's actinide concept was very successful: it allowed the newly synthesized elements to be fitted into the Periodic Table in an apparently logical way, it helped to find methods to synthesize and identify heavier elements, and it found its ultimate confirmation in the correct prediction



Position of the actinides and transactinides in the Periodic Table

of the chemical properties of element 104, which turned out to be the homologue of Hf. Hf is the first element after the lanthanides in the Periodic Table, and therefore element 104 is the first transactinide.

Despite its success, the actinide concept in its initial form was contested. With increasing knowledge of the chemical properties, fundamental differences, not only between lanthanides and actinides, but also between light and heavy actinides became evident. Whereas most of the lanthanide ions exhibit the oxidation number three, some of the early members of the actinide family can be oxidized to the heptavalent state. On the other hand, there is evidence for the existence of monovalent Mendelevium (Z = 101). Furthermore, the lanthanide metals crystallize predominantly in close-packed structures; although these structures can be observed with transplutonium metals (Am, Cm), the lighter actinides (Np, Pu) possess unusual crystal structures of low symmetry. Although both lanthanides and actinides are f-elements, there are differences determined by fundamental differences between 4f and 5f electrons.

This concept was modified recently. In summary, the light Actinides up to Pu show transition element-like behaviour, whereas heavy Actinides from Am onwards display a Rare Earth-like character. This extended concept has been convincingly confirmed by photoelectron spectroscopic experiments on α-Pu and Am, performed at the Institute, as discussed later.

Application of Transuranium Elements

The practical application of transuranium elements depends on their nuclear properties. The nuclei of transuranium elements are unstable, some of them can be fissioned by the absorption of slow neutrons and all decay spontaneously, i.e. they are radioactive.

The fact that ^{239}Pu is fissile permits the best use of natural uranium resources for nuclear energy production. The conversion of non-fissile ^{238}U to ^{239}Pu will help to meet future energy demands in three different ways:

- It can be burnt in situ (i.e. in uranium based fuel elements where it is formed by nuclear reactions) and thus helps to increase the lifetime of the fuel element,
- it can replace ^{235}U in enriched fuel through the recycling of plutonium recovered from spent fuel elements;
- it can be burnt in fast breeder reactors; by this means, more fissile material can be formed in the natural uranium of the core and the blanket than is burnt inside the core.

The radioactivity of transuranium elements is characterized by α-decay and spontaneous fission, accompanied by X-ray and gamma radiation. The α-decay energy of ^{238}Pu can be used as a power source in space technology and medicine. Gamma (^{241}Am) and neutron (^{252}Cf) sources are applied in analysis, medicine and technology.

The Transuranium Institute

Some Historic Dates and Facts

On December 21, 1960, an agreement was signed between the Government of the German Federal Republic and the EURATOM Commission concerning the construction and operation of a transuranium laboratory on the site of the German Nuclear Research Centre near Karlsruhe. The site and the building were to be provided by the national counterpart, with the construction work being supervised and coordinated by a mixed planning group, composed of delegates from the EURATOM Commission and the Gesellschaft für Kernforschung; the laboratory was to be operated by the Commission.

The mixed planning group began its work early in 1961. The ground was broken and the cornerstone laid on April 1, 1963. Plutonium was first introduced into one of the glove-boxes of the Laboratory on February 10, 1965.

The hot cells became operative in 1966. All construction work was finished in the course of 1967.

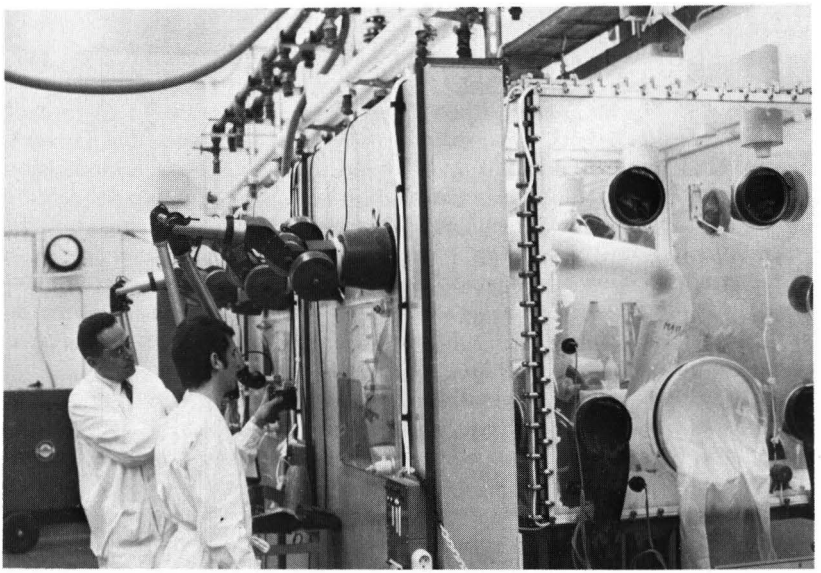
The first significant operation carried out at the Institute to test and demonstrate its technological competence and capacity was the fabrication of 2100 fuel rods for the French zero power reactor MASURCA in 1967.

J. Blin, Director 1963—1968

Personnel

In 1985, the staff of the Institute comprised 210 persons of eight different nationalities, including 43 university-trained engineers and scientists.

Between 1980 and 1985 more than 80 student trainees and guest scientists from 10 different countries spent periods between three months and two years working at the Institute.



Special glove-box providing biological protection by 25 cm of water

Buildings

The building, covering a surface of 16,000 m^2 with a total volume of 188,000 m^3, is divided into wings, each with well defined objectives: Three wings are provided for the manipulation of non-irradiated plutonium and transplutonium elements, one wing for technological operations, and a fifth wing is equipped with hot cells for handling highly radioactive materials.

The Institute has 25 α-laboratories with an effective total suface of 2,540 m^2. Additional hot laboratory space of 330 m^2 is provided by the caissons (α-tight steel structures which house groups of glove-boxes).

The α-laboratories and the caissons are equipped with a total of about 600 glove-boxes, 40 % of which contain an inert gas atmosphere (argon or nitrogen).

The αβγ-laboratory has 21 hot cells. All, except for the disassembly cell, are α,β,γ-tight.

For handling transplutonium elements with lower γ-activity, a line of special glove-boxes is equipped with master-slave manipulators: biological protection is provided by 25 cm of water.

Technical Installations

Seven ventilation installations (one per wing) provide for increasing air pressure differences between non-active zones, active laboratories, glove-boxes, and hot cells, with a total air flow of 600,000 m^3/h.
Two nitrogen purification plants are in operation. One of them with a capacity of 2,000 m^3/h is coupled to the α-tight caissons of the hot cell laboratory, the other delivers up to 1200 m^3/h of pure nitrogen to about 250 glove-boxes. Gas which has been processed in these plants contains 0.5 % of oxygen and only a few ppm of water vapour.

Cost

The construction cost for the laboratory amounted to 16 million UC in 1967[+]. This sum takes into account all buildings and all fixed technical installations, but not the mobile laboratory equipment.

The cost for maintenance and operation of the laboratory was 2.7 million ECU[++] in 1985.

Some Figures (1985)

Electrical power consumption	10.020.000 kWh
Room heating	73.900 GJ
Nitrogen consumption	258.000 m
Hydrogen consumption	33.000 m

In this and other contexts the Laboratory is indebted to the German Nuclear Research Centre (Kernforschungszentrum Karlsruhe).

[+] 1 UC (unit of account) = 3.66 DM (1966)
[++] 1 ECU (European currency unit) = 2.25 DM (1985)

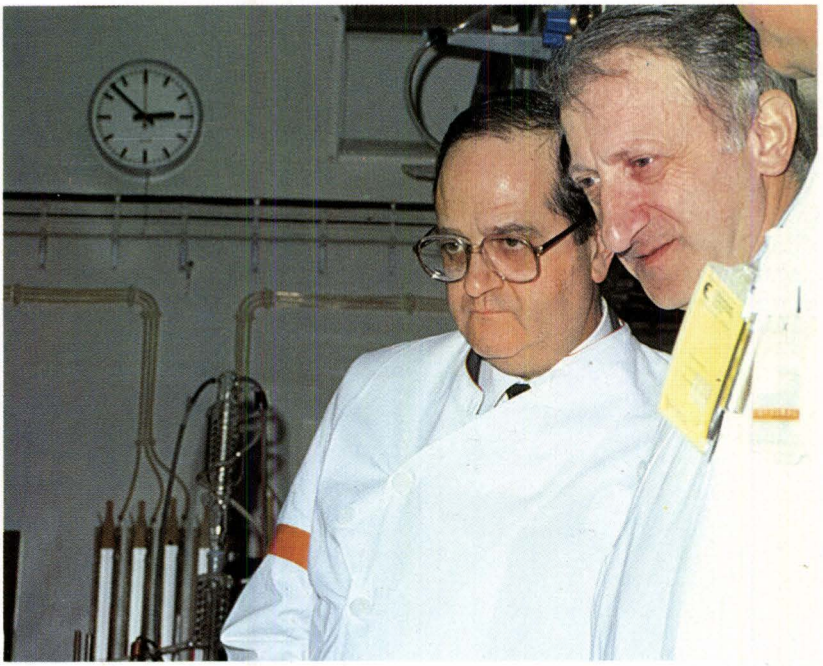
2.2 The Management of the "Nuclear Fuels and Actinide Research" Programme

The Director of the Institute for Transuranium Elements
- responds to the needs and suggestions of a number of authorities and groups and
- at the same time controls the internal structure of the laboratory in order to reach the goals defined in a pluri-annual programme.

The Laboratory, being part of the Joint Research Centre (JRC), proposes its programme to the Director-General of the DG XII/JRC who - after consultation with competent committees - submits it to the Commission, which submits its final proposal to the Council of Ministers.

The Council normally asks for a review by the Group of Atomic Affairs and then defines the contents of the programme and the requirements in budget and manpower for its execution.

Prof. Stelio Villani, Director-General JRC (1974—82), now Director-General of CISE, Milan, together with Prof. Roland Lindner



Prof. Paolo Fasella, Director-General for Science, Research and Development, together with Mr. Jean-Albert Dinkespiler Director-General JRC (1982—86)

In preparing the programme proposal and in following its progress, the Commission and the Research Organisation are advised, aided and supervised by a number of recently formed committees, namely the Board of Governors (outlines of research policy), the Scientific Council (advice on scientific matters), the Management and Coordination Advisory Committee (all aspects of the so-called "action programmes") and the Scientific and Technical Committee (established in the EURATOM Treaty).

On the laboratory scale, the concept of projects is operating. Each project is centred on a major problem which is tackled over a period of years by a team of specialists drawn from a variety of backgrounds.

The laboratory practises very detailed forecasting of the development of the work, which is done by means of project flow-sheets. These are reviewed annually and revised biannually, and allow for a close check on the rate of success.

The responsibility for the execution of each project rests with a project speaker. The aim is to achieve defined results within defined time limits, and for this purpose support in the form of personnel and finance is allotted to each group. Within each project group, the individual scientific or technical collaborator reports directly to the project speaker and is personally responsible for the execution of his task.

This structure provides for optimum efficiency for a laboratory of the size of the Transuranium Institute. It allows the Institute's programme to be executed in a coordinated and open way, while maintaining an acceptable degree of individual freedom and personal responsibility for each employee.

Supervising: the Board of Governors (1982), assessing quality of research on the spot . . .

Moreover, it facilitates the reporting operation and enables the members of supervising committees to verify with relative ease how the allotted funds are used. A multinational laboratory can be justified on a financial basis if its sponsors benefit from its work in relation to their share of the financial burden.

This implies also the execution of medium-term research and of highly specialized operations which the Member States are not willing or able to carry out in their own laboratories. By periodic meetings with the respective departments of the national laboratories and thus by a continuing exchange of ideas, the usefulness of the Laboratory's work is ensured.

. . . the Advisory Committee on Programme Management, after completing its task (July 1984)

2.3 Safety First

The transuranium elements, especially plutonium, are toxic substances. Protection of people working with transuranium nuclides must be based on adequate control and containment of these materials. In addition, although alpha emitting nuclides generally can be handled at short distances, work with irradiated fuel and with certain transplutonium elements requires heavy shielding against gamma-rays and/or neutrons. The following table illustrates the handling problems of ^{144}Ce, a gamma-emitting fission product, of ^{239}Pu and of ^{252}Cf, an alpha-, neutron-, and gamma-emitting transuranium nuclide.

Nuclide	type of radiation	halflife years	shielding required for 1 mg nuclide at 2 m*	annual limit of intake by inhalation, mg
Ce-144 Pr-144	Gamma	0.78	15 cm concrete	5.10^{-6}
Pu-239	Alpha	24 400	no shielding required	7.10^{-5}
Cf-252	Alpha Gamma Neutrons	2.65	90 cm water	3.10^{-8}

* for a 40-hour week occupational exposure

Safety requirements for some radioactive nuclides handled at the TU Institute

The efficient protection of personnel and of the general public against release of and radiation from transuranium nuclides handled in the institute is ensured by

- appropriate working rules and handling techniques
- suitable installations and equipment
- the radiological protection service.

