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radiation protection

Underlying data for derived emergency reference levels

Post-Chernobyl action

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Preface

The Chernobyl accident, which occurred on 26 April 1986, presented major challenges to the European Community with respect to the practical and regulatory aspects of radiation protection, public information, trade, particularly in food, and international politics. The Chernobyl accident was also a major challenge to the international scientific community which had to evaluate rapidly the radiological consequences of the accident and advise on the introduction of any countermeasures. Prior to the accident at Chernobyl, countermeasures to reduce the consequences of radioactive contamination had been conceived largely in the context of relatively small accidental releases and for application over relatively small areas. Less consideration had been given to the practical implications of applying such measures in case of a large source term and a spread over a very large area.

The Radiation Protection Research and Training Programme was influential in a number of important initiatives taken within the Community immediately after the accident. Information was collected by Community scientists and, from it, an assessment made within days of the possible consequences. This showed that the health impact on the population of the European Community was not expected to be significant. About four weeks after the accident, the Programme, together with the US Department of Energy, organised a meeting in Brussels during which the data on dispersion of radioactive material were discussed and evaluated. Several other meetings followed soon after on the transfer of radionuclides in the food chain and possible health effects. These meetings were carried out in close co-operation with the DG XI (Directorate General, Environment, Consumer Protection and Nuclear Safety) within the CEC, and, externally, with international organisations such as the International Atomic Energy Agency (IAEA) and the World Health Organisation (WHO). In addition, the Commission convoked a Committee of high-level independent scientists to assess the scientific evidence from current research in view of recent nuclear incidences, to consider the possible implications for the Basic Standards and emergency reference levels and to advise the Commission on future action in radiological protection including research. (EUR 11449 EN).

Soon after the accident, additional research requirements were identified by the Programme; these were mainly better methods to assess accident consequences and the further improvement of off-site accident management. Several existing contracts were reoriented and new contracts were placed; however, the financial means then available within the Programme were insufficient to fund the additional research identified as necessary. A proposal for a revision of the Programme was, therefore, elaborated in 1986. It comprised 10 specific "post-Chernobyl" research actions. This revision, with an additional budget of 10 MEcu for a period of two years, was adopted by the Council of Ministers on 21 December 1987. With the help of the Management and Coordination Advisory Committee (CGC) "Radiation Protection" a number of institutes was identified to carry out the research in a co-operative manner, and the research began in the spring of 1988.

These post-Chernobyl activities have now been completed. Detailed reports on each of these studies and an additional volume containing the executive summaries of all reports are now available.

- Evaluation of data on the transfer of radionuclides in the food chain,
- Improvement of reliable long-distance atmospheric transport models,
- Radiological aspects of nuclear accident scenarios,
  A. Real-time emergency response systems,
  B. The RADE-AID system,
- Monitoring and surveillance in accident situations,
- Underlying data for derived emergency reference levels,
- Improvement of practical countermeasures against nuclear contamination in the agricultural environment,
- Improvement of practical countermeasures against nuclear contamination in the urban environment,
- Improvement of practical countermeasures: preventive medication,
- Treatment and biological dosimetry of exposed persons,
- Feasibility of studies on health effects due to the reactor accident at Chernobyl.

The research undertaken within the "post-Chernobyl" actions has added considerably to the understanding of the basic underlying mechanisms of the transfer of radionuclides in the environment, of the treatment of accident victims and of how the environmental consequences of accidents may be mitigated. In addition, progress has been made in the setting up environmental surveillance programmes development of predictive and decision-aiding techniques, the implementation of which will lead to significant improvements in off-site accident management. Several new ideas and lines of theoretical and practical research have originated from the post-Chernobyl research and these have already been integrated into the ongoing Community Radiation Protection Research Programme. A further important feature which should not be overlooked, is the close and effective collaboration of many institutes in the research; this has markedly strengthened the ties between Community institutes and scientists. The outcome of all of this work is that the Community and all other countries are now better prepared and co-ordinated should a significant release of radioactivity ever occur again

Further research is continuing within the current Radiation Protection Research and Training Programme 1990-1991 on a number of the "post-Chernobyl" topics; these also form part of the proposal of the specific Programme on "Nuclear Fission Safety" 1992-1993, e.g. real-time emergency management systems, development of countermeasures in the agricultural environment, treatment of radiation accident victims, etc. Moreover, the Community Programme is currently making a significant contribution to an international evaluation, being undertaken by IAEA at the request of the Soviet Government, on the consequences in the USSR of the Chernobyl accident and of the measures being taken to ensure safe living conditions for the affected populations.

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1 INTRODUCTION

If there was an accidental release of radioactive material to atmosphere leading to significant off-site contamination, then various countermeasures would be introduced to reduce the radiation exposure of the population. These countermeasures could include: sheltering, evacuation, and the issue of stable iodine in the short term; together with imposing restrictions on agricultural production, and relocation of people in the medium to long term. In many cases, the introduction of measures to reduce the consumption of contaminated foods would be an important countermeasure. This report is concerned with the underlying information that is required to determine when and if countermeasures should be introduced in the event of an accidental release of radioactive material.

The introduction of countermeasures affects the normal lives of the people concerned and, therefore, undesirable social or economic consequences may follow. It is the task of the competent authorities to make decisions taking into account the positive as well as the negative effects of countermeasures. It is generally accepted that no countermeasure should be introduced unless it produces more good than harm, i.e. the introduction of the countermeasures should be justified. Further, any countermeasure should be introduced in a manner which maximises the net benefit. This is known as optimisation and is complementary to the principle of justification (e.g. see ICRP 1984, IAEA 1985).

The problem of providing guidance for setting Derived Intervention Levels (DIL's) was addressed by the Commission of the European Communities, through the Article 31 Group of Experts who proposed a methodology for determining derived intervention levels for different classes of foods (DIR, 1987). The need was recognised for a compilation of data that would allow more detailed calculations and an examination of the adequacy of the proposals of the Article 31 Group of Experts. In 1987 the Commission of the European Communities set up a programme of work to consider underlying data for derived intervention levels. This report presents the results of this programme of work. The areas considered are data on radioecological models, distribution and consumption of food, dose per unit intake, critical group considerations, emergency management and the effects of countermeasures on doses.

1.1 INFORMATION REQUIRED IN SETTING DERIVED INTERVENTION LEVELS

To assess the consequences of the ingestion of contaminated food after an accident, information is needed on dietary habits and food consumption for a number of population groups. In order to be able to derive intervention levels for food contamination which are applicable to the entire European Community, the diet in each of the member states has to be quantified and, if possible, generalised. Specific groups of the population may be critical in terms of their intake of contaminated food, due to factors influencing food consumption such as age, sex, social class, etc. Dietary intakes are discussed in Chapter 3 of this report.

The distribution of food was recognised to be of major importance by the Article 31 Group of Experts when they introduced the relative contamination factor with a generalised value of 0.1 (Kaul, 1988). This approach takes account of the dilution of contamination which results from food distribution. Generally, however, doses from the ingestion of contaminated food have been calculated on the assumption that food is produced and consumed in the same area. This assumption is only valid for small numbers of people who live in areas of low population density and high food production. It is less valid for the majority of people living in areas of high population density, where local production is insufficient and foodstuffs are imported from other areas. It is therefore necessary to consider the way that foods are distributed between production and consumption. This can be done by comparing the quantities of food imported and locally produced foods for particular areas having determined the areas of production and consumption for different foodstuffs. In addition, information on the exchange of foodstuffs within the Community and with other countries is needed as an input to decisions on countermeasures which might temporarily limit or ban the trade of foodstuffs. This distribution is considered in Chapter 4 of this report.

Concentrations of radionuclides in various foods as a function of time following an accident, together with time integrals of concentration, also form an input to the setting of DILs. These concentrations are predicted by models of the transfer of radionuclides through terrestrial foodchains. They can be used to investigate the extent to which food countermeasures would be required for particular DILs following postulated accidental releases and the length of time that such countermeasures would be required.

Following an actual accident priority would be given to measuring levels of radioactivity in foods and other environmental materials, but the results of terrestrial foodchain models still have a role to play. Firstly, in the period before measurements in food are available, models can be used to predict likely concentrations in food. Secondly, the model predictions and any measurements can be compared to check for consistency and to point out any questionable measurements. Finally, models can be used to predict at what stage any countermeasures might be removed and to examine the impact of different countermeasure options.

Chapter 2 of this report is concerned with foodchain models. A default foodchain model and parameter values are recommended for use in the European Community (EC) in the context of site specific data. There is also a discussion of when such a model is appropriate and when a more detailed model is required.

An important requirement in the derivation of appropriate levels for the control of contaminated foodstuffs is information on doses per unit intake for a range of radionuclides, following intakes by ingestion in different chemical forms and by individuals of different ages. The International Commission on Radiological Protection (ICRP, 1979) recommended biokinetic parameters and dosimetric models for calculating radiation doses for occupationally exposed adults following intakes of radionuclides by inhalation and ingestion. These parameters are, however, not necessarily appropriate for calculating radiation doses to members of the public following the release of radionuclides into the environment. For the calculation of doses to members of the general public, it is necessary to take account of the effect of age on the biokinetics of radionuclides as well as on anatomical and physiological parameters. Incorporation of radionuclides into foodstuffs may also result in changes in their absorption from the gastrointestinal tract. Information is also needed on the transfer of radionuclides to the developing embryo and fetus following intakes of radionuclides by the mother.

The radionuclides for which values of dose per unit intake are given in this report (see Chapter 5) are isotopes of strontium, ruthenium, iodine, caesium, plutonium and americium. In each case, the age groups included in the main calculations are three-month-old infants, one-, five-, ten- and fifteen-year-old children and adults. Doses to the fetus are considered separately. Variability and uncertainty in the calculation of dose per unit intake are estimated for caesium, iodine-131 and plutonium-239.

1.2 ILLUSTRATIVE DOSE CALCULATIONS AND CHARACTERISATION OF CRITICAL GROUPS.

Representative individual doses have been calculated using the various data outlined in Section 1.1, described in detail in Chapters 2 to 5, to illustrate the possible variation between EC countries. These doses are discussed in chapter 6 and also shown is the relative contribution of the intake of different foods to the ingestion dose given deposition at various times of the year. A number of different sets of illustrative individual doses have been calculated. These consider the effect of using different dietary intakes for each EC country compared with using regional or EC averages. The variation of individual dose with age is also considered as is the effect of considering regional agricultural practice compared with an EC "average" practice.

In the methodology applied by the Article 31 Group of Experts for the derivation of intervention levels, the consumption data adopted were based on statistical data. The consumption habits adopted were assumed to be broadly representative of the whole Community and special situations such as high individual consumption of particular foodstuffs or a high level of self-support in an area of above average contamination were not considered. As it is not known to what extent the range in consumption habits within the Community are represented by standard modelling assumptions, information on critical population groups is needed. However, consumption habits for critical groups are not usually recorded in statistical surveys because their diet may include significant proportions of less common foodstuffs that are not taken into account in the representative foodbaskets.

In the region of F.R. Germany bordering the Bavarian Alps, where radiocaesium deposition after the Chernobyl accident was more than 42 kBq m^{-2}, a study has been carried out of food consumption by critical groups of self-supporters, hunters and mushroom-pickers. Information was obtained on the origin, type and amount of contaminated foods consumed throughout the year and compared with similar information for non-self-supporters, chosen as a representative reference group. To examine the influence of consumption habits on the uptake and retention of caesium-137, whole-body measurements were carried out and compared with measurements of activity in foodstuffs. Chapter 7 describes the results of this study.

1.3 THE POSSIBLE EXTENT OF COUNTERMEASURES FOLLOWING AN ACCIDENT

The extent to which countermeasures would be introduced following an accidental release to atmosphere depends on a number of factors. The most important are the size and duration of the release together with the type of countermeasure and criteria adopted for its introduction. The meteorological conditions prevailing at the time and subsequently, plus the season of the year also have an important bearing (Simmonds 1985). The accident at the Chernobyl nuclear reactor led to the release of about 2.7 10^{18} Bq of radioactivity over a period of about 10 days. Over 60% of this activity consisted of noble gas radionuclides, with about 10% being iodine-131 and a few percent being the caesium radioisotopes. This accident led to widespread contamination throughout Europe and the introduction of various countermeasures. For example, in the UK which is nearly 2,000 km from Chernobyl, restrictions on sheep and lamb meat were introduced.

Potential accidental releases even larger than Chernobyl have been postulated, albeit with a very low predicted frequency of occurrence. For example, for a proposed Pressurised Water Reactor (PWR) at Hinkley Point in the UK, one of the release categories considered postulated a release which included about 2 10^{18} Bq iodine-131 and about 3 10^{17} Bq of caesium-134 and caesium-137 together with noble gases and other fission and activation products (Jones and Williams 1988). A release of this magnitude could lead to agricultural restrictions at distances greater than 1000 km from the release point, depending on the release factors listed above. A release about 100 times smaller than this would lead to restrictions for distances of the order of 100 km. For nuclear reactors so called "reference" or "design basis" accidents are postulated. For this type of accident the extent of countermeasures would be much smaller, indeed in many cases they may not be required at all. For a release including say 10^{12} Bq of iodine-131 and 5 10^{11} Bq of caesium-134 and 137, restrictions of a few kilometres only may be required.

In summary, potential accidental releases from nuclear installations could lead to agricultural restrictions at distances from the release point ranging from a few kilometres to more than a 1000 km. The most important factor is the magnitude and composition of the release. Other important factors include the criteria adopted for the introduction of the countermeasures, and the meteorological and environmental conditions pertaining at the time of the release.

1.4 COUNTERMEASURES

The Chernobyl accident clearly demonstrated the impact of contaminated foodstuffs, with various countermeasures introduced over extremely wide territories. Although the concepts of emergency management described earlier were generally accepted, there was a lack of consensus between various countries in the intervention levels for food contamination. Another problem was the lack of knowledge of different types of countermeasures other than food destruction and of other parameters affecting decisions on the appropriate countermeasures.

Chapter 8 of this report deals with a possible methodology to derive intervention levels for food together with a review of countermeasures which can be taken when food contamination exceeds intervention levels. The effectiveness of these countermeasures is assessed and discussed in combination with economical consequences and other factors which affect the feasibility of implementation of these countermeasures. Finally, a selection of the most relevant countermeasures for different emergency situations is made and examples of the derivation of intervention levels for combinations of specific foods and countermeasures are given.

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2 FOODCHAIN MODELS AND MODELLING

2.1 INTRODUCTION

Models to predict the transfer of radionuclides through terrestrial foodchains have a number of uses in the context of Derived Intervention Levels (DILs). The results of such models are in the form of the concentration of a given radionuclide in a particular food as a function of time following an accidental release. The time integrals of concentration can also be obtained. Such results can be used to investigate the extent to which food countermeasures would be required for particular DILs following postulated accidental releases, and the length of time that such countermeasures would be required. Foodchain models can also be used to pre-calculate levels of radioactivity in other environmental materials corresponding to DILs. For example, to relate concentrations in air, or total deposition on grass to concentrations in food.

If there was an actual accident then priority would be given to measuring levels of radioactivity in foods and other environmental materials. These measurements would then be compared with DILs and form the basis of decisions on the implementation of food countermeasures. However, terrestrial foodchain models still have a role to play. Firstly, in the period before measurements in food are available. In many foods, e.g., milk and meat, concentrations are low immediately after the release and take days or even weeks to build up to a maximum. In this period foodchain models can be used to predict likely concentrations based on measured air concentrations or deposition to ground. In this way, the possible extent of food restrictions can be estimated before the measurements are available. Secondly, the model predictions and any measurements can be compared to check for consistency and to point out questionable measurements. Thirdly, models can also be used to estimate what might happen in the future, to predict at what stage countermeasures might be removed and to examine the impact of various countermeasures options. In all such applications of foodchain models the uncertainty and variability associated with the predictions should be borne in mind.

A number of dynamic models for the transfer of radioactivity through the terrestrial foodchain exist in the European Community (EC). One of the goals of this programme of work was to make recommendations on a general model suitable for use in the EC. This model could then be used to calculate Derived Intervention Levels in the absence of site specific information. Two dynamic foodchain models, ECOSYS and FARMLAND (Food Activity from Radionuclide Movement on Land) formed the basis of this work. ECOSYS was developed at the Gesellschaft für Strahlen-und Umweltforschung (GSF) in the Federal Republic of Germany and is described in a number of publications [Pröhl 1990]. FARMLAND was developed at the National Radiological Protection Board in the United Kingdom and is described in a series of publications [Simmonds et al 1979, Simmonds and Crick 1982, Simmonds 1985]. As a first step in recommending a general model, predictions of both ECOSYS and FARMLAND were compared with sets of environmental measurements to test the validity of the models in a variety of situations. Following on from this study, the second stage was to compare the predictions of the two models for a range of situations. These two studies are briefly discussed.

Based on these studies GSF and NRPB were able to recommend a general model for use in the EC in the absence of site specific information. Section 2.2 of this Chapter describes the parameter values and assumptions that form the basis of this model, provides concentrations in various foods following unit deposition to the ground and discusses factors that can lead to variations in the predicted concentrations.

The assumptions regarding agricultural practice have been found to be an important factor in predicting the transfer of radionuclides to terrestrial foods [Simmonds et al 1987]. As part of this programme of work, data on variations in agricultural practice throughout the EC were reviewed. From this review, recommendations were made on representative practices to be assumed in a series of regions in the EC, when other data are not available. This work is discussed in Section 2.3 of this chapter. Finally, the possible variations in concentrations of radionuclides in food in the EC following an accident have been estimated and this is discussed in Section 2.4.

2.1.1 Validation of ECOSYS and FARMLAND

A large number of environmental measurements were made throughout the EC following the 1986 Chernobyl nuclear reactor accident in the USSR. Such data are invaluable for testing the validity of environmental transfer models, such as ECOSYS and FARMLAND. Comparing model predictions with measurement data may enable the identification of deficiencies in model structure, mechanisms that have been overlooked and the use of inappropriate parameter values. The ECOSYS model was developed primarily for use in the FRG and mainly represents conditions in that country, while FARMLAND reflects conditions in the UK. An aim of this study was therefore to test the models using environmental data from other countries. Data sets for model validation were readily available for FRG and UK and efforts were made to obtain suitable data sets for other countries. Unfortunately, this had limited success. In particular, there were no suitable data available for the Mediterranean countries (Spain, Portugal, Greece and the south of France) where the climate and agricultural practices are different to those in the UK and FRG. The majority of data available for the model validation studies were for the pasture-cow-milk pathway. Some data were also available for radionuclide concentrations in sheep, beef and grain. Data were also restricted to concentrations of iodine-131, caesium-134 and caesium-137. These factors limited the extent of the validation exercise but, nevertheless, a number of valuable comparisons between model predictions and measured data could be made. The validation studies carried out for ECOSYS and FARMLAND are summarised below and sample results presented.

The model predictions of ECOSYS were compared with measurement data in four areas: the interception of wet deposited activity; the pasture-cow-milk pathway; the activity in beef; and the activity in grain. Wet deposition is an important mechanism leading to the contamination of foodstuffs. It is essential to know how much of the activity deposited in rain is retained by plants. This interception fraction is modelled in ECOSYS by an approach which takes account of the plant species, its vegetative development (represented by the leaf area index), the amount of precipitation, and the properties of the radioactive element. Measurements of radioactivity in precipitation due to Chernobyl and the initial plant contamination following rainfall were used in the comparison. Also GSF carried out experiments in which contaminated rainwater was sprayed onto different plants. The measured and predicted interception factors were in generally good agreement, with many results agreeing within 10% and the biggest differences being about a factor of two.

A number of different measurements were available to test the predictions of the pasture-cow-milk part of the ECOSYS model. These were for caesium-137 in milk from Southern Bavaria (FRG), caesium and iodine activity in fodder and milk from two farms also in Bavaria, measurements from a feeding experiment carried out at GSF, caesium and iodine measurements in fodder and milk at two dairy farms in the UK and measurements of caesium in milk at Mol, Belgium. The predictions were generally in good agreement, usually within a factor of two of the measurements and often closer. Particularly good agreement was found between the predictions and measurements for milk from farms in Southern Bavaria, as illustrated in Figure 2.1.

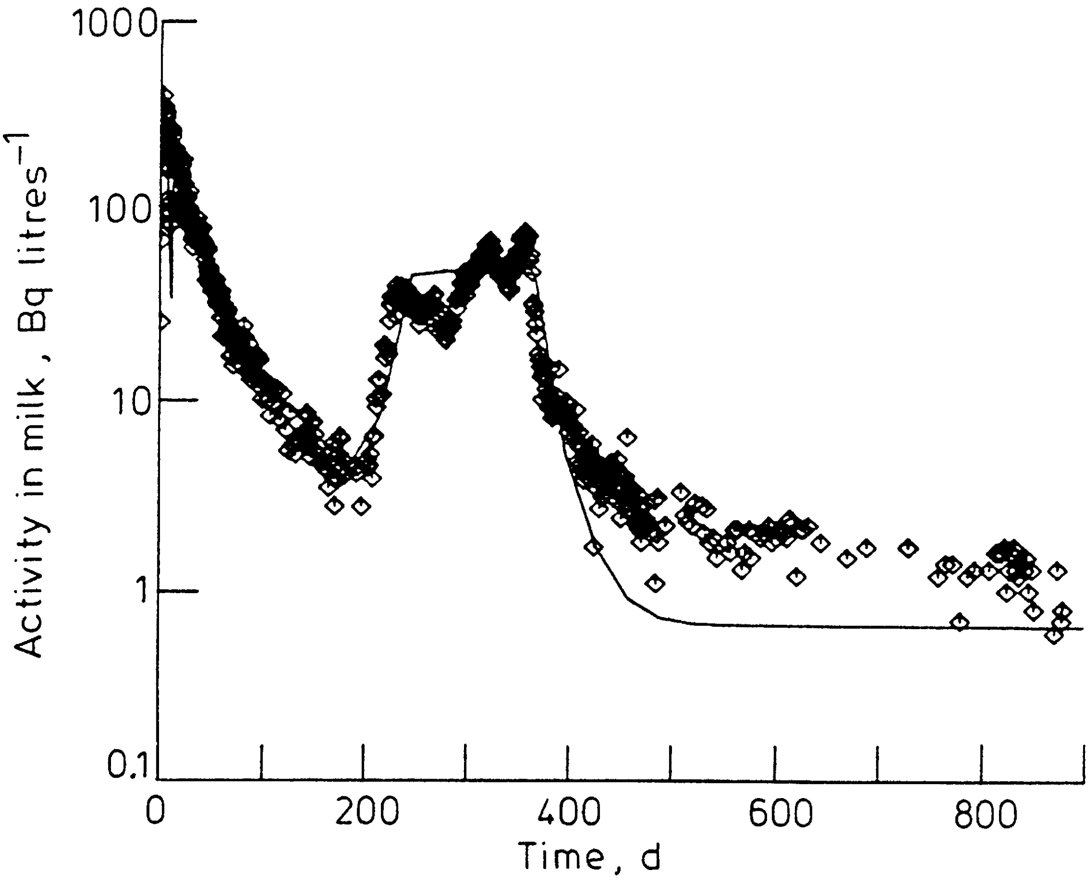


Figure 2.1 Predicted (solid line) and measured (points) caesium-137 activity in the milk from a dairy farm in Southern Bavaria.