Working Rules and Handling Techniques

The benefits of good equipment depend fully upon the persons who work with it, and safe handling of transuranium elements is feasible only when workers follow clearly defined rules. Every worker in the laboratory is well aware of the safety aspects of the work he is doing and consequently willing to accept certain inconveniences caused by the rules and techniques required for working with radioactive substances. Most of these rules are aimed exclusively at the prevention of spills of radioactive material which is handled in each laboratory. In addition, by frequent checking of hands, feet, clothing, and equipment for contamination, each worker contributes to the early detection of uncontained radioactivity.

Activity in a lead cell

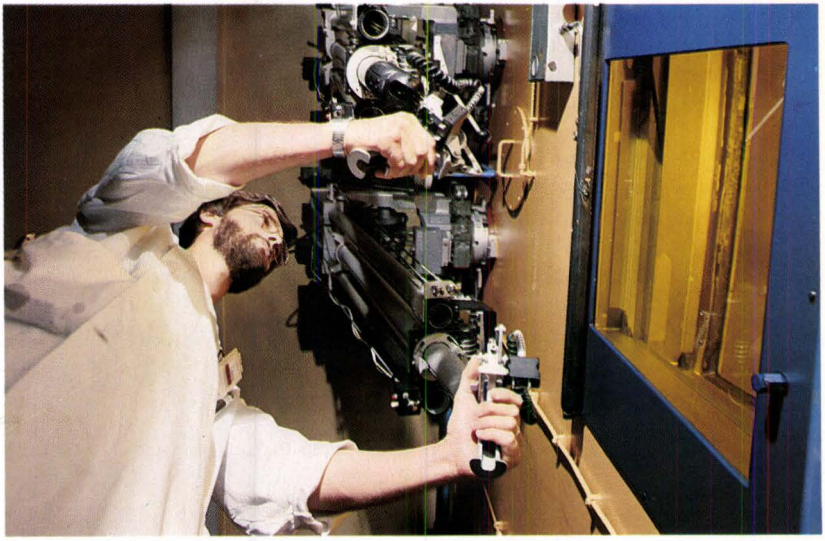
Industrial hygiene and safety aspects are discussed with the Medical Service

The Hot Cell laboratory for post-irradiation examinations

Installations and Equipment

Since control of air purity is of the utmost importance, the buildings of the Institute have been constructed with a view to complete regulation of all air flows. Exchange of air between inside and outside occurs at only a few places and in predetermined quantities. A system of stepwise increasing underpressures forces air entering the buildings to flow in the direction of greater contamination risk. Before leaving the building by way of the exhaust stacks, the air passes through a series of absolute filters. Continuous monitoring of the air leaving these stacks has shown that during the past 5 years the amount of ^{239}Pu given to the atmosphere was less than 0.3 % of the amount permitted according to relevant international standards. In the hot laboratories, the zone of lower pressure, the unirradiated plutonium is

handled in glove-boxes which are at a constant underpressure with respect to the room. All equipment used in these glove-boxes has been carefully selected and checked for all kinds of safety risks. Work with irradiated plutonium or certain transplutonium elements is carried out in hot cells with telemanipulators. A system of automatic and manual alarms connects the various working places with the control room, which is manned continuously.



Telemanipulation

Radiological Protection Service

The radiological protection service of the Laboratory, which is independent of other technical and scientific groups,

- assists in the planning of experiments by advising on safety matters,
- supervises the execution of agreed safety measures and adherence to working rules,
- provides and maintains safety equipment (e.g. gas masks) for the personnel, and instrumentation for checking for contamination and radiation,
- carries out a great variety of measurements aimed at checking the contamination of air, laboratories or equipment, and the radiation doses received by each member of the personnel,
- is able to organise and supply relief in emergency situations (spills, fires, criticality accidents[1]).

Air monitoring is carried out to watch both for any sudden release of substantial amounts of radioactive materials and for a gradual escape which could give rise to a continuous low level of contamination. Continuous air monitors would rapidly detect quantities of radioactivity which exceed the maximum permissible hourly intake. Much more sensitive, but with a delay of eight days, a discontinuous measurement for ^{239}Pu has a limit of detection of $2 \cdot 10^{-11}$ g. The air monitoring programme is complemented by routine contamination checks of laboratory clothing, shoes, laboratory floors, furniture, equipment, and gloves.

The system of alarms mentioned before permits radiological protection personnel to be on the spot within minutes of an incident, so that immediate help is ensured.

A final check on the effectiveness of all safety precautions and on each individual worker is provided by regular analyses for alpha emitters in urine and by the continuous measurement of the external radiation dose received.

Contamination outside hot cells and glove-boxes very rarely exceeds natural background, and the average total body exposure of the personnel is less than 3 % of the limit prescribed yearly for radiation workers. These

[1] Criticality: A state of affairs in which a sufficient quantity of fissile material is assembled in the proper shape and concentration for a self-sustaining chain reaction to take place.

results show that the principle of the International Commission on Radiological Protection that doses be kept as low as readily achievable is put into practice in the Institute for Transuranium Elements.

The following figures demonstrate the activity of the Institute's radiological protection service:

- Hand and foot monitors in continuous operation	40
- Alarm sensors installed in glove-boxes and connected to the control room	1.800
- Measurements of air sampling filters per year	18.000

Fire protection group during training in the Hot Cells

3 The Programme

Scope of the Programme 1984—87

Project 1: Operation Limits of Nuclear Fuels

The Project has two Subprojects:

1.1 "Advanced Fuel Optimisation" with regard to burn-up, rod power and mechanical stability, should be achieved on the basis of the large amount of information obtained during the study of the swelling of carbides, 1973—1983. Following a decision of the advisory bodies taken early in 1985, this Subproject concentrates on the development and testing of mixed uranium-plutonium nitrides. Ongoing experimental efforts are being accompanied by modelling work.

1.2 "Properties of Reactor Materials" at High Temperatures have been studied for several years. In the present programme, efforts are focussed on the thermal expansion below and above the melting point of oxide fuels. Measurements of the specific heat at constant pressure in the liquid range fill a crucial gap of knowledge of thermophysical properties necessary for the prediction of fuel behaviour under accident conditions. The same is true for the thermal conductivity of nuclear fuels, which at present is not known well enough at temperatures above 2500 K.

Project 2: Transient Behaviour of Oxide Fuels

Modelling and Transient Experiments are performed in order to study the effect of temperature transients on unirradiated fuel and (in hot cell simulation experiments) on irradiated specimens. The operational transient behaviour of LWR fuels is compared with model predictions. The kinetics of volatile fission products are studied by ion implantation.

Project 3: Actinide Cycle Safety

The Project has three Subprojects:

3.1 "The Formation of Actinides (FACT)" in high burn-up LWR and FBR fuels is becoming a decisive factor for the handling of irradiated and recycled fuel and for the fuel cycle in general, due to the radiation hazards involved. Thus, the formation of heavy metal isotopes and especially of minor actinides is measured with high precision under typical FBR power reactor and prototype conditions. The results are compared with computer predictions. Radiation doses are calculated. Capsule irradiations of milli-

gram amounts as well as of whole fuel pellets are necessary. In the latter case, isotopic analysis is being complemented by a chemical treatment, which forms a natural link to Subproject "REPRO". Finally, Thermophysical characteristics, phase diagrams and fuel-clad interaction of fuel containing significant amounts of minor actinides are being determined.

3.2 "Safe Handling of Nuclear Fuels (SHAPE)" is, to a large extent, an aerosol problem. This is why plutonium aerosols generated in typical fuel fabrication processes are being measured and characterised and concentrations and size distributions compared with the predictions of appropriate computer codes. Together with a clarification of processes responsible for radioactive particle "sticking" (to glove-box walls), this should lead to a better evaluation of plutonium handling risks. The mechanisms of radioactive aerosol transport in the case of glove-box fires are being studied, and standard dispersion patterns for plutonium aerosols in typical glove-box fire situations are being defined. Measured dispersion data are being compared with predictions of mathematical compartment fire models in order to assess the radiological consequences of fire situations beyond those experimentally investigated. Animal exposure experiments are being performed to identify biological systems which are responsible for transport and retention of inhaled plutonium aerosol particles in lung tissue, in close cooperation with specialized laboratories.

3.3 Selected key problems in **"Nuclear Fuel Reprocessing (REPRO)"** are identified and treated, like those associated with Pu-containing residues, with ^{237}Np and the deviation of actinides before they enter the waste stream during reprocessing.

Project 4: Actinide Research

The Project has two Subprojects:

4.1 "Actinide Chemistry" deals with the production and characterisation of specific compounds of minor and major actinides with high purity and reproducible physical and chemical characteristics. Basic physico-chemical properties like crystal structure, pVT-diagrams and stability regions of these compounds are being studied.

4.2 "Actinide Physics" is concerned with the determination of thermodynamic, magnetic and electronic properties of these materials, which are representative of certain bonding types. Some of these measurements are performed under extremely high pressures. Special consideration is given to surface properties. This is done in the double context of understanding the influence of 5f electrons on the chemical bond and on producing a basis for possible catalytic effects of actinide compounds.

Detailed Description*

Project 1: "Operation Limits of Nuclear Fuels"

The first aim of the Project is to provide a set of coherent high temperature data for a better understanding and prediction of fuel behaviour under operational conditions and for safety risk assessments of the current generation of LMFBRs using a mixed oxide core. It is generally felt that a deeper insight into the basic phenomena is needed to evaluate both the oxide fuel behaviour under transient power-coolant mismatch conditions and the consequences of a hypothetical core disruptive accident or of the more realistic subassembly accident. The need for a coherent set of key data in the very high temperature range is widely recognized, and the availability of these data will contribute to improve core safety analysis and make predictions of material behaviour with pending economic consequences (as avoiding oversized reactor components and containments and reducing conservative operational margins) more accurate. The Subproject "Properties of Reactor Materials at High Temperature" caters to this.

The second aspect deals with the Subproject on "Advanced Fuel Optimisation" which must be considered a worthwile long-term investement in fast reactor fuel technology. It must be recognised that although adequate and possibly mature for commercial units, the mixed oxide approach in fast reactors has inherent limitations. It is generally felt that a decisive step in cost reduction of fast breeder reactors can be achieved in both investments and reactor operation by using an advanced (dense) fuel such as mixed carbide, nitride or carbonitride. Although these compounds have similar properties and similar behaviour under irradiation, it seems likely that the nitride will be the potential winner because it is the only fuel material compatible with the conventional PUREX reprocessing method (see "Project Reprocessing of Nuclear Fuels").

The Subproject on the "Optimization of Advanced LMFBR Fuels" draws origin and benefits from the previous involvement of the staff mainly in carbides, but also in the whole family of possible advanced (dense) fuels, which was investigated through a moderate but continuous effort independent of the political and budgetary fluctuations of the national research policies of the Member States.

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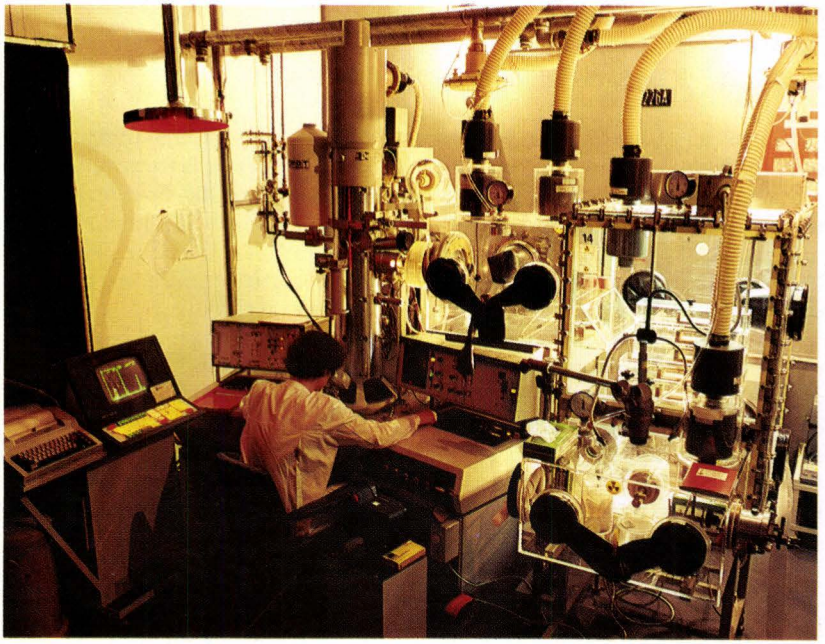
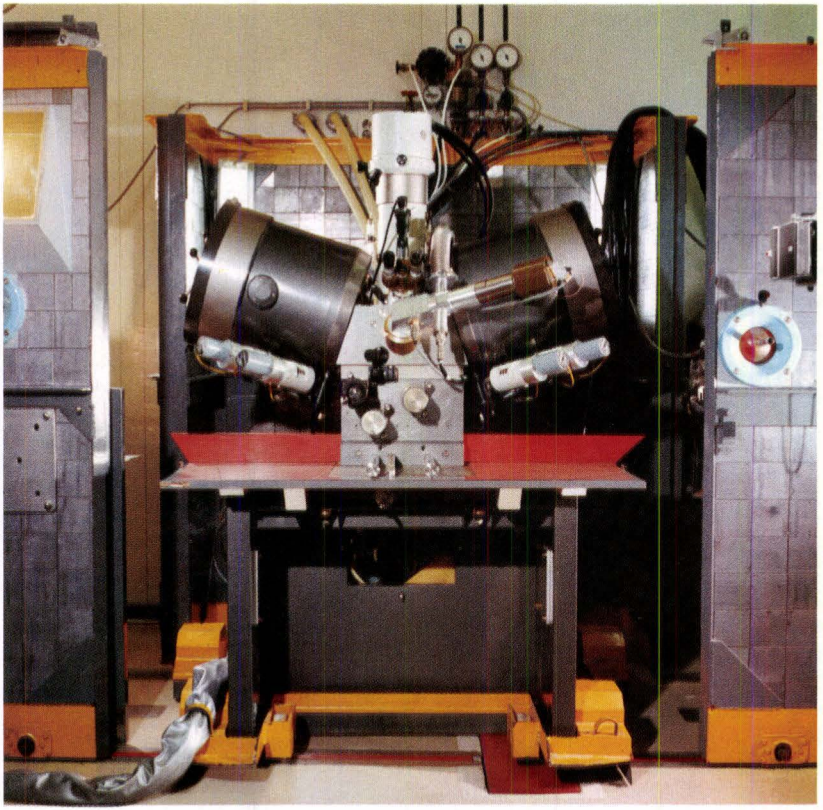
* Excerpt from Evaluation Report by A. Gauvenet, H. Eschrich, A. R. Mackintosh, R. Rometsch, L. van Hove, J. K. Wright and M. Zifferero on the "Nuclear Fuels and Actinide Research" programme.