Only one set of data was available to test the ECOSYS predictions for the transfer of radioactivity to beef. These were obtained from an experiment at GSF in which three cows were fed variable quantities of caesium-137 over a period of 78 days before slaughter. The ECOSYS predictions for the concentration of caesium-137 in meat at the time of slaughter were then compared with the measured concentrations. For two of the cows the two concentrations were virtually identical, while for the third cow the calculated concentration was 530 Bq/kg compared with that measured of 730 Bq/kg.

Concentrations of caesium-137 in various types of grain were measured in the Munich area following the Chernobyl accident. Assuming an average deposition for the area, concentration in grain was predicted by ECOSYS. Given the large local variations in deposition, the predictions were in good agreement with the measured concentrations.

The results of the FARMLAND model were also compared with several sets of measurement data, some of them being obtained from the Biosphere Model Validation Study (BIOMOVS) in which NRPB is participating [NIRP 1988]. The data sets used were for the pasture-cow-milk pathway, the activity in beef, the activity in sheep meat and the activity in grain. FARMLAND was developed as a general model for use in the UK and although it is flexible enough to be used with site specific information, where available, default parameter values were used for this study. However, where possible, an account of the agricultural practices appropriate for each measurement site was taken.

In comparing the FARMLAND predictions with measurements for the pasture-cow-milk pathway the overall transfer was broken down into components. These were the transfer of: total deposition to concentration in grass; deposition onto grass to concentration in milk and concentration in grass to concentration in milk. These comparisons were carried out using measurements of iodine-131, caesium-134 and caesium-137. In general, the predicted concentrations of all three radionuclides in grass agreed well with the measured concentrations. The measured concentrations showed a small difference between sites and across countries, although the variation of concentration with time is similar for all the sites. The largest difference (about a factor of five) between model predictions and measurements was for concentrations in grass at a farm in Cumbria, UK.

However, agreement was good when the results were normalised to deposition onto grass and not the total deposition to ground (grass and soil), suggesting that the interception factor assumed in the model was too high for this particular case. This was due to the heavy rainfall experienced at the Cumbrian farm at the time of the Chernobyl deposition, an effect that is not usually modelled in FARMLAND. For all of the other sets of measurement data the agreement with predictions indicated that the use of a generic interception factor was reasonable. Figure 2.2 shows the measured concentration of caesium-134 and caesium-137 in cow's milk following deposition at a number of sites and the FARMLAND predictions. This figure again shows a variation between sites with the FARMLAND results being a reasonable representation of the measurements as a whole. For iodine-131 FARMLAND predicted concentrations in milk about a factor of five higher than those measured. These results suggest that the transfer of iodine from intake by the cow to milk is lower than that assumed as a default in the FARMLAND model. However, the question remains whether this is only the case for the form of iodine resulting from Chernobyl or whether it is more generally true.

The FARMLAND model predictions for concentrations of caesium-137 in beef were also compared with measurement data. FARMLAND predicted concentrations in beef 2 to 3 times higher than those measured in the GSF feeding trials discussed earlier. This is thought to be due to a difference in transfer of caesium to beef from lactating and non-lactating animals. The GSF experiment was carried out on lactating cows for which the transfer to meat is lower, while the transfer assumed in FARMLAND is more appropriate to non-lactating cattle. There were also limited data available on caesium-137 concentrations in beef for Italy and Denmark. However, full sets of environmental measurements were not available (e.g., depositions and grass concentrations) making interpretation of the results difficult. Given this, the model predictions were in reasonable agreement with the measured data.

At Mol in Belgium measurements of iodine-131, caesium-134 and caesium-137 were made in muscle, kidney and the liver of sheep, both for young and adult animals. In general, the concentration in the meat of the younger animals is higher than the older animals and the concentrations in kidney and the liver are slightly higher than those in muscle. The model in FARMLAND does not distinguish between young and old animals nor between these organs and tissues. For all three radionuclides the model

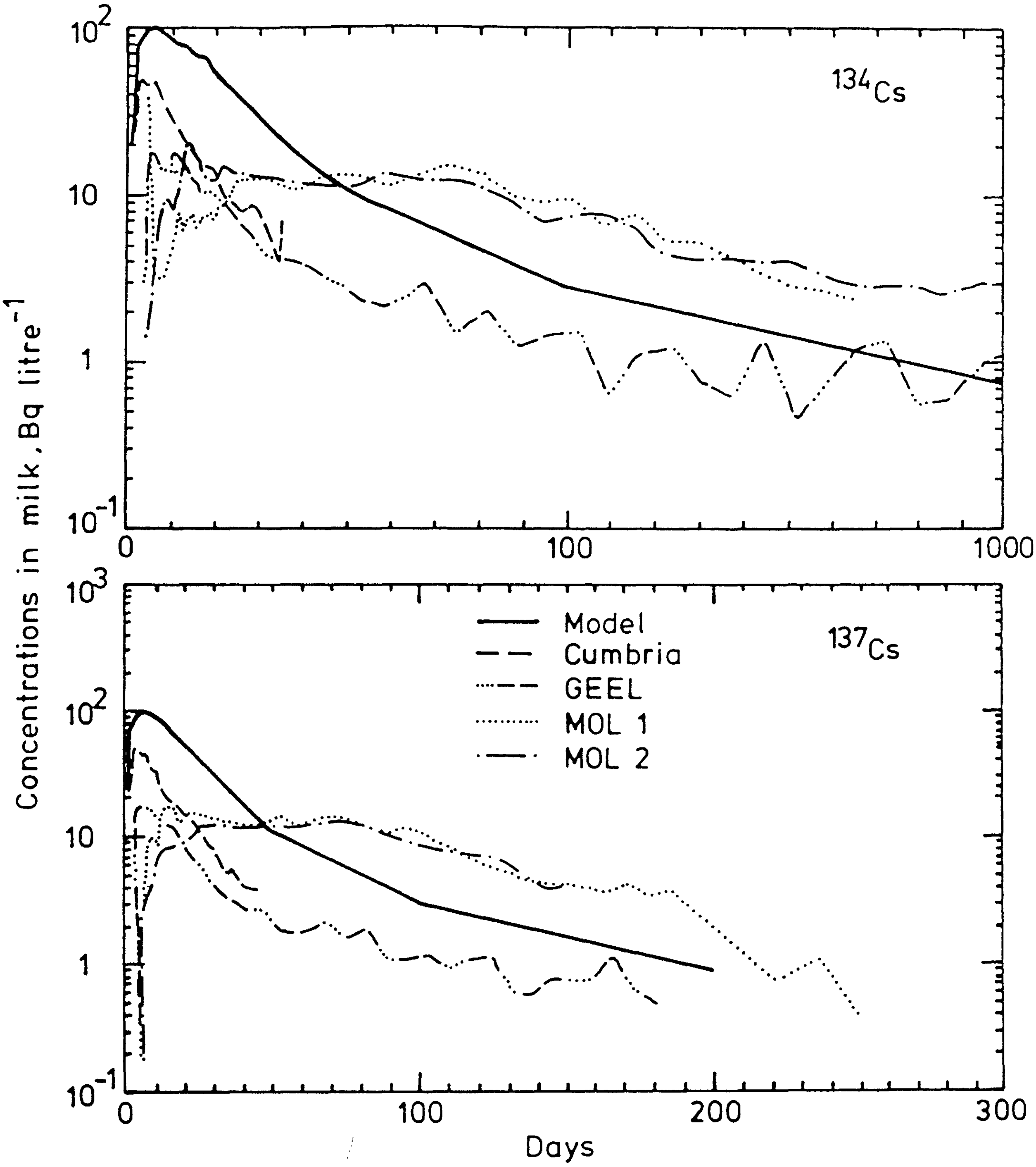


Figure 2.2 Caesium-134 and caesium-137 concentrations in cows milk normalised to 1000 Bq/m^2 total deposition, predicted using FARMLAND and measured at various locations.

predictions tend to overestimate the concentrations in sheep meat but the variation of concentration with time is reasonable over the period for which there are measurements.

As discussed earlier, measurements of caesium-137 in various grain crops at harvest were made in the Munich Region of the FRG following Chernobyl. A comparison was made between the FARMLAND model predictions and these measured concentrations. The model predictions were made for a deposit on the 1st May and harvest on 1st September and no attempt was made to model differences between the different crops. The predicted concentration fell within the range of measured concentrations for the various cereal types being more consistent with the levels in winter varieties.

In summary, both ECOSYS and FARMLAND were in reasonable agreement with measurement data for a variety of situations. FARMLAND has been developed as a general model and default model parameters were used in the comparisons. This tended to lead to greater differences than found using ECOSYS, a more detailed model that takes into account more site specific factors, notably relating to deposition. In addition, the models and parameter values used in ECOSYS had been modified following Chernobyl to take account of the transfer data available. The FARMLAND models and parameter values are those that were considered appropriate before Chernobyl.

2.1.2 Comparisons of model predictions of ECOSYS and FARMLAND

Following the validation exercise summarised in the previous section, the two models, ECOSYS and FARMLAND, were compared for a number of situations. This was to enable the differences between the models to be quantified and understood so their importance could be assessed. This was a necessary stage leading to the development of recommended databases for activity concentrations in various foods for use in various parts of the EC.

For the comparison the agricultural practices assumed were fixed to eliminate any differences due to these assumptions. The agricultural practices chosen for the comparisons are those representative of practices in the FRG or the UK or both. They are not necessarily representative for all other EC countries (see Section 2.3 of this Chapter).

Four radionuclides were considered in the comparison: strontium-90, caesium-137, iodine-131 and ruthenium-106. These radionuclides could be radiologically significant following an accident and are thought to indicate the likely range in differences between the two models. Predictions of the models were compared for wet and dry conditions starting with total wet deposition and amount of rainfall, and time integrated concentrations in air, respectively. The foods included in the comparison are: winter wheat, spring wheat, potatoes, root vegetables, green vegetables, cows milk, beef (cows and bulls) and sheep meat. Both models, notably ECOSYS, can include a range of other foods but these were not considered.

Both FARMLAND and ECOSYS can take into account the effect that accidents at different times of the year can have on subsequent transfer of activity to food. Although many seasonal differences are due to farming practices, other factors, such as the stage of the development of the plant at the time of deposition, can also affect the final concentration in food. The farming practices used by the two models in this comparison are the same, but to enable other seasonal effects to be studied the comparison was made for four different times of the year. These times were:

January 1st - Representing a time of minimum plant growth for many crops and when animals are often housed indoors.
May 1st - Representing a time at the beginning of intensive vegetation growth and when animals are outside.
July 1st - Representing a time when most crops are at a stage of maximum development.
September 1st - Representing a time at around harvest of some important feed crops and foods.