Electron microscope for investigating radioactive samples

The originality of the JRC Karlsruhe contribution arises from a double approach: A classical engineering-type one, oriented towards testing of the technological performance and determination of limiting factors of the main pin concepts (helium and sodium bond); and a more fundamental research-type approach where basic in-pile mechanisms contributing to the swelling of the fuel are being identified and quantified by means of a whole set of advanced examination techniques at a submicroscopic scale for highly irradiated plutonium-bearing fuels like transmission - or replica-electron microscopy combined with microprobe analysis, techniques, which, to a large extent, have been developed for that purpose at JRC Karlsruhe. The combination of these two approaches to fuel optimization which bridges the gap between materials science and technology is exemplary and could be extended with benefit to other nuclear or non-nuclear fields.

The output from the advanced fuels Subproject carries promises of high cost reduction with regard to the reactor components, the reactor operation and the fuel cycle as a whole. On the basis of the existing experience on advanced fuels in general, and of the known specifications for an optimized carbide in particular, the development of a corresponding nitride should be feasible with the available means.



Shielded electron microprobe for analysing irradiated fuel elements

Incentives for the Development of an Advanced Fuel

As mentioned above, decisive reductions in cost for both reactor investments (RI^1) and reactor operation (RO^2) can be obtained by using an advanced fuel such as mixed uranium plutonium carbide or nitride instead of the currently used oxide.

I. Impact on Reactor Cost and Component Sizing

1. Effect of the Fuel Compatibility with Sodium

Long-term operation at nominal power is expected with failed subassemblies (up to one year as compared to a few hours with mixed oxide) with subsequent improvement on plant load factor (suppression of reactor shutdowns for discharge: RO).

With no further evolution of failure in sodium, internal storage space for the removal of decay heat can be provided at the periphery of the core (i.e., the costly auxiliary sodium pool for the discharge of failed subassemblies with high residual power can be eliminated) (RI). Suppression of storage is also a possiblity in the case of a single batch core (RI).

2. Effect of the Improved Neutronic Properties of the Fuel

Several options are offered to core designers to take advantage of the high fissile atom density, high specific power and low plutonium enrichment.

Sub-assemblies with large diameter pins can induce a low core pressure drop, thus reducing the highly expensive pumping capacity (RI) and pumping power requirements (RO).

As a consequence of low plutonium enrichment, reactivity losses with burnup can be minimized, so that the whole core is irradiated and discharged in a single batch (RI + RO).

For the same reason, control rod depletion with burnup can be kept at a minimum, or the number of control rods is minimized (RI + RO).

When necessary, a high breeding ratio and a low doubling time can be achieved with a minimum of plutonium inventory.

3. Core Size Reduction (RI)

A reduction of core size, and a streamlining of the reactor block with its accessories, containment vessels and confinement, can be obtained (RI).

- The low fission gas release from advanced fuels makes it possible to reduce the pin length (short plenum) and hence the core height (RI).

- The high density of the advanced fuels makes it possible to reduce the diameter of the core (RI).

4. Effect of Simplification of the Fuel Handling System

Major cost reductions result from a simplification of the fuel handling system by

- the possibility to evacuate decayed fuel assemblies at low temperature, thus avoiding sodium which is necessary at high residual power (RI);

- a good compatibility of the cold decayed fuel with water (sodium removal by rinsing) and air in hot cells (RI).

II. Impact on the Fuel Cycle Cost

Some other important advantages of advanced fuel arise from

- the reduction of the fabrication cost by the use of large diameter pins,

- the compatibility with the Purex process (nitrides),

- the reduction of the reprocessing cost by lowering the number of subassemblies to be treated.

The Adjustment of Material Properties to Specific Uses for Advanced Fuels

Expressed in a very general fashion, a fuel pin is a stack of fuel pellets housed in a stainless steel tubing, in an inert atmosphere or medium. For the high burnup aimed at for LMFBRs, a fraction of 15 to 20 % void volume must be provided to accommodate fuel swelling.

In the sodium-bonded carbide or nitride fuel element concept, the pellets are very dense (low porosity) and most of the void volume is provided by the large sodium-filled gap between the pellet stack and the cladding. The technological limit of such a pin is reached when the swollen fuel contacts the cladding and induces cladding failures due to mechanical interactions with the cladding.

In the helium-bonded pin concept, the fuel stack-cladding gap is reduced to the mechanical clearance, and most of the void volume is provided by the porosity of the low density pellets: in this concept the pellet contacts the cladding very early but the porosity provides space to accommodate the swelling of the fuel.

Both these fuel pin concepts, however, present specific difficulties due to the inherent properties of the fuel materials, and in this field the contribution of JRC Karlsruhe is decisive for a controlled production of tailored materials adjusted to specific uses.

With the sodium-bonded pin concept, conventional high density pellets are fractured under the thermal stresses which develop during normal reactor operation. Very often pellet chips move into the sodium bonding and act as wedges between stack and cladding, leading to a premature "end of life" of the pin due to clad failure. Facing this, JRC Karlsruhe has shown the way: the propensity of high density ceramic fuel to fracture can be considerably reduced by adjusting fabrication parameters like carbide concentration and microstructure, and an adequate dispersion of a second phase at the grain boundaries of the carbide induces a micro-crack network which keeps the pellets intact during reactor operation.

With the helium-bonded carbide/nitride fuel pin concept, two kinds of difficulties arise when the conventional two-step fabrication procedure is applied to low density pellets: difficulties to produce these pellets with a given narrow margin of specifications and the necessity to minimize oxygen pollution which may induce material instability and enhance fuel swelling. To cope with these problems, JRC Karlsruhe has developped a very simple, economic, and safe handling and fabrication procedure, in which stable pellets are produced with the desired specifications in a reproducible way by directly pressing the pellets and eliminating the conventional intermediate crushing step. It must be emphasized that this "direct pressing" technique, which minimizes radioactive pollution, represents a progress which is comparable to the one that has been made with the sol-gel technique in terms of safe handling.

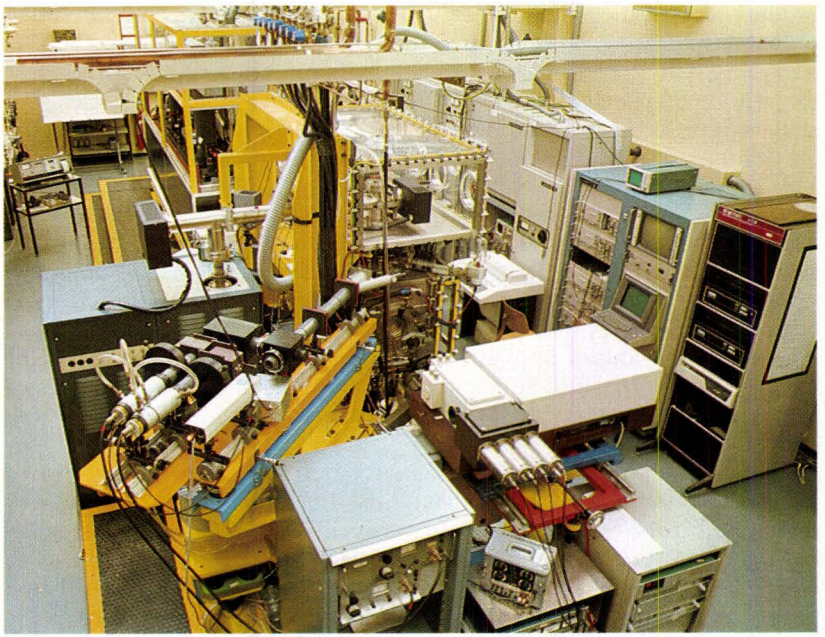
These activities, where material is tailored on the basis of an analysis of the application requirements, are exemplary and could be extended to other nuclear or non-nuclear materials. This should be kept in mind when new materials science research programmes are being defined within the European Community.

As to the implementation methodology, the approach chosen for the database Subproject (High Temperature Properties of Reactor Materials) covers the temperature range of 2000 to 5000 K and uses the most advanced experimental techniques. They deal with problems of handling molten UO_2, laser volatilization combined with mass spectroscopy for the determination of the partial pressures of vapour species, with multi-wavelength pyrometry and ultrasonic thermometry for molten fuel, multi-beam splitting laser heating, determination of volume changes by an X-ray shadow technique and with laser holography. Most of the uncertainties aris-

ing from chemical pollution at high temperatures in classical methods are eliminated by using extremely clean experimental conditions (laser pulse heating, containment of the molten zone in a crucible of the same material or by acoustic levitation, minimization of evaporation of the sample).

The properties under investigation are vapour pressure, pVT data for the determination of the equation of state, liquid density, specific heat and thermal conductivity at temperatures up to and beyond the melting point.

The research output of the "High Temperature Properties" Subproject is likely to have a favourable impact on reactor safety studies by providing fundamental physical data which are needed for refining and deepening present knowledge of the behaviour of nuclear fuels for the current generation of fast breeders under extreme (accident) conditions.



Laser equipment for measuring vapour pressures of nuclear fuel at extremely high temperatures (> 5000 K)

Project 2: "Transient Behaviour of Oxide Fuels"

The Project studies the transient behaviour of LWR fuel and serves essentially two purposes:

- to obtain a better understanding of the factors that are limiting today's burnup in LWR fuels and their operation in the load-following mode or under more severe transient conditions, and

- to contribute to a preliminary source term evaluation by quantifying the likely release of fission products from the fuel after failure of the cladding or under more degraded conditions.

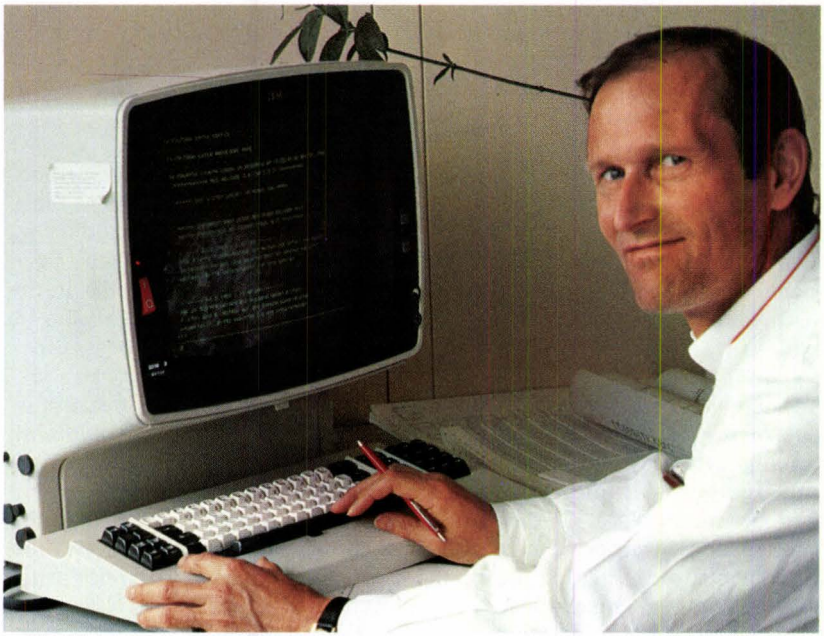
By describing and, if possible, quantifying the physical, chemical and mechanical processes occurring in the fuel under irradiation, the Project aims to contribute with adequate codes to the construction of models which should be capable to predict the release of fission gas and volatile fission products and of fuel swelling, the ultimate aim being an estimation of the probability of fuel rod failure at normal operation conditions and at mild transients. This contribution is essentially based on the quantification of the release of selected fission products under transient conditions. The achievement of this objective would have a beneficial effect on the economy of nuclear power by opening possibilities of increasing the burnup of a given fuel type.

The main body of analyses, however, is based on the specific method developed at JRC Karlsruhe for advanced fuels: A fundamental approach where basic phenomena are investigated and quantified, and a more engineering-type approach, where physically based and (or) empirical models are introduced in a fuel element behaviour code. At present the engineering approach is dominating, while other fundamental questions (migration of micro bubbles of fission gas) are treated less intensively.

An important parallel line of detailed experiments has been designed which simulates thermal in-pile conditions for a fuel rod in a hot cell by direct electrical heating. In these experiments, which support the model development work, pieces of LWR fuel which have been pre-irradiated to 30-50 GWd/t are subjected to thermal ramps. The released volatile fission products are collected and analysed. More fundamental work, such as ion implantation into a UO_2 matrix, provides tools to assess fission product diffusion and gaseous fission product behaviour.

In evaluating the potential impact of this Project on the improvement of the fuel cycle economy and, at large, on nuclear fuel safety and reliability, it is of fundamental interest that the option between the once-through and the closed fuel cycle is still open. With plans to establish or expand fuel re-

processing capabilities in several countries of the EC, one might conclude that in Europe the decision has already been taken in favour of a fuel cycle which includes recycling of plutonium and recovery of uranium. However, the concept of the once-through cycle has strong advocates and, at present, is followed and adopted in many important nuclear programmes, the US programme for one. Whatever the option taken, the incentives towards higher LWR fuel burnup and general improvement of fuel utilization are strong. It is therefore not unlikely that a new generation of high-efficiency fuels will be developed in the foreseeable future, irrespective of the availability of fuel recycling. Under these aspects the Project can be considered timely and deserving high priority.



Modelling needs computers

Its principal objective is the quantification of the physical, chemical and mechanical processes occurring in the oxide matrix as a consequence of irradiation and temperature-power transients. This quantification aims at an improvement of existing models by reducing the uncertainty in our knowledge about fission product behaviour under normal and incidental operating conditions. The aim is a more accurate model which predicts the release of fission products under transient conditions.

Project 3: "Actinide Cycle Safety"

3.1 "Formation of Actinides (FACT)"

The formation of transuranium elements is studied in this Subproject. Samples of standard LWR fuel elements have been experimentally analysed for their actinide content. The build-up of less abundant isotopes of uranium and plutonium (^{232}U, ^{236}Pu) and of minor actinide nuclides (^{237}Np, $^{241\text{-}243}$Am, $^{242\text{-}247}$Cm) was determined and compared with predictions of computer codes. For analogous studies on standard fast reactor fuels no samples were available. Therefore, irradiation experiments with single actinide nuclides (in milligram quantities) and actinide mixed oxides (in gram quantities) are underway. In order to analyse the aspects of an irradiation of fuels containing minor actinides, the main parameters determining the irradiation behaviour were measured: Thermal conductivity, oxygen potentials of mixed oxides and compatibility with liquid sodium. The evolution of linear power with time was calculated.

The post-irradiation isotope analyses of standard LWR fuels are providing the first comprehensive data sets on actinide abundance in spent fuels. Such information is used (also by external organisations) to validate results of computer codes. The samples originate from pellets (cut from spent fuel pins) or from the dissolution of complete fuel assemblies in the nearby reprocessing plant (WAK). Results were obtained on mixed (Pu,U) oxides (irradiated in a PWR), as well.

An analogous study for fast reactor fuels could not be made because of lack of fuel samples. For this reason irradiation experiments containing different actinides are underway in fast reactors. From post-irradiation isotope analysis, the integral cross-sections will be determined which will then be compared with those calculated from the existing differential cross-section libraries. The procedure requires a precise characterisation of the neutron energy flux during the irradiation, which is often not available for commercial reasons. In an irradiation experiment in KNK II this information is obtained from dosimeter capsules irradiated at the same position as the fuel samples.

Since the minor actinides, Np, Am, Cm are fast reactor fuels, the cost-benefit ratio of their recycle has been assessed. So far it appears that the costs for separating the minor actinides from the PUREX high active waste stream and their make-up into fast reactor fuels are in part compensated by the gain in nuclear energy production. The benefit from a higher Pu breeding gain in the fast reactor is not yet taken into account in this analysis. To assess the increased occupational radiation hazard in fuel cycles involving minor actinides, the dose-rates of minor-actinide containing fuels were

compared with those of standard mixed-oxide fuels. Theoretical estimates have been confirmed by experimental results on the fresh fuels. The same comparison has to be made for radiation doses of the spent fuels when the irradiations underway are completed.

The Subproject FACT contributes valuable information which is needed to optimise the LWR fuel cycle. With the help of accurate actinide analyses of spent fuels the uncertainties in computer code predictions are reduced, which again aids in developing a new generation of LWR fuels.

The re-evalution of the radiological risk of minor actinides could have an impact on the future technical development of the fuel cycle, which consequently would improve the social acceptance of nuclear energy generation. Especially in the case that the impeding radiological hazard of neptunium in a geological repository is confirmed, the recycle of minor actinides in FBRs seems to be an alternative waste management policy which might be attractive to the nuclear industry because it seems neutral in cost.

The Subproject FACT can further contribute to the economy and safety of the nuclear fuel cycle, especially in the optimisation of computer codes, predicting the evolution of actinides in power stations and the assessment of the impact of possible minor actinide recycling.

Taking into account the relevant recommendations of the French Ministre de la Recherche et de l'Industrie and the resolution of the German Parliament on the same subject, the long-term option of recycling minor actinides should be more deeply analysed for its costs and benefits. This requires a broader understanding of the irradiation behaviour of minor actinide-containing fuels.

These studies are important for the design of a rational and optimized fuel cycle policy. They have not only technical aspects but also economic implications, where potential advantages have to be balanced against corresponding costs and additional risks.

3.2 "Safe Handling of Nuclear Fuels (SHAPE)"

As part of a larger project on "Actinide Cycle Safety", the Subproject on the "Safe Handling of Nuclear Fuels" concentrates on the study of formation and properties of plutonium-containing aerosols generated in typical fuel fabrication processes during normal and off-normal conditions. Plutonium fuel fabrication entails constant and rigid controls to ensure adequate radiological protection for operators. Over prolonged periods of time, plutonium "dusts" tend to accumulate on the inner walls of the first

containment of the processing line, normally alpha-tight glove-boxes kept under negative pressure, and thus constitute a radiation hazard due to the α-emission from heavier isotopes, the abundance of which increases with each recycling step. Hence the tendency to automate plutonium fuel fabrication or to look for process improvements which would reduce the amount of internal contamination of the enclosures (sol-gel-approach). Remote controls and/or automation do not, however, solve this problem completely, since contact maintenance is periodically required in various fabrication steps and in case of major breakdowns. Of major concern are also the radiological consequences of incidental actinide release from the primary containment caused by fires, explosions, and earthquakes.

A first objective of Subproject SHAPE is the reduction of the radiological health hazards of current plutonium manufacturing processes by minimising the quantity of plutonium lost to the internal walls and surfaces of the process line and enclosures. To achieve this objective, research is pursued on the mechanism of plutonium aerosols and their interaction with different surface materials.

A second objective of the Subproject is the identification of generation and dispersion mechanisms for plutonium-bearing aerosols in glove-box fires.

A common by-product of both activities is the development of instrumental methods to detect, measure and characterize plutonium-bearing aerosols. A parallel line of research deals with metabolic studies of plutonium absorbed by inhalation of plutonium aerosols in rats. JRC Karlsruhe being specialized in aerosol production, this activity is the subject of a cooperation with the Institute for Genetics and Toxicology of the Kernforschungszentrum Karlsruhe.

The experimental approach to study aerosol formation and properties makes use of advanced electron-optical techniques such as scanning transmission electron microscopy, which allows for a complete characterization of the morphology and composition of aerosol particles. Sticking properties are investigated as a function of the chemical nature and the surface quality of the substrate as well as of the nature of the aerosol. Specific sampling devices had to be designed and methodologies developed to continuously monitor the principal aerodynamic parameters.

Since aerosol nature and characteristics depend on the condition of their generation (normal operation or accidents such as fires), a technique has been developed to produce cerium/europium containing aerosols (to simulate plutonium/americium behaviour) by burning full-scale glove-boxes in enclosures under well defined conditions. On a smaller scale, experi-

ments are performed also with plutonium bearing material submitted to fire under controlled conditions to provide a means for calibration and comparison with the cerium containing aerosols. Codes are being developed in parallel to the experiments with the goal to improve glove-box design so that wall and inner surface contamination can be kept at a minimum.

3.3 "Reprocessing of Nuclear Fuels (REPRO)"

The Project operates along two lines:

a) Studies on reprocessing of fast breeder fuels, i.e. mixed oxides and advanced fuel (mixed carbides MC, mixed carbonitrides MCN or mixed nitrides MN, with $M = U_{0.8}Pu_{0.2}$).

Like oxides the latter fuels are expected to be reprocessed using the Purex process. The irradiated advanced fuels have, however, to be treated by new appropriate head-end procedures, so as to produce fuel solutions meeting the requirements of the subsequent extraction process.

For advanced fuels, two distinctly different head-end procedures leading to acceptable feed solutions for the Purex process have been studied and compared: i) controlled oxidation with Ar/O_2 and CO_2 followed by dissolution of the resulting oxides in nitric acid, and ii) direct dissolution of the fuel in nitric acid followed, in the case of carbides, by an oxidation of the carbonaceous by-products by chemical oxidants or by photochemical means. The resulting gaseous, liquid and solid phases have been studied by mass spectrometry, gas chromatography, infrared spectroscopy, spectrophotometry, ion chromatography, liquid scintillation counting, potentiometric titration, γ- and α-spectroscopy, and X-ray diffraction analysis. Extraction procedures using preferably tributyl phosphate (TBP) - the extractant of the Purex process - have extensively been applied in this investigation.

The solubility of mixed oxides is being studied with emphasis on the characterisation of the insoluble residues.

b) Development of methods for the recovery and purification of actinides from waste and fuel solutions of different origin and composition (oxides, carbides and nitrides).

The aim of this effort is to recycle the major actinides (U,Pu) and in addition to separate the minor actinides, mainly Np and Am, from the reprocessing streams before they enter the normal process waste streams (ILLW or LLLW), to be conditioned for final storage.

Different possibilities are being explored for the chemical separation of fission products, nitric acid and actinides, such as extraction chromatography and ion exchange. The actinide separation schemes are implemented in a Mulitpurpose Unit, which is being developed and installed in hot cells. The separation of uranium and plutonium from dissolved fuels (MO_2,MC,MN) or from waste solutions is carried out in chromatographic columns filled with an inert granular material impregnated with TBP. The highly active effluent is routed to a second set of columns, where the individual actinides are separated from the fission products by cation exchange under high pressure conditions. This column system can be supplemented by additional columns for the separation of selected fission products. The Multipurpose Unit has a high degree of flexibility so that also other separation techniques could be tested. It can deal with any type of fuel including special fuels based on minor actinides. Special emphasis is placed on the behaviour of Np in these separation procedures.

The recovered actinides will be available for fuel refabrication (U,Pu) and/or for the fabrication of special actinide fuels (Am,Np).

The most direct benefit from the work on advanced fuels is to be seen in connection with the implementation of the fast breeder reactor. For the advanced fuels a certain lack of experience with reprocessing could hamper the introduction of these fuels on an industrial scale. From the results of the experiments in the Subproject it can be concluded that the advanced fuels can be reprocessed by the Purex process if certain adaptations are carried out in the head-end, as described above. A viable concept has been established and reprocessing can be considered to be at an equivalent level of development as the other steps of the fuel cycle for advanced fuels.

Another topic is related to the borderline between reprocessing and waste management. In the second Castaing report on waste a plea was made for "forced reprocessing"; especially concerning the actinides, higher separation factors were called for. Lowering the An-content in the waste would decrease its potential long-term hazards, facilitate the packaging (especially valid for MAW) and reduce the disposal costs. Such improvements in the separations are to be realized during reprocessing. Similar ideas are behind the efforts embodied in subproject REPRO in that experiments will be carried out aiming at a deviation of the An-elements before they enter the waste streams. Sudies of the distribution of Np on the various streams are of special interest out of safety considerations; this element has come in focus in connection with the recent change in its hazard evaluation; its chemical behaviour and migration properties are key issues. Pertinent separations will be carried out in the above described Multipurpose Unit.

Project 4: "Actinide Research"

This programme is concerned essentially with fundamental research, with the aim of producing new actinide materials, usually in the form of single crystals, and measuring and understanding their properties. It is relevant to the JRC and to the European Community at a number of different levels.

Firstly, it provides the fundamental underpinning without which the applied actinide research programme of the JRC could not develop satisfactorily. Since the termination of the basic actinide research by the U.S. Department of Energy some years ago, JRC Karlsruhe has become the only source for information on the physical and chemical properties of actinide materials which is essential for the nuclear fuels, waste management and other actinide-related programmes.

Secondly, it utilizes the special facilities and expertise which are available at the Karlsruhe laboratories to provide materials, information and knowledge about the actinides to the European scientific community. Both research laboratories and institutes of higher education benefit from this service which, because of the scale of the facilities involved and the special problems of handling highly radioactive materials, is naturally placed at a centralized facility serving the whole of the European Community.