Activity concentrations and time-integrated concentrations were compared for each radionuclide and time of the year for each of the foods listed. No account was taken of losses due to preparation and processing or of radioactive decay before consumption of the food. For all foods except winter and spring wheat, concentrations were compared at 7 days, 14 days, 30 days, 6 months, 1 year and 50 years following deposition. For the two wheat crops the concentrations at the harvest in the year of deposition, the harvest in the following year and the concentration at 50 years were compared. In addition, for green vegetables and grass activity concentrations immediately following wet and dry deposition were compared.

This comparison produced many detailed results and it is only possible to summarise the principal findings here and to present some illustrative results.

The way in which the deposition of radionuclides to plant and soil is modelled in ECOSYS and FARMLAND is rather different. In FARMLAND foliar contamination is modelled using an interception factor to represent the fraction of the deposit which lands on the plant. There is no differentiation between dry and wet deposition and seasonal variations are not taken into account. ECOSYS adopts a more complex approach to modelling the interception and retention of activity on plants. Dry deposition is modelled taking into account the stage of development of plants, characterised by the leaf area index at the time of deposition. For the interception of wet deposited material an approach is used taking into account the stage of development, the water storage capacity of plant leaves and the ability of the radioactive element to be fixed onto the plant. These different approaches to modelling dry and wet deposition were an important reason for differences found in the model comparison.

The differences found are illustrated in Tables 2.1 and 2.2 for wet and dry deposition, respectively both on July 1st. For the various foods and radionuclides the ECOSYS and FARMLAND predictions are given for activity initially deposited on the plant and the total deposited (plant plus soil). For wet deposition, in general differences between the two models are very small, often being within a factor of 2 or 3. In ECOSYS, caesium and ruthenium are assumed to be about half as available as strontium, while the availability of iodine is taken to be about half that of caesium. This and the differences in interception between the two models leads to the observed variation in predictions. The smallest differences seen are for green vegetables as both models assume a constant stage of plant development at the time of deposition with no seasonal effects. The largest differences in the predicted wet deposition (greater than an order of magnitude) were seen for depositions at times of the year when there are very low yields of crops, for example, due to the dying back of potatoes in September, due to the very early development of winter wheat in January and spring wheat in May, and due to the lack of growth of grass in winter. These effects are all modelled in ECOSYS but not explicitly in FARMLAND and hence led to the observed differences in predicted depositions. However, due to other transfer processes these large differences did not necessarily lead to large differences in the predicted concentrations at harvest, or in the meat and milk from grazing animals. The wet deposition to plants predicted by ECOSYS varies with the amount of rainfall, while that predicted by FARMLAND is constant. For typical rainfall of a few millimeters onto grass the predictions of the two models are in reasonable agreement. At much higher rainfall rates ECOSYS predicts lower deposition than FARMLAND by up to a factor of 10, while for lower rainfall rates ECOSYS predicts higher deposition by up to a factor of 4.

Table 2.1: Predictions of wet deposition by ECOSYS and FARMLAND

Deposition: July 1st

Crop	Nuclide	Wet Deposition(1) (Bq m^{-2})			
		Plant			Total(2)
		ECOSYS	FARMLAND	E/F	
Green Vegetables	Sr-90	1.0E+02	6.0E+01	1.7	2.0E+02
	Cs-137	5.9E+03	6.0E+03	.98	2.0E+04
	I-131	1.3E+04	2.7E+04	.48	9.0E+04
	Ru-106	2.1E+03	2.1E+03	1.0	7.0E+03
Winter wheat	Sr-90	7.2E+01	6.2E+01	1.2	2.0E+02
	Cs-137	3.8E+03	6.2E+03	.61	2.0E+04
	I-131	8.5E+03	2.8E+04	.30	9.0E+04
	Ru-106	1.3E+03	2.2E+03	.59	7.0E+03
Spring wheat	Sr-90	7.6E+01	6.2E+01	1.2	2.0E+02
	Cs-137	4.0E+03	6.2E+03	.65	2.0E+04
	I-131	9.0E+03	2.8E+04	.32	9.0E+04
	Ru-106	1.4E+03	2.2E+03	.64	7.0E+03
Potatoes	Sr-90	8.2E+01	8.0E+01	1.0	2.0E+02
	Cs-137	4.7E+03	8.0E+03	.59	2.0E+04
	I-131	1.1E+04	3.6E+04	.31	9.0E+04
	Ru-106	1.6E+03	2.8E+03	.57	7.0E+03
Root Vegetables	Sr-90	1.0E+02	8.0E+01	1.3	2.0E+02
	Cs-137	5.9E+03	8.0E+03	.74	2.0E+04
	I-131	1.3E+04	3.6E+04	.36	9.0E+04
	Ru-106	2.1E+03	2.8E+03	.75	7.0E+03
Grass	Sr-90	8.2E+01	5.0E+01	1.6	2.0E+02
	Cs-137	4.3E+03	5.0E+03	.86	2.0E+04
	I-131	9.8E+03	2.3E+04	.43	9.0E+04
	Ru-106	1.5E+03	1.8E+03	.83	7.0E+03

Notes:

1) Depositions calculated from wet deposition for 5 mm rainfall. ECOSYS will predict different wet deposition to plant for different amounts of rainfall.

2) This deposition (plant + surrounding soil) is not used in ECOSYS. Deposition to plant surface and total deposition to grass are used.

Table 2.2: Predictions of dry deposition by ECOSYS and FARMLAND

Deposition: July 1st

Crop	Nuclide	Dry Deposition(1) (Bq m^{-2})					
		Plant			Total(2)		
		ECOSYS	FARMLAND	E/F	ECOSYS	FARMLAND	E/F
Green vegetables	Sr-90	2.2E+01	3.2	6.9	2.7E+01	1.1E+01	2.5
	Cs-137	2.2E+03	3.2E+02	6.9	2.7E+03	1.1E+03	2.5
	I-131	3.5E+04	4.6E+03	7.6	4.1E+04	1.5E+04	2.7
	Ru-106	6.5E+02	9.7E+01	6.7	8.1E+02	3.2E+02	2.5
Winter wheat	Sr-90	1.5E+01	3.4	4.4	2.0E+01	1.1E+01	1.8
	Cs-137	1.5E+03	3.4E+02	4.4	2.0E+03	1.1E+03	1.8
	I-131	2.3E+04	4.8E+03	4.8	2.9E+03	1.5E+04	1.9
	Ru-106	4.4E+02	1.0E+02	4.4	6.0E+02	3.2E+02	1.9
Spring wheat	Sr-90	1.8E+01	3.4	5.3	2.3E+01	1.1E+01	2.1
	Cs-137	1.8E+03	3.4E+02	5.3	2.3E+03	1.1E+03	2.1
	I-131	2.9E+04	4.8E+03	6.0	3.5E+04	1.5E+04	2.3
	Ru-106	5.4E+02	1.0E+02	5.4	6.8E+02	3.2E+02	2.1
Potatoes	Sr-90	2.2E+01	4.3	5.1	2.7E+01	1.1E+01	2.5
	Cs-137	2.2E+03	4.3E+02	5.1	2.7E+03	1.1E+03	2.5
	I-131	3.5E+04	6.1E+03	5.7	4.1E+04	1.5E+04	2.7
	Ru-106	6.5E+02	1.3E+02	5.0	8.1E+02	3.2E+02	2.5
Root Vegetables	Sr-90	2.2E+01	4.3	5.1	2.7E+01	1.1E+01	2.5
	Cs-137	2.2E+03	4.3E+02	5.1	2.7E+03	1.1E+03	2.5
	I-131	3.5E+04	6.1E+03	5.7	4.1E+04	1.5E+04	2.7
	Ru-106	6.5E+02	1.3E+02	5.0	8.1E+02	3.2E+02	2.5
Grass	Sr-90	1.3E+01	2.7	4.8	1.8E+01	1.1E+01	1.6
	Cs-137	1.3E+03	2.7E+02	4.8	1.8E+03	1.1E+03	1.6
	I-131	2.0E+04	3.8E+03	5.3	2.6E+04	1.5E+04	1.7
	Ru-106	3.8E+02	8.1E+01	4.7	5.4E+02	3.2E+02	1.7

Notes:

1) Depositions calculated from time-integrated air concentrations.

2) This deposition (plant + surrounding soil) is not used in ECOSYS. Deposition to plant surface and total deposition to grass are used.

For dry deposition, as illustrated in Table 2.2, the depositions to plants predicted by FARMLAND are in general lower than those predicted by ECOSYS. The exception is, as for wet deposition, where ECOSYS assumes a low plant yield and hence deposition, when FARMLAND predictions are higher.

The translocation of radionuclides from the foliage to the edible parts of the crop is modelled in a similar way in ECOSYS and FARMLAND. In this comparison, only winter and spring wheat were considered and, for winter wheat, especially at the beginning of the growing period, translocation rates are assumed in FARMLAND which are much higher than those assumed in ECOSYS. However, in the model validation study both models predicted concentrations in winter grain within or close to the range obtained from measurements.

The approach for estimating the contamination of plants due to root uptake is similar in both models. There are some differences in the soil-plant transfer factors but they did not lead to substantial differences in predictions. The assumptions made for the soil mass and the leaching of radionuclides out of the root zone caused differences in the predicted activity concentrations which were of minor importance. An exception is the modelling of the root uptake of radionuclides by pasture grass. In FARMLAND, the deposition to soil is assumed to be immediately mixed in the top 0-1 cm layer, whereas ECOSYS assumes uniform mixing of the radionuclides over the layer 0-10 cm immediately after the deposition. This can lead to higher initial concentrations in grass from root uptake in the FARMLAND predictions compared to those of ECOSYS for times when deposition occurs while the land is fallow. The external contamination of the grazed grass dominates the concentrations at times soon after deposition in the FARMLAND model, and at most times of the year in ECOSYS and the higher concentrations are only seen for the growing of silage grass, where the land is fallow if deposition occurs during the winter.

There are some differences in the parameters used to model the transfer of radionuclides to animal food products. For strontium, the differences are of little importance but for caesium, the transfer factors for beef and cow's milk are more than a factor of 2 different.

2.2 CHOICE OF A DEFAULT MODEL FOR THE TRANSFER OF RADIONUCLIDES IN THE FOOD CHAIN

2.2.1 Model parameters

The default model is based on FARMLAND and ECOSYS using the results of the studies discussed previously. Recommendations are made of values of various parameters and these can be used with either model or any similar model.

Deposition and Interception

As already discussed in Chapter 2.1.2, the two models, FARMLAND and ECOSYS, apply very different approaches for the prediction of the initial contamination of plants after deposition. In FARMLAND, no distinction is made between dry and wet deposited radionuclides. The input for the model is the total, wet and dry, deposited activity (Bq/m^2) for which a constant interception factor is applied at all times of the year (see Table 2.3). The interception factor used as a default in FARMLAND was chosen in conjunction with the default yield for each plant and the half-time used for the retention of activity on the plant's surface (Simmonds 1985) and would be adjusted for different plant yields, etc.

The ECOSYS approach is more complex; dry and wet deposition is modelled separately. The starting points are the integrated activity concentration in air (Bq/m^3), the activity deposited during rainfall (Bq/m^2) and the total amount of rainfall (mm) taking into account the standing biomass and the actual leaf area for pasture grass and all other plants, respectively.

The deposition velocities for the different plants and different times of the year according to the two approaches are summarized in Table 2.3. The greatest differences are seen for those times of the year when there is little plant development.