Thirdly, the scientific information which is generated by the actinide programme has an important influence on the materials science research programmes in Europe by improving the general understanding of materials, especially their magnetic properties and the description of the electronic states in metals and compounds.

Finally, the presence of a major centre for actinide research in Karlsurhe induces a healthy research collaboration among laboratories in Europe, and between them and other research institutions, particularly in the USA.

Some of the main achievements of the programme in recent years are the following:

a) The production and characterization of a wide range of crystals of actinide compounds, most of which have not previously been grown.

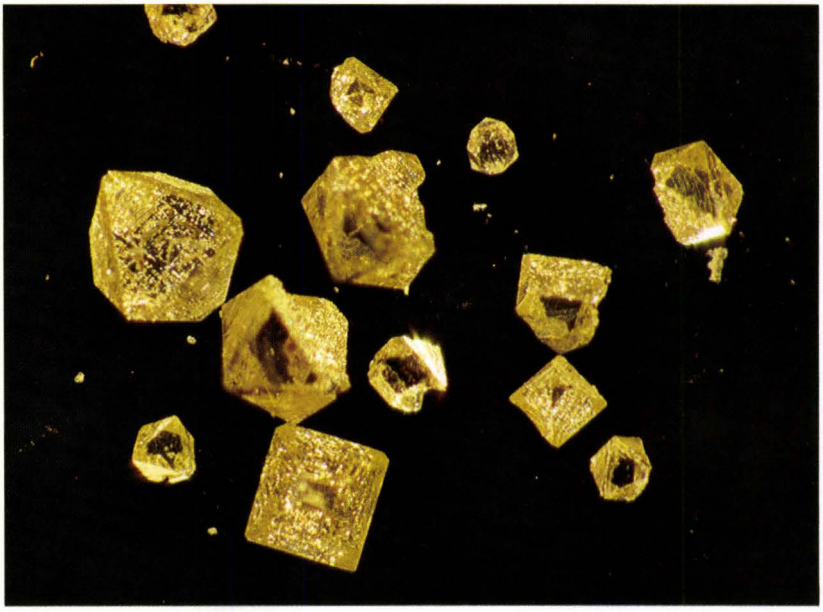
b) The measurements of the thermodynamic and magnetic properties of actinide materials. In particular the studies of structures and phase transitions at high pressure, using a diamond-anvil X-ray diffractometer, have contributed decisively to the elucidation of the electronic

structure of the actinides. In the lighter elements, the 5f electrons have been shown to be itinerant, analogous to the 3d electrons in the transition metals, while they are localized, like the 4f electrons in the Rare Earths, in the heavier elements. The localized-itinerant transition can also be induced by pressure.

c) The study of the electronic structures by photo-emission, which again gives important and direct information on the behaviour of the 5f electrons.

d) Theoretical studies of the relationship between the electronic states and other properties, using calculations of the band structure.

e) Studies of the magnetic structures and excitations of the actinides by neutron scattering. A number of novel phenomena have been observed, which deserve extensive further investigations.



ThO_2 single crystals

A partial list of collaborating institutions, taken from the Multiannual Programme, is

University of Liège, Dept. of Chemistry
Danish Atomic Energy Commission, Risø
CEA-CEN, Cadarache
CNRS, Strasbourg
CEA-CEN, Institut Laue-Langevin, Grenoble
Technische Universität München
Kernforschungszentrum Karlsruhe
University of Parma, Depts. of Chemistry and Physics
Hasylab, Hamburg
ETH Zürich, Dept. of Physics
AERE-Harwell, Chemistry Division
Argonne National Laboratory

"Prospective Studies" (Free Research)

Each JRC Establishment has the possibility to execute investigations outside the official programme with the aim of being prepared for new activities. At TU Karlsruhe, two minor studies have thus been launched in 1982/83.

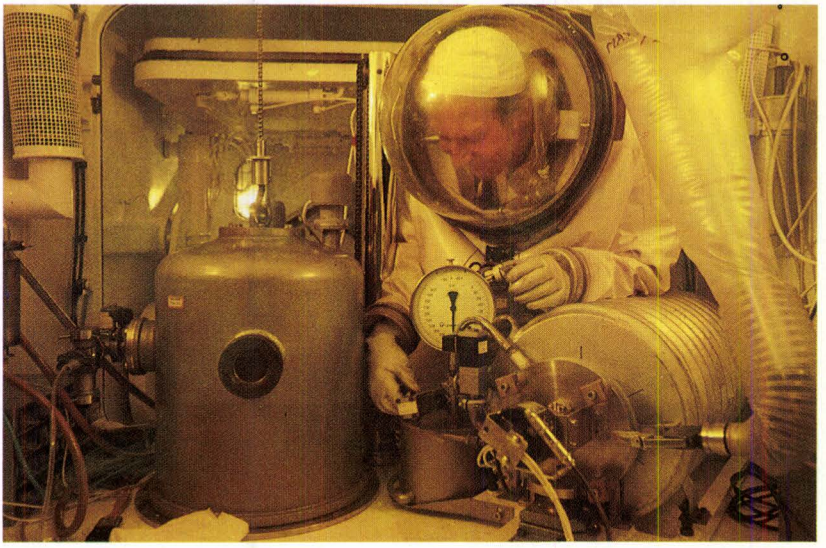
1. Following a demand to better intertwine the activities with those of the Ispra Establishment and considering the large socio-economic impact of the programme in question, special studies have been undertaken in the field of airborne noxes. Thus the competence of a newly established laboratory for Gas Kinetics and Molecular Spectroscopy, also serving the nuclear programme, could be used. High Temperature Combustion Studies, undertaken already at the end of the 70s, paved the way and had prepared the construction of special equipment like a differential pumping station serving mass spectrometers and thus allowing mass spectrometric analysis of gas reactions at atmospheric pressure; coherent Anti-Stokes-Raman scattering and different gas analysis equipment including gas chromatographs.

The basic idea is to identify crucial points of the whole domain from the formation of pollutants to their impact and to work on them by coherent investigations both in the laboratory and in the field. In this context, emissions from concentrated point or line sources of nitrogen oxydes and hydrocarbons have been followed over the range of a few kilometers, their transformation reactions and impact on the vegetation in Alpine regions being measured. As a by-product, an Alpine road tunnel could be used for precise measurements of the emissions stemming from a fleet of cars moving at different speeds. The literature values obtained by stationary equipment were confirmed but the drag effect of the moving fleet resulted in slightly decreased emissions both inside and outside the tunnel.

The accuracy of the hydrocarbon emission values was not high enough to settle definitely whether or not they increase significantly with higher speeds. A new experiment with more and improved equipment could probably clarify this matter.

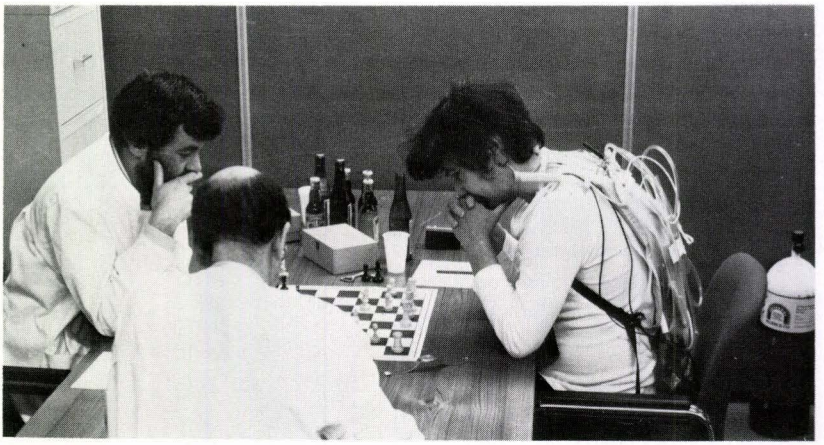
Measuring NO_x emissions

2. The second line of new research stemmed from a practical problem, namely the continuous monitoring of decontamination personnel, working in heavy protective suits.



Physical stress . . .

Here the method of transcutaneous oxygen determination was employed, using simultaneously oxygen electrodes at different temperatures. The values varied with physical and mental stress and might allow the use of the signals as stress indicators, transmitted by microwaves to the supervisor of the operation. This method, if elaborated further, might have general application in occupational health supervision of personnel working under difficult environmental conditions.



. . . mental stress

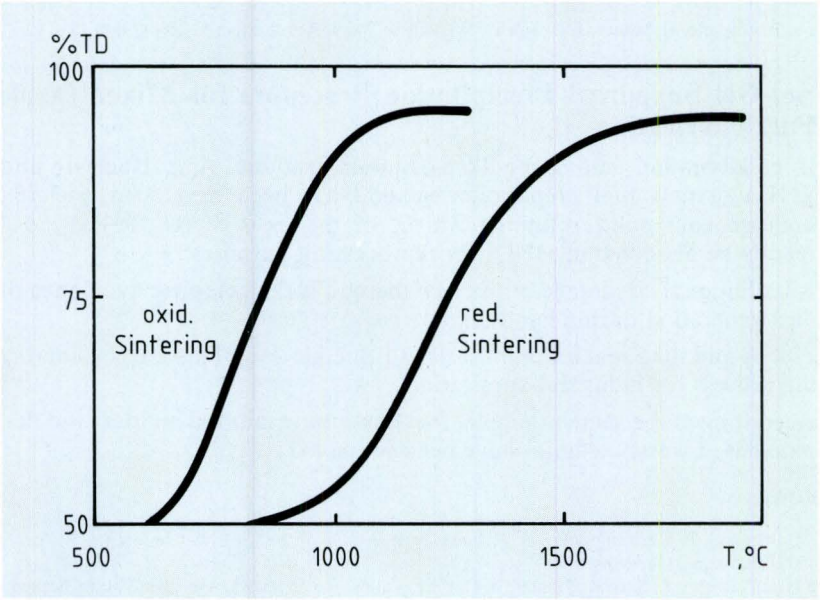
The total of these new activities is supported by research contracts with universities, using competence also available for nuclear work and does not occupy more than 5 % of the staff.

4 Some Recent Accomplishments

Self-Diffusion in Mixed Oxides

Measurements of the uranium self-diffusion in stoichiometric and hyperstoichiometric uranium dioxide have been performed at the Institute.[1] The measurements have shown that uranium diffusion is enhanced by up to a factor of 10^5 in an oxidizing atmosphere, and hence sintering of uranium dioxide fuel can be accelerated and occurs already at lower temperatures (below 1200 °C) in a properly chosen oxidizing gas mixture than in the conventional sintering atmosphere.

The investigation of heavy metal interdiffusion has resulted in an improved method for LWR fuel fabrication with important savings in energy, time, and capital investment.
Kraftwerk-Union applied the new process in the production of a load for refuelling the Obrigheim reactor, realizing energy savings during fabrication up to a factor of 7 and fourfold time savings.[2]
South Korea and China have shown interest in the process, too.



Density of UO_2 as a function of sintering temperatures for reducing and oxidizing atmosphere (TD: theoretical density)

References

1 H. J. Matzke, J. Nucl. Mater, 30 (1969) 26
2 W. Dörr and H. Assmann, Proc. 4th Int. Meeting on Modern Ceramics Technologies CIMTEC, St.-Vincent, Italy (1979)

Actinide Photoelectron Spectroscopy

Photoelectron spectroscopy of α-plutonium and americium metal with varying photon excitation energies has shown that for plutonium the highest conduction electron states at the Fermi energy E_F are dominated by 5f electrons which take part in the chemical bonding (Figure, curve 1). For americium, practically no 5f electrons are found at the Fermi energy but about 3 eV below (Figure, curve 2). Thus, in americium the 5f electrons do not belong to the conduction band and therefore do not take part in the chemical bonding.
As clearly demonstrated in the photo electron spectrum (Figure, curve 2), this behaviour of the 5f electrons in americium is very similar to that of the 4f electrons in the rare earth metals (e.g., samarium, Figure, curve 3) and not to that of the light actinides[1].

This is the first experimental confirmation of solid state theories which predict 5f electrons not to belong to the conduction electrons, i.e., to be localized in americium and heavier actinides.

Reference

1 J. R. Naegele, L. Manes, J. C. Spirlet, W. Müller, Phys. Rev. Letters 52, 20, (1984) 1834

Sol-Gel Supported Precipitation Procedure for Mixed Oxide Fuel Fabrication

In collaboration among the Transuranium Institute, Agip Nucleare and ENEA, a new fuel preparation method has been developed, yielding homogeneous solid solutions which, in the case of (U, Pu) O_2, can readily be dissolved in HNO_3 for reprocessing purposes[1].