Table 2.3: Deposition velocities used in ECOSYS and FARMLAND

Plant	Deposition velocity for particles (mm/s)*				
	ECOSYS				FARMLAND
	Jan 1st	May 1st	Jul 1st	Sep 1st	all times
Grass	.015	1.2	1.2	1.2	.30
Wi-wheat	.0026	.66	1.4	-	.30
Sp-wheat	-	.007	1.7	-	.30
Potatoes	-	-	2.0	.60	.40
Root veg.	-	2.0	2.0	2.0	.40
Leafy veg.	2.0	2.0	2.0	2.0	.30
Soil	.50	.50	.50	.50	.70/.60

* The deposition velocity for elemental iodine is a factor of 10 higher in both models.

Although the effective deposition velocities used may be quite different, the differences in the resulting initial contamination of plants are less pronounced due to the effect of using different plant yields.

In ECOSYS the interception of wet deposited activity is modelled taking into account the biomass or the leaf area, the amount of rainfall, and the chemical properties of the radionuclide considered according to:

$$f_w = \min\left(1; \frac{LAI \cdot k \cdot S\left(1-e^{-\frac{\ln 2}{3kS} \cdot R}\right)}{R}\right)$$

with

LAI = leaf area index
S = storage capacity of plant (mm)
k = element dependent factor
R = amount of rainfall (mm)

For the storage capacity of water S, for maize, grass, and cereals a value of 0.2 mm can be assumed. For all other plants, a value for S of 0.3 mm is appropriate (Pröhl, 1990). The factor k is 0.5, 1.0 and 2.0 for iodine, caesium and strontium, respectively. The interception factors for grass and winter wheat for different times of the year as a function of the amount of rainfall are shown in Tables 2.4 and 2.5.

Again, the differences between the two approaches are most pronounced for times of the year in which the standing biomass is very low, for example in January. For a low total amount of rainfall ECOSYS predicts a higher interception, whereas for heavy rainfall the interception predicted by FARMLAND is higher. The FARMLAND predictions are generally in the middle of the ECOSYS predictions for deposits in light and heavy rainfall. For example, for pasture grass the FARMLAND approach fits the predictions of ECOSYS well for a total rainfall of 2 mm, 3.5 mm and 7 mm for iodine, caesium and strontium, respectively.

The discussion of the differences between the two approaches also illustrates the influence of the weather conditions during the passage of the cloud on the deposition of radionuclides on plants and soil. The different complexity of the approaches suggest different areas of application. FARMLAND uses a generic approach and is most suitable in wide ranging assessments of the consequences of potential accidents and for situations where only limited information about the deposition and the contribution of dry and wet deposition is available. ECOSYS uses a more complex approach and it is particularly appropriate to apply this model in emergency situations when different weather conditions have to be considered and information about the deposition characteristics is available from monitoring networks.

For the default model either the generic interception factors as used in FARMLAND are appropriate, or for more complex models such as ECOSYS, parameter values corresponding to deposition in 3 mm rain should be used.

Translocation

The movement of activity from the foliage to edible parts of the plant is quantified by using a translocation factor, which is defined as the fraction of activity deposited on the foliage per m^2 soil area which is transferred to the edible part of the plant harvested per m^2. The translocation factors for cereals and potatoes as a function of the time of deposition are given in Table 2.6. The values are based on Pröhl (1990) and Simmonds (1985).

Table 2.4: Interception of wet deposited activity on grass for different amounts of rainfall and different times according to ECOSYS and FARMLAND

Iodine:

Rainfall (mm)	Interception factor ECOSYS 1st Jan	 1st May	 1st Jul	 1st Sep	 FARMLAND all times
.1	.015	1.0	1.0	1.0	0.3
.5	.0096	.74	.74	.74	0.3
1.	.007	.49	.49	.49	0.3
2.	.0035	.27	.27	.27	0.3
3.	.0023	.18	.18	.18	0.3
5.	.0014	.11	.11	.11	0.3
10.	.0007	.054	.054	.054	0.3

Caesium:

Rainfall (mm)	Interception factor ECOSYS 1st Jan	 1st May	 1st Jul	 1st Sep	 FARMLAND all times
.1	.016	1.0	1.0	1.0	0.3
.5	.012	.95	.95	.95	0.3
1.	.010	.75	.75	.75	0.3
2.	.0063	.49	.49	.49	0.3
3.	.0045	.35	.35	.35	0.3
5.	.0030	.22	.22	.22	0.3
10.	.0014	.11	.11	.11	0.3

Strontium:

Rainfall (mm)	Interception factor ECOSYS 1st Jan	 1st May	 1st Jul	 1st Sep	 FARMLAND all times
.1	.017	1.0	1.0	1.0	0.3
.5	.014	1.0	1.0	1.0	0.3
1.	.013	.95	.95	.95	0.3
2.	.0096	.75	.75	.75	0.3
3.	.0077	.60	.60	.60	0.3
5.	.006	.41	.41	.41	0.3
10.	.003	.22	.22	.22	0.3

Table 2.5: Interception of wet deposited activity on winter wheat for different amounts of rainfall and different times according to ECOSYS and FARMLAND

Iodine:

Rainfall (mm)	Interception factor			
	ECOSYS			FARMLAND
	1st Jan	1st May	1st Jul	all times
.1	.002	.47	.98	0.3
.5	.0012	.31	.65	0.3
1.	.001	.21	.43	0.3
2.	.0005	.11	.24	0.3
3.	.0003	.076	.16	0.3
5.	.0002	.046	.095	0.3
10.	.0001	.023	.048	0.3

Caesium:

Rainfall (mm)	Interception factor			
	ECOSYS			FARMLAND
	1st Jan	1st May	1st Jul	all times
.1	.002	.50	1.0	0.3
.5	.0016	.40	.90	0.3
1.	.0011	.29	.65	0.3
2.	.0008	.21	.46	0.3
3.	.0006	.15	.33	0.3
5.	.0004	.092	.20	0.3
10.	.0002	.046	.10	0.3

Strontium:

Rainfall (mm)	Interception factor			
	ECOSYS			FARMLAND
	1st Jan	1st May	1st Jul	all times
.1	.002	.52	1.0	0.3
.5	.0018	.46	.95	0.3
1.	.0016	.40	.83	0.3
2.	.0012	.31	.65	0.3
3.	.0010	.25	.52	0.3
5.	.0007	.17	.36	0.3
10.	.0004	.09	.19	0.3

Table 2.6: Translocation of strontium, caesium and iodine for wheat and potatoes

Time before harvest (days)	Translocation % Wheat Sr	Translocation % Wheat Cs, I	Translocation % Potatoes Cs, I
0	7.5	7.5	0
30	1.5	12	8
60	0.2	8	15
90	0	2 (0.2*)	10
120	0	0.5 (0*)	2.1

* values for spring wheat

Transfer factors soil-plant

The transfer factors used for the calculation of the plant contamination through the uptake of radionuclides from the soil (Table 2.7) are taken from the IUR-data bank (Frissel and Köster, 1987). The transfer factors used are standardized to a pH-value of 6, an organic matter content of 4% for arable soil and 10% for pasture soil, and for the time two years after the deposition. The values are given for loam soil. They should only be used if no site-specific information is available.

Table 2.7: Transfer factors soil-plant for strontium and caesium

Plant	Transfer factors (Bq/kg f.w./Bq/kg d.w.) plant soil strontium	Transfer factors (Bq/kg f.w./Bq/kg d.w.) plant soil caesium
Grass	0.05	0.03
Wheat	0.20	0.01
Potatoes	0.05	0.007
Root vegetables	0.1	0.005
Leafy vegetables	0.3	0.02

The transfer factors of strontium and caesium are assumed to decrease with time, due to fixation and leaching, with half-times of 13 years and 8.5 years, respectively (Frissel and Köster, 1987).

Due to the short half-life of I-131, the root uptake of iodine was neglected in the context of DILs.

Transfer factors feed-animal products

The transfer factors for the calculation of the activity concentration in animal food products are summarized in Table 2.8. These transfer parameters are based on those given by Pröhl (1990) and Simmonds (1985) and on measurements carried out after the Chernobyl accident.

Table 2.8: Transfer factors feed-animal products for strontium, iodine and caesium

Animal Product	Transfer factor feed-animal product		
	Sr	I	Cs
Cow's milk	2E-03	5E-03	5E-03
Sheep milk	1E-02	5E-01	6E-02
Goat's milk	1E-02	5E-01	6E-02
Beef	3E-04	2E-03	3E-02
Lamb	3E-03	5E-02	5E-01
Pork	2E-03	5E-03	4E-01

Element-independent parameters

The default values for the most important element-independent parameters are summarized in Table 2.9. The assumptions about the agricultural practices in the default model are listed in Table 2.10.

Table 2.9: Default values for element-independent parameters

Parameter	Value
Weathering half-life	14 d
soil mass	
arable land	350 kg/ m^2
pasture	140 kg/ m^2
dry matter intake	
cow	13 kg/d
pig	2.5 kg/d
lamb	1.5 kg/d

Table 2.10: Assumed agricultural practices for the default food chain model

Product	Agricultural Practice
Green vegetables	continuous harvesting throughout the year
Winter wheat	sown: 1st October harvested: 5th August
Spring wheat	sown: 15th April harvested: 15th August
Root vegetables	planted: 1st May harvested: 1st August to 31st October
Potatoes	planted: 15th May harvested: 1st August to 25th Sept.
Cows - milk and beef	graze pasture: 1st May to 31st October eat silage/hay: 1st November to 1st May
Sheep - meat	graze pasture: 1st May to 31st October eat silage/hay: 1st November to 1st May
Pigs	eat winter wheat grown under conditions described above

2.2.2 Activity concentrations in foodstuffs calculated using the default model

Using the model and parameter values given, activity concentrations and time-integrated activity concentrations were calculated using ECOSYS for spring and winter grain, potatoes, leafy vegetables, root vegetables, milk, beef, lamb, and pork following deposition on 1 January, 1 May and 1 July. The results are given in Tables 2.11 to 2.16.

The results are given for the concentration at the time of harvest without taking into account changes in the activity concentration due to preparing, processing, and storage. For the calculations, a wet deposition of 1000 Bq per square meter during a precipitation of 3 mm was assumed.

Following deposition on 1 January for all plants except leafy vegetables, only the uptake of radionuclides via the roots is of importance. The resulting activity concentrations are relatively small compared to the activities following deposition at other times of year when the uptake of radionuclides via the foliage is important.

The importance of the direct foliage contamination process is greatest following deposition on 1 July when most plant canopies are fully developed and therefore the interception is at a very high level. For deposition on 1st May, foliar uptake is only relevant for winter wheat and leafy vegetables and pasture grass. Potatoes, root vegetables and spring wheat are at the beginning of, or have still not started their development, and therefore foliar uptake is not important for these crops for the growing conditions considered here. The decline of the activity concentrations in leafy vegetables is slower following a deposition in January compared with one in May or July due to the longer weathering half-life in winter.

There is an important difference between caesium and strontium. The caesium is very mobile in plants, leading to high activities in grain, potatoes and root vegetables after depositions during the growing period. Strontium is translocated only to a very little extent; therefore the contamination due to foliar uptake is relatively small compared with a caesium (e.g., grain) or does not occur (potatoes and root vegetables). On the other hand the sorption of caesium in soils is stronger than that of strontium. This results in long-term contaminations due to root uptake for caesium which are about an order of magnitude lower than for strontium.

For the animal food products the activity concentrations have peaks soon after deposition. A second peak but at a lower level can be observed during the winter following the deposition when contaminated hay and silage is fed to the animals.

For I-131, due to the short half-life, only the contamination of leafy vegetables and milk is of importance. A second peak of the concentration in milk in winter cannot be observed.

Following deposition during the growing period, the biggest part of the integrated activity concentrations result from the contamination in the first year which is due to the importance of foliar uptake. Exceptions are the activities of Sr-90 in potatoes and root vegetables. In most cases the integrals are significantly higher (up to more than an order of magnitude) after depositions in May or July.

Table 2.11: Time-dependence of the Cs-137 activity in various foodstuffs predicted using the default model for a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm

Time — Activity concentration in Bq/kg (fresh weight)

1st January

Time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	2.04E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	1.85E+02	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	1.46E+02	0.00E+00
.5 years	0.00E+00	0.00E+00	0.00E+00	5.69E-02	0.00E+00
1 years	2.10E-02	2.23E-02	2.92E-02	5.40E-02	1.59E-02
50 years	1.20E-04	1.65E-04	1.65E-04	3.15E-04	8.99E-05

Time	beef(cow)	pork	lamb	milk
7 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
.5 years	3.55E-01	0.00E+00	1.51E+01	7.43E-02
1 years	4.30E-01	2.34E-02	1.67E+01	7.33E-02
50 years	2.26E-03	1.96E-04	9.30E-02	3.77E-04

1st May

Time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	1.37E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	8.10E+01	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	1.84E+01	0.00E+00
.5 years	2.19E-02	4.99E+00	2.00E-01	5.69E-02	1.63E-02
1 years	2.16E-02	4.93E+00	1.97E-01	5.40E-02	3.08E+00
50 years	1.24E-04	1.71E-04	1.71E-04	3.26E-04	9.30E-05

Time	beef(cow)	pork	lamb	milk
7 days	3.64E+01	0.00E+00	4.69E+01	3.48E+01
14 days	6.97E+01	0.00E+00	8.73E+01	3.73E+01
30 days	9.78E+01	0.00E+00	1.13E+02	2.04E+01
.5 years	1.25E+01	3.38E+00	2.43E+01	3.19E+00
1 years	4.92E+01	5.81E+00	5.77E+01	5.72E+00
50 years	2.34E-03	2.03E-04	9.63E-02	3.90E-04

1st July

Time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	1.37E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	8.10E+01	0.00E+00
30 days	1.01E+01	0.00E+00	0.00E+00	1.84E+01	2.25E+01
.5 years	1.34E+01	6.87E+01	6.41E+01	5.69E-02	2.24E+01
1 years	1.32E+01	6.80E+01	6.33E+01	5.40E-02	2.21E+01
50 years	1.26E-04	1.74E-04	1.74E-04	3.31E-04	9.47E-05

Time	beef(cow)	beef(bull)	pork	lamb	milk
7 days	5.64E+01	0.00E+00	0.00E+00	1.04E+02	4.85E+01
14 days	8.85E+01	0.00E+00	0.00E+00	1.57E+02	3.92E+01
30 days	1.11E+02	0.00E+00	0.00E+00	1.79E+02	2.09E+01
.5 years	6.52E+01	5.05E-01	7.18E+01	9.52E+01	1.27E+01
1 years	1.87E+01	5.23E-01	8.00E+01	2.61E+01	2.18E-01
50 years	2.38E-03	1.45E-04	2.07E-04	9.80E-02	3.97E-04

Table 2.12: Time-dependence of the Sr-90 activity in various foodstuffs predicted using the default model for a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm

Time	Activity concentration (Bq/kg) (fresh weight)				
	1st January				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	3.11E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	2.82E+02	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	2.23E+02	0.00E+00
.5 years	0.00E+00	0.00E+00	0.00E+00	8.27E-02	0.00E+00
1 years	1.37E-01	4.13E-01	5.42E-01	7.96E-02	2.73E-01
50 years	3.05E-03	1.20E-02	1.20E-02	1.80E-02	6.05E-03
	beef(cow)	pork	lamb	milk	
7 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
14 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
30 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
.5 years	6.42E-03	0.00E+00	9.68E-02	4.56E-02	
1 years	6.46E-03	2.34E-03	9.66E-02	4.51E-02	
50 years	1.48E-04	6.93E-05	2.13E-03	9.93E-04	
	1st May				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	2.08E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	1.23E+02	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	2.85E+01	0.00E+00
.5 years	1.41E-01	1.89E-01	4.85E-01	8.27E-01	2.78E-01
1 years	1.39E-01	1.87E-01	4.80E-01	7.96E-01	2.78E-01
50 years	3.13E-03	1.23E-02	1.23E-02	1.85E-02	6.21E-03
	beef(cow)	pork	lamb	milk	
7 days	3.93E+00	0.00E+00	2.11E+01	2.86E+01	
14 days	3.59E+00	0.00E+00	1.94E+00	2.62E+01	
30 days	1.62E+00	0.00E+00	9.24E-01	1.15E+00	
.5 years	3.07E-01	1.06E-03	2.51E-01	2.17E+00	
1 years	3.94E-01	1.07E-03	2.93E-01	2.64E+00	
50 years	1.51E-04	7.10E-05	2.19E-03	1.02E-03	
	1st July				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	2.08E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	1.23E+01	0.00E+00
30 days	6.15E-02	0.00E+00	0.00E+00	2.85E+01	9.66E-02
.5 years	1.42E-01	1.33E+01	9.46E+01	8.27E-01	2.20E-01
1 years	1.40E-01	1.31E+01	9.34E+01	7.96E-01	2.17E-01
50 years	3.17E-03	1.25E-05	1.25E-02	1.87E-02	6.29E-03
	beef(cow)	beef(bull)	lamb	milk	
7 days	5.04E+00	0.00E+00	3.89E+00	3.67E+01	
14 days	3.62E+00	0.00E+00	2.81E+00	2.64E+01	
30 days	1.63E+00	0.00E+00	1.31E+00	1.15E+01	
.5 years	1.17E+00	7.53E-02	9.24E-01	8.25E+00	
1 years	3.15E-02	7.49E-02	1.03E-01	4.95E-02	
50 years	1.53E-04	7.20E-05	2.21E-03	1.03E-03	

Table 2.13: Time-dependence of the I-131 activity in various foodstuffs predicted using the default model for a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm

Time	Activity concentration (Bq/kg) (fresh weight)				
	1st January				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	6.13E+01	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	3.04E+01	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	5.52E+00	0.00E+00
.5 years	0.00E+00	0.00E+00	0.00E+00	3.80E-08	0.00E+00
1 years	5.03E-15	3.83E-15	5.04E-15	5.02E-15	5.06E-15
50 years	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	beef(cow)	pork	lamb	milk	
7 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
14 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
30 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
.5 years	1.22E-08	0.00E+00	2.35E-08	3.07E-08	
1 years	1.63E-15	5.75E-17	3.13E-15	4.07E-15	
50 years	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	1st May				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	4.11E+01	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	1.33E+01	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	7.05E-01	0.00E+00
.5 years	3.81E-08	3.57E-07	4.51E-08	3.80E-08	3.80E-08
1 years	5.05E-15	4.74E-14	5.98E-15	5.02E-15	3.54E-14
50 years	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	beef(cow)	pork	lamb	milk	
7 days	2.18E+00	0.00E+00	2.91E+00	1.20E+01	
14 days	1.85E+00	0.00E+00	2.47E+00	6.03E+00	
30 days	3.43E-01	0.00E+00	4.59E-01	6.06E-01	
.5 years	4.48E-08	5.25E-09	6.68E-08	2.44E-07	
1 years	2.34E-14	7.11E-16	3.21E-14	3.95E-14	
50 years	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	1st July				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	4.11E+01	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	1.33E+01	0.00E+00
30 days	3.90E-01	0.00E+00	0.00E+00	7.05E-01	8.53E-01
.5 years	1.02E-06	4.76E-06	4.45E-06	3.80E-08	1.68E-06
1 years	1.36E-13	6.31E-13	5.89E-13	5.02E-15	2.23E-13
50 years	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	beef(cow)	pork	lamb	milk	
7 days	3.80E+00	0.00E+00	6.35E+00	1.56E+01	
14 days	2.22E+00	0.00E+00	4.27E+00	6.04E+00	
30 days	3.60E-01	0.00E+00	6.93E-01	6.06E-01	
.5 years	3.38E-07	7.14E-08	6.50E-07	8.48E-07	
1 years	1.77E-15	9.47E-15	3.41E-15	4.01E-15	
50 years	0.00E+00	0.00E+00	0.00E+00	0.00E+00	

Table 2.14: Integrated activity concentration of Cs-137 in various foodstuffs predicted using the default model for a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm

Integrated time	Integrated activity concentration (Bq*d/kg) (fresh weight)				
	1st January				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	1.49E+03	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	2.84E+03	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	5.63E+03	0.00E+00
.5 years	0.00E+00	0.00E+00	0.00E+00	1.30E+04	0.00E+00
1 years	3.26E+00	3.35E+00	4.10E+00	1.30E+04	2.45E+00
50 years	7.54E+01	1.01E+02	1.04E+02	1.32E+04	5.62E+01
	beef(cow)	pork	lamb	milk	
7 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
14 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
30 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
.5 years	1.37E+01	0.00E+00	6.15E+02	4.38E+00	
1 years	8.78E+01	1.62E+00	3.63E+03	1.73E+01	
50 years	1.44E+03	1.18E+02	5.91E+04	2.43E+02	
	1st May				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	1.43E+03	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	2.15E+03	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	2.86E+03	0.00E+00
.5 years	2.05E+00	4.45E+02	1.58E+01	2.99E+03	2.88E+02
1 years	5.98E+00	1.34E+03	5.18E+01	3.00E+03	8.49E+02
50 years	7.79E+01	1.91E+03	1.68E+02	3.18E+03	1.18E+03
	beef(cow)	pork	lamb	milk	
7 days	1.44E+02	0.00E+00	1.88E+02	1.80E+02	
14 days	5.38E+02	0.00E+00	6.87E+02	4.45E+02	
30 days	2.06E+03	0.00E+00	2.51E+03	9.17E+02	
.5 years	8.84E+03	8.59E+01	1.03E+04	1.56E+03	
1 years	1.66E+04	1.04E+03	2.04E+04	3.09E+03	
50 years	2.02E+04	2.23E+03	7.70E+04	3.38E+03	
	1st July				
	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	1.43E+03	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	2.15E+03	0.00E+00
30 days	1.01E+01	0.00E+00	0.00E+00	2.86E+03	2.25E+01
.5 years	2.19E+03	1.04E+04	9.01E+03	2.99E+03	3.45E+03
1 years	4.60E+03	2.27E+04	2.05E+04	3.00E+03	7.48E+03
50 years	5.06E+03	2.51E+04	2.34E+04	3.18E+03	8.20E+03
	beef(cow)	pork	lamb	milk	
7 days	2.42E+02	0.00E+00	4.54E+02	2.93E+02	
14 days	7.77E+02	0.00E+00	1.42E+03	5.97E+02	
30 days	2.56E+03	0.00E+00	4.43E+03	1.08E+03	
.5 years	1.20E+04	4.99E+03	1.82E+04	2.40E+03	
1 years	2.32E+04	1.93E+04	3.35E+04	4.01E+03	
50 years	2.53E+04	2.94E+04	8.90E+04	4.24E+03	

Table 2.15: Integrated activity concentration of Sr-90 in various foodstuffs predicted using the default model for a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm

Integrated time — Integrated activity concentration (Bq*d/kg) (fresh weight)