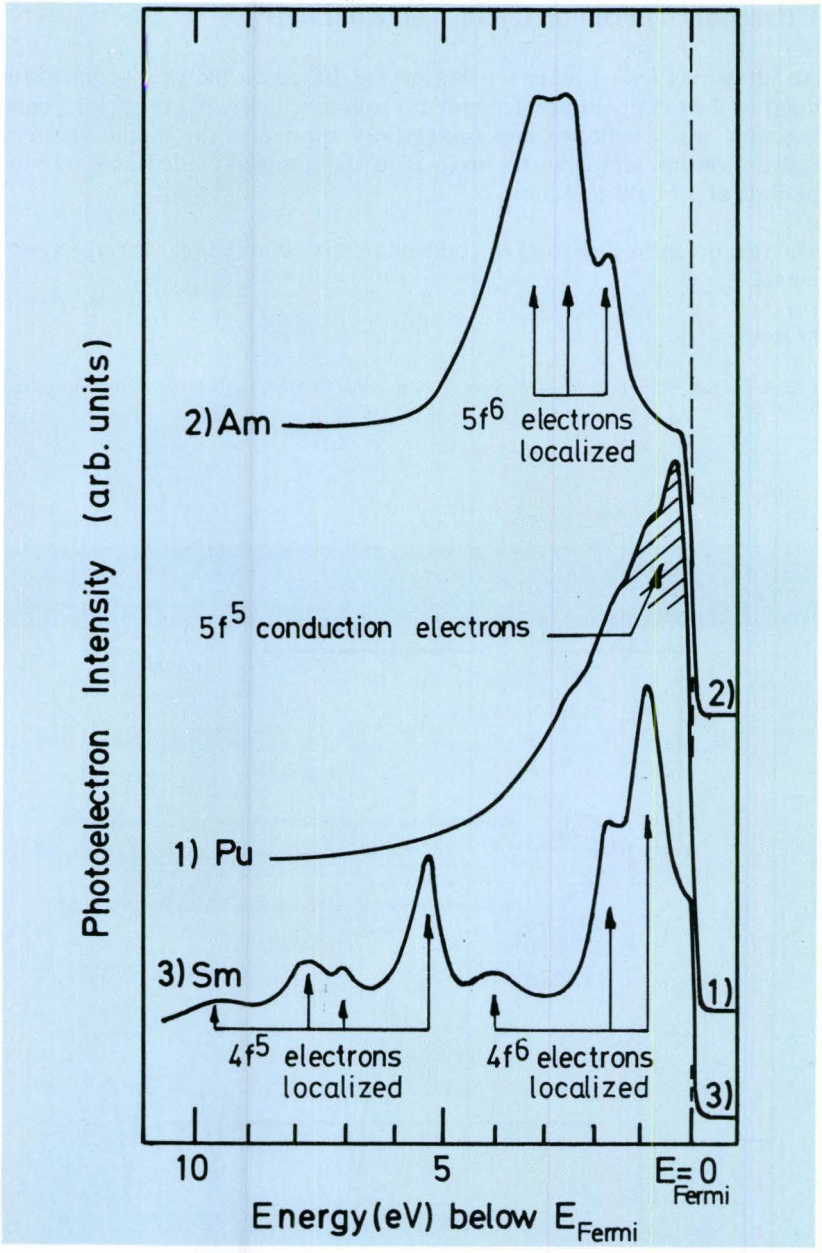
An additional advantage of the new method is the complete avoidance of dust generation during handling.

ENEA and the French Commisariat à l'Energie Atomique are considering the process for industrial application.

According to the same principle, fuel-containing minor actinides[2] and titanate-based waste ceramics have been produced[3].

References

1 G. Cogliati, P. Gerontopoulos, K. Richter, Transactions of the '79 ENS Conference, May 6-7, 1979, Hamburg, Germany
2 H. E. Schmidt, C. Sari, K. Richter, P. Gerontopoulos, Actinides '85, Aix-en-Provence, September 2-6, 1985
3 P. Gerontopoulos, G. Arcangeli, S. Cao, E. Crispino, M. Forno, E. Müller, 185th ACS National Meeting of the American Chemical Society, Seattle, Wash., USA, March 20-25, 1983



Conduction band photoelectron spectra of the actinides Am and α-Pu and the Rare Earth Sm for UV excitation (40.8 eV)

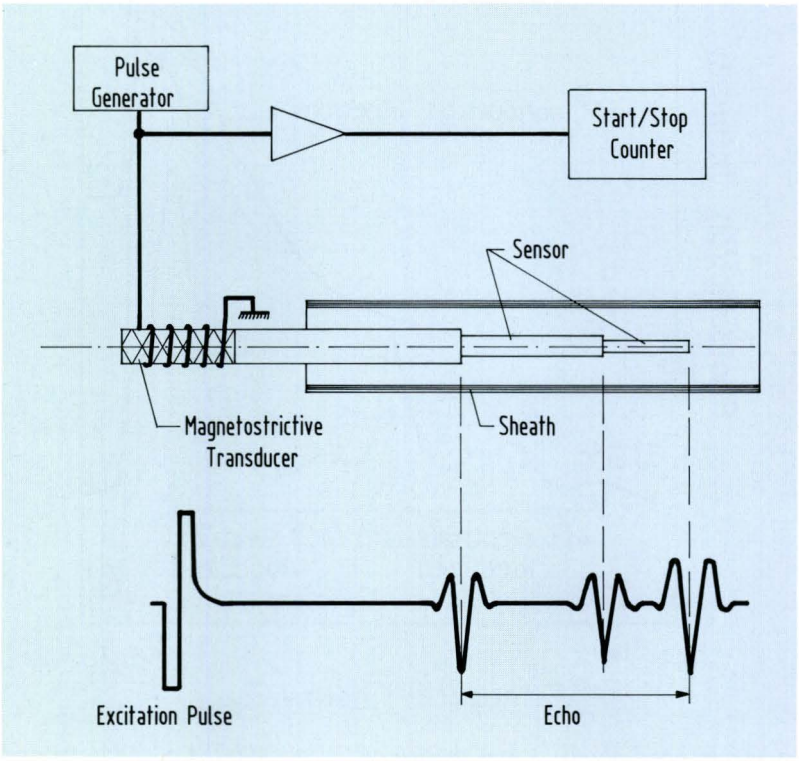
Ultrasonic Thermometry in Nuclear Fuels

An ultrasonic temperature sensing device, based on the precise measurement of the - temperature-dependent - sound velocity in a refractory sensing wire, was developed and successfully applied to the inpile measurement of central temperatures up to 2800 °C in mixed oxide fuel pins over periods of 30 days and more[1].

The instrument is also used in connection with in-pile fuel melting experiments.

Reference

1 H. A. Tasman, H. E. Schmidt, J. Richter, M. Campana, G. Fayl, High Temp. - High Pressures 9 (1977) 387



Working principle of the ultrasonic thermometer

The Thermal Conductivity of Liquid Uranium Oxide Fuel

Thermophysical parameters like the thermal conductivity of molten uranium dioxide are important for the assessment of the possiblities of Post-Accident Heat Removal (PAHR) from a damaged reactor core.

Whereas earlier data[1,2], based on non-stationary (diffusivity) measurements with tungsten-encapsulated samples appeared to be surprisingly high (10 W/m °C), direct conductivity measurements on molten UO_2 contained in solid urania yielded values (below 3 W/m °C) in accordance with theoretical expectations, thus furnishing a basis for physically sound extrapolations[3].

References

1 C. S. Kim, A. Blomquist, J. Haley, R. Land, J. Fischer, M. G. Chasanov, L. Leibowitz, Proc. 7th Symposium on Thermophysical Properties Gaithersburg MD, 1977, p. 338-343
2 C. Otter, D. Damien, High Temp.-High Pressures 16 (1984) 1
3 H. A. Tasman, D. Pel, J. Richter, H. E. Schmidt, High Temp.-High Pressures 15 (1983) 419

Direct Pressing Method for Carbide Fuel Fabrication

A new fuel fabrication procedure for advanced fuels has been developed which is based on carbothermic reduction and which avoids the comminution step, typical of conventional methods.

With the new procedure, dust generation and thus the operators' risks are considerably reduced. It also offers certain economic advantages.

Reference

1 K. Richter, G. Kramer, C. Sari, P. Werner, Nuclear Technology, to be published.

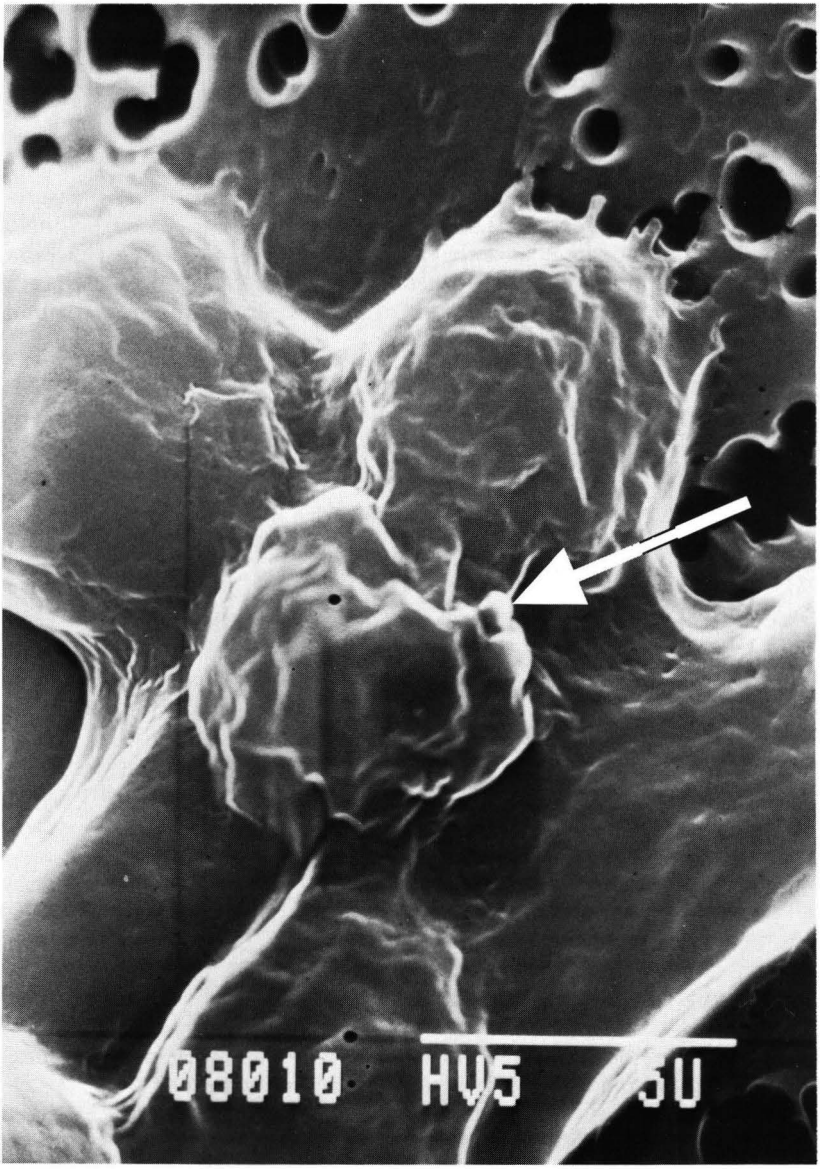
Plutonium Oxide Aerosol Research

Experiments are being carried out to investigate the biochemistry of uranium-plutonium oxide aerosol particle interaction with lung tissue.

The in-vitro uptake of such a particle by a rat lung cell has been observed and photographed for the first time in the scanning electron microscope[1].

Reference

1 L. Müller, G. Hotz, S. Pickering, I. Ray, A. Seidel, H. Thiele, TU Programme Progress Report 38, July - December 1984



UPu Oxide particle engulfed by rat lung cell

High-Temperature Vapour Pressure Measurements on Uranium Dioxide

Discrepancies between experimentally determined high-temperature vapour pressures of UO_2 and data obtained by thermodynamic extrapolation could be resolved by the observation of intrisic positive ion emission at elevated temperature[1].

Thus, the equation of state for UO_2, important for reactor safety calculations, could be evaluated on physical arguments and used with confidence for the first time.

Reference

1 R. W. Ohse, J. F. Babelot, C. Cercignani, J. P. Hiernaut, M. Hoch, G. J. Hyland, J. Magill, J. Nucl. Mater. 130 (1985) 165

5 Beyond the Day's Work ...

The European School of Karlsruhe

Following the initiative of a parents' association, the first European School for the children of Commission staff was founded in 1957 in Luxembourg. Other schools followed in Belgium, in Italy and The Netherlands. After the decision to build the European Institute for Transuranium Elements in Karlsruhe, the European School of Karlsruhe opened its doors in 1962.

The European School System is an attempt to coeducate children of different mother tongues. Lessons are taught in German, English, French, Italian, and Dutch according to a common plan. To promote mutual understanding, in elementary school classes, children from different countries are taught some subjects in a language which is not their mother tongue (the so-called European hours). At the upper high-school level, history and geography, e. g., are given in the first foreign language (either English, French or German).

The school comprises a Kindergarten (minimum age for admittance 3 years), an elementary school with five grades (minimum age for admit-

tance 5 years), and a seven grade high school. The final examination (baccalauréat européen, europäisches Abitur) entitles to access to all universities of the Member States of the European Communities.

Pupils at play . . .

As to be expected, relations between the European School of Karlsruhe and the Institute are very close. The Director of the Institute is a member of the Governing Board of the school, and the Parents Association is run primarily by members of the Institute.

In 1985 there were

323 pupils in the German division,
289 pupils in the French division,
294 pupils in the Italian division,
61 pupils in the Dutch division and
72 pupils in the English division,
with altogether

73 children in Kindergarten,
450 children in elementary school and
516 children in high-school.