1st January

Integrated time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	2.27E+03	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	4.33E+03	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	8.35E+03	0.00E+00
.5 years	0.00E+00	0.00E+00	0.00E+00	1.96E+04	0.00E+00
1 years	2.13E+01	6.27E+01	7.68E+01	2.00E+04	4.24E+01
50 years	6.48E+02	2.51E+03	2.55E+03	2.37E+04	1.28E+03

Integrated time	beef(cow)	pork	lamb	milk
7 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
.5 years	3.87E-01	0.00E+00	5.76E+02	2.78E+00
1 years	1.57E+00	2.42E-01	2.36E+01	1.11E+01
50 years	3.16E+01	1.43E+01	4.58E+02	2.14E+02

1st May

Integrated time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	2.17E+03	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	3.26E+03	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	4.35E+03	0.00E+00
.5 years	1.32E+01	1.69E+01	3.84E+01	4.66E+03	2.61E+01
1 years	3.85E+01	5.09E+01	1.26E+02	4.81E+03	7.66E+01
50 years	6.64E+02	2.48E+03	2.59E+03	8.48E+03	1.31E+03

Integrated time	beef(cow)	pork	lamb	milk
7 days	2.44E+01	0.00E+00	1.31E+01	1.77E+02
14 days	5.18E+01	0.00E+00	2.78E+01	3.77E+02
30 days	9.29E+01	0.00E+00	5.05E+01	6.74E+02
.5 years	1.31E+02	4.44E-02	8.49E+01	9.20E+02
1 years	2.57E+02	2.37E-01	1.67E+02	1.80E+03
50 years	2.96E+02	1.41E+01	6.03E+02	2.02E+03

1st July

Integrated time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	2.17E+03	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	3.26E+03	0.00E+00
30 days	6.15E-02	0.00E+00	0.00E+00	4.35E+03	9.66E-02
.5 years	2.03E+01	2.00E+03	1.33E+03	4.66E+03	3.39E+03
1 years	4.58E+01	4.39E+03	3.03E+03	4.81E+03	7.34E+01
50 years	6.53E+02	7.22E+03	5.81E+03	8.38E+03	1.27E+03

Integrated time	beef(cow)	pork	lamb	milk
7 days	3.85E+01	0.00E+00	2.97E+01	2.80E+02
14 days	6.78E+01	0.00E+00	5.23E+01	4.94E+02
30 days	1.09E+02	0.00E+00	8.49E+01	7.91E+02
.5 years	2.15E+02	7.71E+00	1.76E+02	1.52E+03
1 years	3.60E+02	2.13E+01	2.95E+02	2.52E+03
50 years	3.98E+02	4.10E+01	7.17E+02	2.72E+03

Table 2.16: Integrated activity concentration of I-131 in various foodstuffs predicted using the default model for a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm

Integrated time | Integrated activity concentration (Bq*d/kg) (fresh weight)

1st January

Integrated time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	5.92E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	8.85E+02	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	1.12E+03	0.00E+00
.5 years	0.00E+00	0.00E+00	0.00E+00	1.17E+03	0.00E+00
1 years	3.73E-08	2.01E-08	1.11E-08	1.17E+03	3.73E-08
50 years	3.73E-08	2.01E-08	1.11E-08	1.17E+03	3.73E-08

Integrated time	beef(cow)	pork	lamb	milk
7 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	0.00E+00
.5 years	1.84E-05	0.00E+00	3.54E-05	8.18E-05
1 years	1.86E-05	3.03E-12	3.57E-12	8.22E-05
50 years	1.86E-05	3.03E-12	3.57E-12	8.22E-05

1st May

Integrated time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	6.09E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	7.69E+02	0.00E+00
30 days	0.00E+00	0.00E+00	0.00E+00	8.37E+02	0.00E+00
.5 years	1.21E-03	8.02E-03	4.26E-04	8.40E+02	1.19E-02
1 years	1.21E-03	8.02E-03	4.26E-04	8.40E+02	1.19E-02
50 years	1.21E-03	8.02E-03	4.26E-04	8.40E+02	1.19E-02

Integrated time	beef(cow)	pork	lamb	milk
7 days	1.11E+01	0.00E+00	1.48E+01	9.21E+01
14 days	2.58E+01	0.00E+00	3.44E+01	1.53E+02
30 days	4.13E+01	0.00E+00	5.52E+01	1.90E+02
.5 years	4.39E+01	1.16E-06	5.87E+01	1.94E+02
1 years	4.39E+01	1.21E-06	5.87E+01	1.94E+02
50 years	4.39E+01	1.21E-06	5.87E+01	1.94E+02

1st July

Integrated time	potatoes	winter wheat	spring wheat	leafy vegetables	root vegetables
7 days	0.00E+00	0.00E+00	0.00E+00	6.09E+02	0.00E+00
14 days	0.00E+00	0.00E+00	0.00E+00	7.69E+02	0.00E+00
30 days	3.90E-01	0.00E+00	0.00E+00	8.37E+02	8.53E-01
.5 years	6.14E+00	2.09E+01	8.24E+00	8.40E+02	1.03E+01
1 years	6.14E+00	2.09E+01	8.24E+00	8.40E+02	1.03E+01
50 years	6.14E+00	2.09E+01	8.24E+00	8.40E+02	1.03E+01

Integrated time	beef(cow)	pork	lamb	milk
7 days	1.88E+01	0.00E+00	3.61E+01	1.50E+02
14 days	3.81E+01	0.00E+00	7.33E+01	2.16E+02
30 days	5.54E+01	0.00E+00	1.07E+02	2.53E+02
.5 years	5.81E+01	3.16E-03	1.12E+02	2.57E+02
1 years	5.81E+01	3.16E-03	1.12E+02	2.57E+02
50 years	5.81E+01	3.16E-03	1.12E+02	2.57E+02

2.2.3 The effect of the type of deposition on the predicted concentrations

The results presented in Tables 2.11 to 2.16 were calculated using ECOSYS and were for a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm. As discussed in section 2.2.1 the initial contamination of the plants is strongly dependent on the characteristics of the deposition. In order to illustrate this effect, results are given in Tables 2.17 to 2.19 for equivalent total deposits which lead to the same initial contamination of the plant as 1000 Bq/m^2 during a rainfall of 3 mm in ECOSYS. For rainfall below 3 mm, the wet deposited activity leading to the same initial contamination is lower than 1000 Bq/m^2, for those above 3 mm it is higher than 1000 Bq/m^2 as rainfall and interception are inversely proportional. In these tables, the air concentration which leads to the same initial contamination as the wet deposition scenarios is also given. For comparison purposes the equivalent input for FARMLAND is given which results in the same initial contamination as the other deposition scenarios. It should be noted that the contamination of the soil which is relevant for root uptake is different for the different deposition patterns.

It is seen from these tables that using the default interception factor in FARMLAND and the default parameters corresponding to 3 mm rainfall in ECOSYS gives similar results for caesium. However, for iodine and strontium it may be more appropriate to assume 2 and 6 mm total rainfalls for iodine and strontium, respectively as the defaults.

Table 2.17: Equivalent deposition scenarios which lead to the same initial contamination of plants as a deposition of 1000 Bq/m^2 Cs-137 during a rainfall of 3 mm for a deposition on 1st May and 1st July

1st May

Deposition scenario	Pasture	Leafy vegetables	Winter wheat	Spring wheat	Root vegetables	Potatoes
wet, 0.5 mm 1)	370	470	380	380	-	-
wet, 1 mm	470	560	520	520	-	-
wet, 2 mm	710	760	710	710	-	-
wet, 3 mm	1000	1000	1000	1000	-	-
wet, 5 mm	1600	1600	1600	1600	-	-
wet,10 mm	3300	3000	3300	3300	-	-
dry,equivalent air concentr. ECOSYS (Bqh/m^3)2)	84	63	63	63	-	-
equivalent input to FARMLAND Bq/m^2)3)	1170	1500	500	300	-	-

1) a deposition of 370 Bq/ m^2 during a rainfall of 0.5 mm gives the same initial contamination of pasture grass as a deposition of 1000 Bq/ m^2 during a rainfall of 3 mm

2) an integrated air concentration of 84 Bqh/ m^3 gives the same initial contamination of pasture grass as a wet deposition of 1000 Bq/ m^2 during a rainfall of 3 mm

3) a total deposition of 1170 Bq/ m^2 as input for FARMLAND gives the same initial contamination of pasture grass as a wet deposition of 1000 Bq/ m^2 during a rainfall of 3 mm in ECOSYS

1st July

Deposition scenario	Pasture	Leafy vegetables	Winter wheat	Spring wheat	Root vegetables	Potatoes
wet, 0.5 mm	370	470	370	370	470	470
wet, 1 mm	470	560	510	510	560	560
wet, 2 mm	710	760	720	720	760	760
wet, 3 mm	1000	1000	1000	1000	1000	1000
wet, 5 mm	1600	1600	1600	1600	1600	1600
wet,10 mm	3200	3300	3300	3300	3000	3000
dry,equivalent air concentr. ECOSYS (Bqh/ m^3	84	63	68	63	63	50
equivalent input to FARMLAND Bq/ m^2	1170	1500	1100	1080	1500	1200

Table 2.18: Equivalent deposition scenarios which lead to the same initial contamination of plants as a wet deposition of 1000 Bq/m^2 Sr-90 during a rainfall of 3 mm

1st May

Deposition scenario	Pasture	Leafy vegetables	Winter wheat	Spring wheat	Root vegetables	Potatoes
wet, 0.5 mm	600	690	540	540	-	-
wet, 1 mm	630	720	430	630	-	-
wet, 2 mm	800	850	810	810	-	-
wet, 3 mm	1000	1000	1000	1000	-	-
wet, 5 mm	1500	1400	1500	1500	-	-
wet,10 mm	2700	2400	2800	2800	-	-
dry,equivalent air concentr. ECOSYS (Bqh/ m^3)	140	96	110	110	-	-
equivalent input to FARMLAND Bq/ m^2	2000	2300	830	510	-	-

1st July

Deposition scenario	Pasture	Leafy vegetables	Winter wheat	Spring wheat	Root vegetables	Potatoes
wet, 0.5 mm	600	690	550	550	690	690
wet, 1 mm	630	720	630	630	720	720
wet, 2 mm	800	850	800	800	850	850
wet, 3 mm	1000	1000	1000	1000	1000	1000
wet, 5 mm	1500	1400	1500	1500	1400	1400
wet,10 mm	2700	2400	2700	2700	2400	2400
dry,equivalent air concentr. ECOSYS (Bqh/m^3)	140	96	110	110	96	77
equivalent input to FARMLAND Bq/ m^2	2000	2300	1700	1800	2300	1800

Table 2.19: Equivalent deposition scenarios which lead to the same initial contamination of plants as a wet deposition of 1000 Bq/m^2 I-131 during a rainfall of 3 mm

1st May

Deposition scenario	Pasture	Leafy vegetables	Winter wheat	Spring wheat	Root vegetables	Potatoes
wet, 0.5 mm	240	300	250	250	-	-
wet, 1 mm	370	410	360	360	-	-
wet, 2 mm	660	670	690	690	-	-
wet, 3 mm	1000	1000	1000	1000	-	-
wet, 5 mm	1600	1600	1700	1700	-	-
wet,10 mm	3300	3200	3300	3300	-	-
dry,equivalent air concentr. ECOSYS (Bqh/m^3)	43	33	60	33	-	-
equivalent input to FARMLAND Bq/m^2	600	800	470	160	-	-

1st July

Deposition scenario	Pasture	Leafy vegetables	Winter wheat	Spring wheat	Root vegetables	Potatoes
wet, 0.5 mm	240	300	250	250	300	300
wet, 1 mm	370	410	370	370	410	410
wet, 2 mm	660	670	670	670	670	670
wet, 3 mm	1000	1000	1000	1000	1000	1000
wet, 5 mm	1600	1600	1700	1700	1600	1600
wet,10 mm	3300	3200	3300	3300	3200	3300
dry,equivalent air concentr. ECOSYS (Bqh/m^3)	43	33	33	32	33	27
equivalent input to FARMLAND Bq/m^2	600	800	530	560	800	640

2.3 GROWTH CONDITIONS WITHIN THE COUNTRIES OF THE EC

Within the countries of the EC the conditions relating to plant growth change considerably due to the different climates. The most important factors are the temperature together with the precipitation and its distribution during the year. According to Schnelle (1970) the countries of the European Community can be divided into four regions (see Figure 2.3). Northwest Europe, made up of the U.K., Ireland, Belgium, the Netherlands, and the northwest of France (region 1) has a rather uniform distribution of rainfall during the year. Winters are mild and summers are relatively cool, the difference between the average temperatures of the warmest and coldest month of the year is about 10 to 15°C (Heyer, 1981) due to the influence of the Gulf Stream. This enables a very early start of growth of plants in spring, which ends very late in autumn. In the regions near the coast, plant growth does not stop during the winter.