. . . students getting acquainted with science

Leisure . . .

Staff members and visiting scientists may choose from a large number of social activities. These are, at least partially, financed by the Commission and managed by a committee (COPAS) which is composed of delegates from the administration and elected respresentatives of the personnel.

At present COPAS supports some twenty different groups whose activities range from judo, skiing, soccer and tennis to chess, photography and stamp collecting. The sports groups take advantage of the excellent facilities of the European School and regularly participate in tournaments with other national and European institutions.

COPAS also arranges seasonal social gatherings, such as dances in February and November, a general sports day for all members of the Institute and their families, a family excursion on Schuman Day, May 9, and a Christmas party for the children.

After working hours

Thus, there are ample opportunities for the staff members and their families to get together; the children even more so as a result of the summer holiday camps, arranged with financial support from the Commission during school holidays.

. . . and Education

A variety of opportunities exist for staff members to broaden their knowledge and improve their abilities and skills.

A local Training Committee monitors external and in-house educational possibilities, organises visits to specialised exhibits and research facilities, arranges internal courses, etc. Lectures are given on subjects such as reactor safety, health physics, solid state physics, the nuclear fuel cycle, computing, etc.

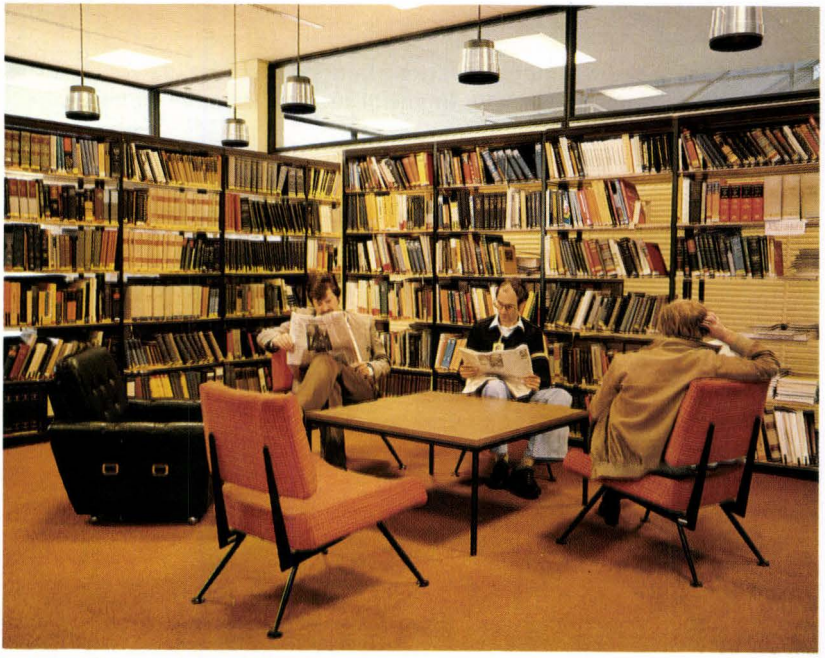
The Training Committee deliberating

All members of the Institute may attend courses, evening classes, and specialist training programmes with financial support from the Commission.

The educational programme is rounded off by the Institute's seminars, where interested staff members and guests gather every two weeks to discuss problems of general interest or to listen to invited lectures on topics which range from fuel technology, energy policy, ecology and catalysis to preventive medicine, synergetics, and the European implications of modern art.

The Training section's special library with books, scientific magazines, audio and video tapes on a wide range of disciplines permits study also after working hours.

Learning by listening . . .



. . . and by reading

The City with the European Touch

Karlsruhe is situated in the Rhine valley, bordering the Black Forest, midway between the Castle of Heidelberg and the Cathedral of Strasbourg. Different stories are told why and how the city of Karlsruhe was founded in 1715 by the Markgraf Karl Wilhelm von Baden-Durlach. Children learn at school that Karl Wilhelm's wife had lost her fan in the forest called Hardtwald. On his attempt to find it, the Markgraf fell asleep under an oak tree and saw in his dream how the fan turned into a fan-shaped city, and he promised to build this city as he had seen it.

The other version has it that the Markgraf's wife was jealous of him, with good reason, which made the Markgraf suffer so much that he left her alone in the Durlach Castle and moved into a newly constructed residence in the Hardtwald, the architecture of which was inspired by Versailles ... The city of Karlsruhe, meaning Karl's resting place, then grew around the castle. In his new residence, the Markgraf was surrounded by a female bodyguard, called tulip girls, which sheds some doubt on the justification for the choice of name for the place.

Whatever may have been the reason for founding Karlsruhe, the result impressed Thomas Jefferson so much that he recommended it as a model for the construction of the American capital, Washington, D. C.

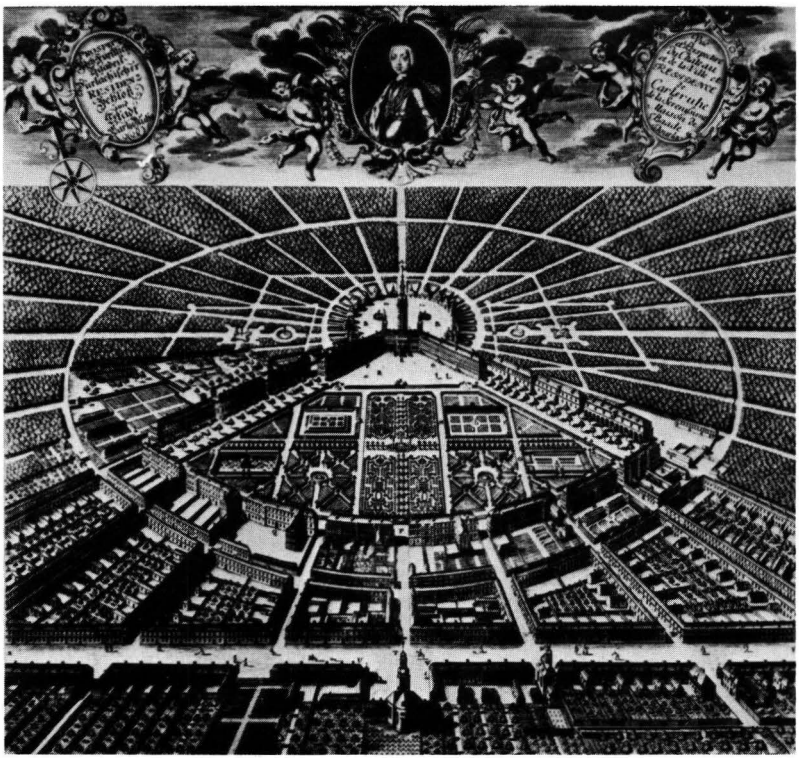
Right from the beginning of its history, Karlsruhe was a truly European city:

- It was constructed with the aid of masons and workers from southern Italy, who added a particular note to the local dialect, the Brigande-Deutsch which may still be heard in the streets of old Karlsruhe.
- In 1825 the Karlsruhe Polytechnical School (Technical University) was founded by Tulla according to the model of the Ecole Polytechnique in Paris.
- Since 1955, Karlsruhe has had friendly links with two partner cities, the French city of Nancy and the English city of Nottingham.
- Karlsruhe is the terminal of oil pipelines from the Mediterranean and from the Black Sea and hosts several multinational petrochemical firms.

Karlsruhe, finally, is not only the home of the European Institute for Transuranium Elements, but also of the first European School in the Federal Republic of Germany.

Some dates:

1715 Foundation of the city by Markgraf Karl Wilhelm
1806 Karlsruhe becomes the capital of Grossherzogtum Baden
1825 Foundation of the Technical University of Karlsruhe
1902 Karlsruhe has a population of 100.000
1984 The population of Karlsruhe exceeds 270.000.



6 Contacts and Contracts

Examples of International Cooperation between the European Institute for Transuranium Elements in Karlsruhe and Industry, Universities and Government Institutions 1980 - 1985

Austria

- **Technical University Vienna**: Actinide Solid State Theory

Belgium

- **University of Antwerp**: Laser Activated Mass Microprobe Analysis of Glove Box Fire Residues
- **University of Liège**: Single Crystal Growth; Single Crystal X-Ray Diffraction; Metal Refining; Electrochemistry of Molten Salts; Analysis of Fuel Dissolution Residues; Spark Mass Spectrometry for Actinide Compound Analysis
- **University of Namur**: Electron Spectroscopy
- **University Louvain la Neuve**: Ion Chromatography of Organic Compounds Formed During Carbide Dissolution
- **CEN Mol**: Advisory Activity on Hot Cell Utilisation
- **JRC Geel (BCMN)**: Single Crystal Growth, Metal Refining, Preparation of Reference Samples
- **Belgonucléaire, Mol:** Analysis of Irradiated LWR Fuel

Brazil

- **University of Sao Paolo**: Mixed U,Pu-Oxide Interdiffusion Studies

Canada

- **AECL, Chalk River Nuclear Laboratories**: Studies of Fission Product and Fission Product Precursor Diffusion

Denmark

- **University of Copenhagen**: High-Pressure X-Ray Diffraction Studies; Band Structure Calculations
- **Risø National Laboratory**: Study of Transient Behaviour of Oxide Fuels; Fission Gas Analysis in LWR Fuels; Statistical Thermodynamics of Non-Stoichiometric Oxides
- **Technical University of Lyngby**: High-Pressure X-Ray Diffraction Studies

Federal Republic of Germany

- **Nuclear Research Centre Karlsruhe**

IMF/PSB: Investigation of the in-pile behaviour of uranium-plutonium-carbides (1982-1984)
IMF3: Thermal conductivity measurements on mixed oxide (1982-85)
IMF3: Investigation of the influence of fabrication parameters and microstructure on the thermal transport properties of mixed oxides (1984)
INR: Studies of the equation of state of fast breeder fuel (1976-84)
IEKP: Measurement of fission gas diffusion in nuclear fuels after ion implantation in a cyclotron
IMF1: Regular information exchange on actual problems of fuel research
IMF: Development of mathematical models on the behaviour of fuels under transient conditions (1980-81)
FR2: Irradiation of uranium-americium-oxide-samples in a thermal flux (1984)
KNK: Irradiation of uranium-americium-oxide-samples in a fast flux (1984)
INR: Calculation of fission yields of higher actinides
LIT: New encapsulation of a Cf-252-source (1982)
PSB: Fabrication of 23 U,PU-carbide-fuel rods (1982)
PSB: Decontamination of 6 unirradiated KNKII-fuel rods (1982)
PSB: Post-irradiation examination of 2 test fuel pins (CAREL) (1982)
EKS: Fabrication of PuO_2-specimens (1983)
INR: Fabrication of PuO_2-specimens
IMF1: FEM-calculations on temperature and stress distribution in irradiated fuel-pellets (1981-82)
IGT: Investigations on the biochemistry of the interaction between lung tissue and inhaled mixed aerosols (1982-85)
IHCh: Dissolution of residues of mixed oxide reprocessing (1983)
INE/HDB: Studies of actinide separation of medium active waste, studies on glasses

- **University of Karlsruhe**

Inst. Angew. Mathematik: Calculations relative to the determination of the thermal contact conductance between fuel and cladding in a transient in-pile experiment (TREGAP) (1980-81)
Inst. Phys. Chemie: Development of an autoclave for the determination of the critical data of alkali-metals, performance of measurements, determination of pVT-data of alkali-metals (1977-82)

- **University of Saarbrücken**

  Inst. f. Anal. und Radiochemie: Development of procedures for the analysis of residues of advanced fuels after dissolution in liquid tin (1980-81); Development of analytical methods for the characterisation of actinides (1982-83); Development of methods for the separation of selected fission products from medium active waste (1983-84); Production of actinide single crystals (1982)

- **University of Paderborn**

  Fachb. 6 Experimentalphysik: Development of methods for the generation of high pressures and for the determination of crystal structures under pressure by X-ray diffraction (1980-84); Development of systems for pressure measurement (1980)

- **University of Regensburg**

  Fakultät für Chemie: Development of chemical separation methods for isotope analysis (1979-1981)

- **Technische Hochschule Darmstadt**

  Inst. für Reaktortechn.: Fuel-pin code development (since 1980)

- **University of Marburg**

  Studies for the determination of critical data on the equation of state of alkali metals (1983)

- **University of Bochum**

  Studies on the emission of charged particles from heated fuel surfaces (1983)

- **Technical University of Munich**

  Mössbauer-Spectroscopy on Np and Np-compounds under normal and elevated pressures (1977-84); Photoemission- theory (1984)

- **University of Bonn**

  Production of an encapsulated NpO_2-specimen (1984)

- **Max-Planck-Institute for Solid State Research Stuttgart**

  Calculation of band structures of actinides (1978-81)

  Calculations relative to the transport-theory and phase-transitions in nuclear fuels (1984-85)

- **Hahn-Meitner-Institute Berlin**

  Investigation of radiation damage in glasses

- **Physikalisch-Technische Bundesanstalt Braunschweig**

  Encapsulation of a 2 mg Cf-252-neutron-source (1981)

- **Deutsches Elektronen-Synchrotron Hamburg**

  Measurement of X-ray diffraction under pressure and of photoelectron-emission (1982-85)

- **Kernforschungs-Anlage Jülich**

  Inst. f. Festkörper-Physik: Band structure calculations on actinides

- **Alkem, Wolfgang bei Hanau**

  REM-investigations on $(U,Pu)O_2$-tablets (1980)
  Residual gas analysis on nonirradiated $(U,Pu)O_2$ tablets (1981)
  Recovery and purification of americium
  Filling gas analysis on unirradiated $(U,Pu)O_2$ fuel rods (1980)

- **Wiederaufarbeitungsanlage Karlsruhe (WAK)**

  Burn-up determination by isotope correlation

- **Interatom Bensberg**

  Investigation of the mechanical stability of B_4C-tablets under temperature load (1980)

- **Kraftwerk-Union Erlangen**

  Mass-spectrometric and isotope analysis of irradiated fuels (1985); Systematic study of irradiated commercial LWR fuel up to high burn up including power transients (1983-87),
  Mass-spectrometric investigation of a boric-acid specimen (1982) (1985),
  Li isotope analysis (1982) (1984)

- **Nuclear Power Station Neckarwestheim**

  Mass-spectrometric determination of the ($^{10}B^{11}B$)-ratio in boron specimens (1980-1985)

France

- **CEN Cadarache**: Safety Analysis of Minor Actinide Fuel Irradiation; Use of Ultrasonic Thermometers for Irradiation Experiment Scarabee; Measurement of Specific Heat of MA Fuel Samples (in preparation); Collaboration for development of nitride fuel (fabrication and irradiation testing); Determination of Fission Product Cross Sections (TACO irradiation); General Exchange of Experience with the Staff of the Plutonium Department (formerly at Fontenay-aux-Roses)
- **CEN Grenoble**: Neutron Diffraction Studies; Magnetic Studies with Actinide Samples; Actinide Crystal Field Calculations; Studies of Transient Behaviour of Oxide Fuels; Development of Ultrasonic Thermometers for In-Pile Experiment in Phebus; In-Pile Post Accident Heat Removal Studies with Ultrasonic Thermometers (PAHR); Irradiation Experiments GOCAR and RADIF
- **CEA Marcoule**: Minor Actinide Irradiation in a Fast Flux (Phenix)
- **CNRS Meudon**: Lanthanide and Actinide Monoxide Synthesis under Pressure
- **CNRS Odeillo**: Attempts to Measure Specific Heat on Liquid Uranium Dioxide in a Mirror Furnace by Sample Levitation
- **CNRS Orleans**: High Temperature Thermophysical Property Studies on Refractories
- **CNRS Strasbourg**: Mössbauer Spectroscopy with Actinides and Actinide Compounds
- **Institute Laue-Langevin, Grenoble**: Neutron Diffraction Studies with Actinides
- **University Paris Sud**: Optical Spectroscopy of Actinides
- **University of Strabourg**: Studies of Catalysis and Surface Reactions Involving Actinides
- **Institut Franco-Allemand, St. Louis**: Feasibility Study on Holographic Fuel Expansion Measurements
- **Laboratoire Curie, Paris**: Neutron Diffraction and Mössbauer Spectroscopy with Actinides
- **L.U.R.E., Orsay**: Synchrotron Radiation Spectroscopy

Greece

- **University of Patras:** Development of Fission Product Release Code MITRA

Italy

- **AGIP Nucleare, Milan**: Development of Fuel Fabrication Methods Involving Gel-Supported Precipitation; SUPERFACT Fuel Preparation
- **Politecnica Milano**: Gas Dynamic Studies of Laser-Induced Supersonic Gas Jet; T-Profile Calculations in Laser Heated Specimens; Mach Disk Technique for Vapour Pressure Measurements
- **University of Milan**: Development of Solid EMF-Cells; Oxygen Potential Measurements in Irradiated Fuels
- **Istituto Nazionale Fisica Nucleare, Frascati**: Synchrotron Radiation Spectroscopy with Actinides
- **CNEN Rome**: Preparation of Americium Dioxide GSP Fuel
- **CNEN Casaccia**: Development of Fuel Fabrication Techniques
- **University of Ancona**: Neutron Diffraction Studies with Actinides
- **University of Padua**: Preparation of Actinide Compounds
- **University of Parma**: Crystallography of Actinides, Crystal Field Calculations, EPR with Actinides; Magnetic and HPRXD Studies with Actinides; Statistical Thermodynamics
- **University of Rome**: Studies on Vapour Pressure over Liquid Uranium Dioxide, Mass Spectrometry at Very High Temperatures; Equation of State Studies with Uranium Dioxide
- **Lavoro e Ambiente, Bologna**: Development of Equipment for Aerosol Generation and Characterisation, Small Scale Glove Box Fire Testing
- **ENEA Bologna:** Preparation of an Instrumented Irradiation Experiment with Mixed Carbides Using Ultrasonic Thermometers
- **JRC Ispra**: Participation in Research Programmes on Radioactive Waste, Safeguards and Reactor Safety

Japan

- **CRIEPI, Tokyo**: Hertzian Indentation Measurements on Nuclear Fuels

The Netherlands

- **University of Nijmegen**: Study of the Kinetics of Chemical Surface Reactions
- **JRC Petten**: Irradiation Testing (in HFR) of Fuel Pins Equipped with Ultrasonic Thermometers; Irradiation Testing of FBR Carbide and Nitride Fuels

Sweden

- **University of Uppsala**: Actinide Solid State Theory; Transcutaneous Oxygen Potential Measurements
- **University of Gothenburg**: Surface Energy and Hertzian Indentation Measurements on Nuclear Fuels

Switzerland

- **ETH Zürich**: Single Crystal Growth, Measurement of Magnetic Properties of Actinides; Transcutaneous Oxygen Potential Measurements

United Kingdom

- **UKAEA Risley**: Safety Study for Minor Actinide Fuel Irradiation
- **AERE Harwell**: Measurement of Specific Heat and Electric Properties of Actinides at Low Temperatures; Oxygen Potential Measurements in Irradiated FBR Fuel; Fuel Reprocessing Studies
- **ICI, Runcorn**: Calculation of Fission Product Behaviour
- **CEGB Berkeley**: Scanning Transmission Microscopy of LWR Fuel (1982)
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United States of America

- **Argonne National Laboratory**: Neutron Diffraction Studies on Actinides; Studies on the Behaviour of Fission Products in HCDA Situations; Studies on Critical Thermodynamic Data of Alkali Metals
- **Los Alamos National Laboratory**: Thermodynamic Studies on Actinide Hydrides; Low Temperature Specific Heat and Superconductivity Studies with Actinides; Photoelectron Emission Spectroscopy
- **Oak Ridge National Laboratory**: Optical Spectroscopy of Actinides under High Pressures, High-Pressure X-Ray Diffraction Studies
- **Rockwell International, Golden, Co**: Thermodynamics of Actinide Hydride Systems
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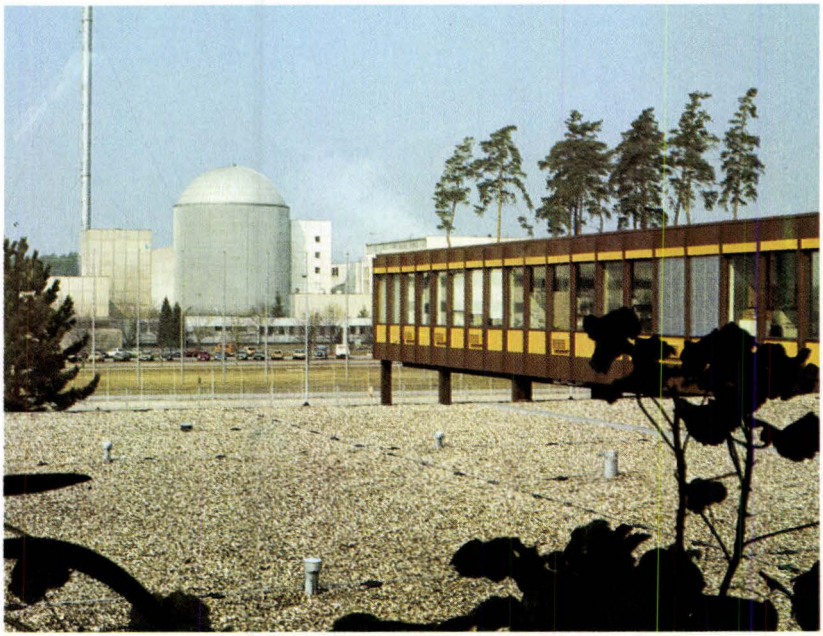

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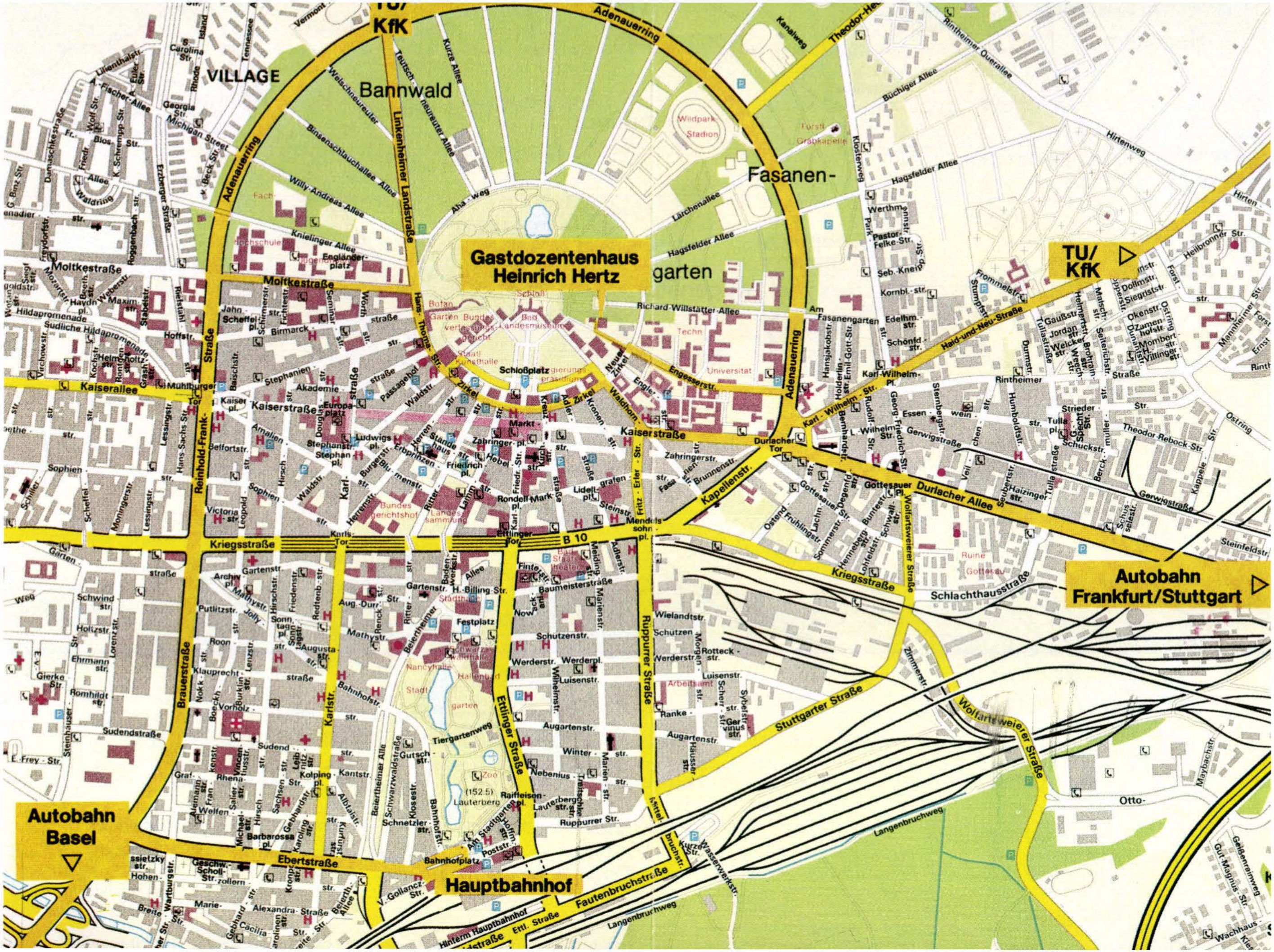
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EUR 10480 — The European Institute for Transuranium Elements

Luxembourg: Office for Official Publications of the European Communities

1986 — 96 pp. — 14.8 × 21.0 cm

Nuclear science and technology series
EN

ISBN: 92-825:6100-3

Catalogue number: CD-NE-86-018-EN-C

Price (excluding VAT) in Luxembourg
ECU 7.92 BFR 350 IRL 5.70 UKL 5.20 USD 7.50

Abstract

The European Institute for Transuranium Elements, the Karlsruhe Establishment of the European Commission's Joint Research Centre is presented.

The report describes the political and technical background which led to the creation of the Institute, presents the present research programme, quotes some important results obtained during the last years, indicates collaborations with external organisations, and lists some recent publications by the Institute's staff.

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ECU 7 92	BFR 350	IRL 5 70	UKL 5 20	USD 7 50

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ISBN 92-825-6100-3

EUR 10480 EN