In Central Europe including the Federal Republic of Germany (region 2) the climate is similar, but the difference between summer and winter is more pronounced. The difference between the average temperature of the warmest and the coldest month is about 20°C. Therefore, the period for plant growth is shorter in region 2 compared with region 1. In normal years the growth stops totally during the winter due to the low temperatures. In region 2, the rainfall is also more or less uniformly distributed during the year, but higher temperatures in summer lead to a higher evaporation which may result in some years in temporary water deficits during the summer. This particularly influences the date of harvest of cereals which is earlier in region 2 compared with region 1.

Region 3 which includes the north of Spain, and the middle and the west of France is characterized by mild winters. The average temperature of the coldest month is about 5°C and the growth does not stop during the winter. The average temperature of the warmest month is typically around 20°C. The maximum amount of rain falls during the winter months, whereas in summer the minimum amount of rainfall occurs. The evaporation during the summer months typically exceeds the precipitation, resulting in relatively early dates of harvest of cereals.

The south of Europe with Portugal, south Spain, Italy, south France and Greece (region 4) is similar to region 3, but the temperatures in winter and summer are up to 5°C higher and the water deficit in summer is more pronounced.

Table 2.20 shows the times of sowing and harvesting of cereals and potatoes for the four regions considered. From region 1 to 4 the sowing and harvest starts progressively earlier. Due to the dependence of translocation on the stage of development of the crop, similar deposition patterns at different locations at a particular time of year, may result in rather different activity concentrations in grain.

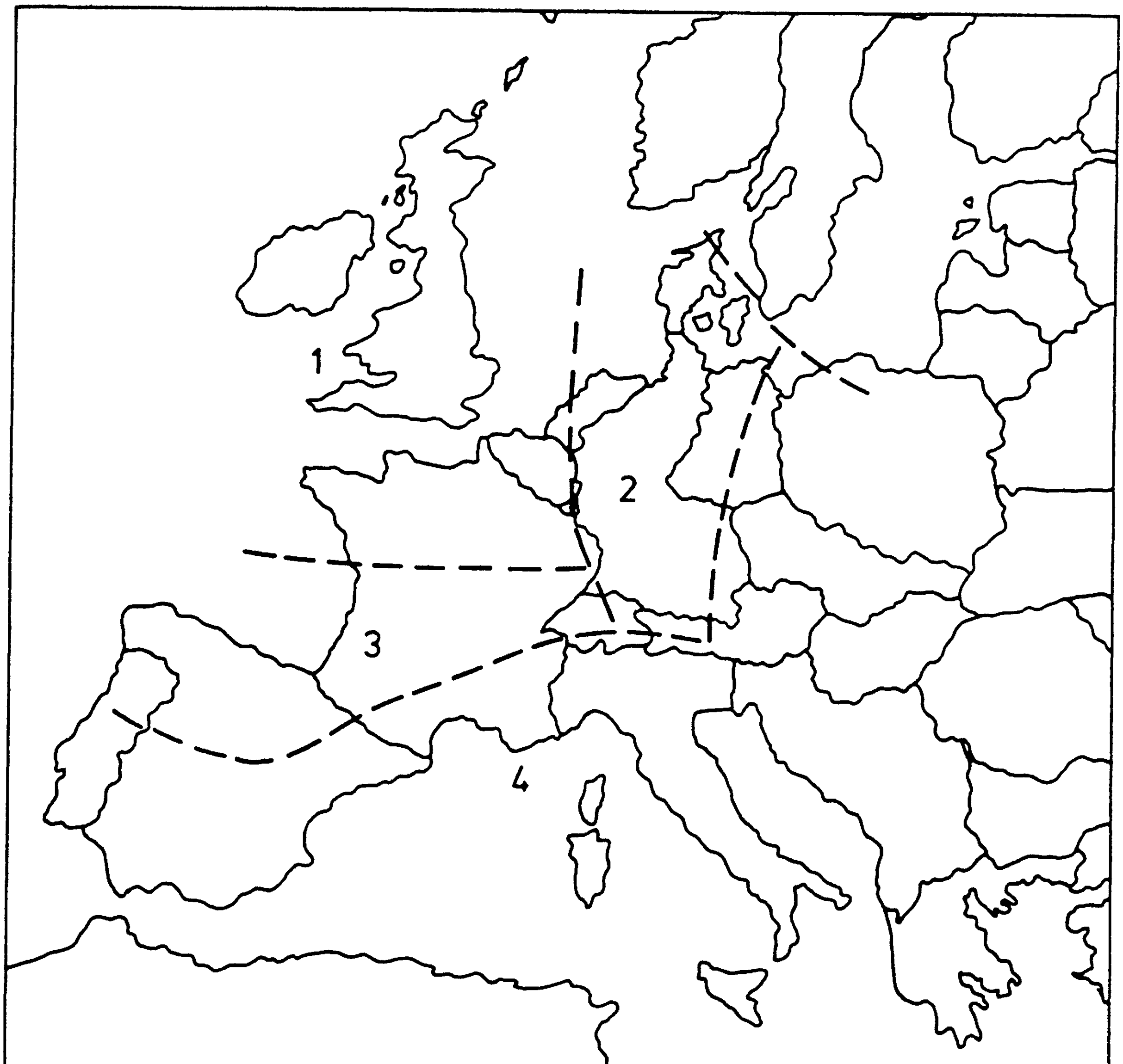


Figure 2.3: Map showing the four regions chosen to represent variations in farming practices.

For potatoes the situation is more complicated. The length of the growing period is very dependent on the variety, ranging from 2 to 7 months. Within the countries of the European Community potatoes are harvested all through the year, but harvesting between December to April is restricted to the most southern parts of Spain, Italy including Sicily, and Greece including Crete. The overall area under cultivation for harvest in winter and early spring is relatively small compared with the total potato production. In other parts of Europe, potatoes are planted between February and June and harvested from June to November. The main harvest is from August to October.

Table 2.20: Dates of sowing and harvesting in Europe

Plant	Region 1	2	3	4
Spring cereals				
- sowing	1.3.	1.4	15.2.	15.2.
- harvesting	15.8.	10.8	15.7.	30.6.
Winter cereals				
- sowing	1.11.	20.10.	10.11.	10.11.
- ear emergence	10.6.	15.6.	30.5.	15.5.
- harvest	15.8.	10.8.	20.7.	30.6.
Pasture				
- start of grazing	20.4.	1.5.	10.4.*	1.4.*
- end of grazing	31.10.	20.10.	10.11.*	10.11.*
Potatoes				
- planting	Feb-Apr	Mar-May	Feb-Jun	Feb/Sep
- harvesting	Jun-Nov	Jun-Oct	May-Nov	Apr-Jun Nov-Jan**

Notes:

* The dates for the beginning and end of grazing in Regions 3 and 4 are particularly variable.

** In the extreme south of Europe (e.g., Crete, Malta, Sicily) there may be a second growing period for potatoes with planting in September and harvesting from November to January.

Concerning the grazing period, it should be noted that in the southern part of Europe, especially in region 4, the growth of grass decreases dramatically during the summer due to the lack of water. Intensive grazing can only be continued during the summer if irrigation water is applied. Therefore, no general estimation of the radionuclide transfer through the pasture-cow-milk pathway is possible. On the other hand, in southern Europe goats and sheep are used for milk production and they are often kept on extensively used areas. In summer, when the grass has died back due to the water deficit, these animals also eat leaves of trees and bushes, which again makes the prediction of the transfer of activity to milk very difficult.

Finally, it should be noted that the growing periods given in Table 2.20 can vary from year to year due to the actual weather conditions. Furthermore, increasing altitude delays the start of growth in spring and brings forward the end of growth in autumn. However, mountain regions are not normally important for food production.

2.4 THE VARIATION IN THE PREDICTED RADIONUCLIDE CONCENTRATIONS IN FOOD ACROSS THE EC DUE TO DIFFERENT FARMING PRACTICES

As discussed in the previous section there are significant variations in the farming practices adopted in different regions of the EC. The effect of this variation on predicted radionuclide concentrations in food was determined. Continuing on from the review discussed in Section 2.3 of this chapter, the EC was divided into four regions as shown in Figure 2.4. For each region concentrations in food were calculated using the 'default' foodchain model described in section 2.2, with the appropriate farming practice for each region. Results were obtained for a variety of crops (winter and spring grain, potatoes and leafy vegetables) and for milk, beef and sheep meat. The radionuclides considered were strontium-90, caesium-137 and iodine-131, with deposition occurring at three times of year (1 January, 1 May and 1 July). The variation in concentration with time was determined together with the time-integrated concentrations in each food. The latter results enabled the effect of the different farming practices on the intake of activity by man to be seen. Often what appeared to be large variations in concentrations as a function of time have little effect on the total integrated concentration, and hence intake.

The results obtained in this study are discussed in two sections, the first on foods derived from grazing animals and the second on crops.

2.4.1 Foods derived from grazing animals

The important variations between the various regions of the EC for cattle and sheep are due to the length of time animals are grazing outdoors on pasture and the period over which winter fodder is grown and harvested. Details of the times assumed for each of these aspects are given in Table 2.21. Also in region 2 grass dies right back during the winter months and so if deposition occurs during this time it is almost entirely to the soil. In the other regions it is assumed that the grass does not die in the winter, although it grows more slowly which affects the weathering of activity from its surface.

Table 2.22 gives the predicted concentrations in winter fodder, assumed to be hay or silage, at the time when the animals go indoors for each of the three times of deposition considered. For deposition in January there was very little difference between the four regions because contamination of the crop was due primarily to root uptake and soil contamination in all regions.

Table 2.21: Farming practices assumed for regions of the EC for cattle and sheep

Outdoor grazing periods for cattle and sheep

Region(1)	Animals go outdoors(2)	Animals go indoors(3)
1	20 April	31 Oct
2	1 May	20 Nov
3	10 April	10 Nov
4	1 April	10 Nov

Growth and harvesting for silage/hay for winter fodder

Region	Growing period in year of harvest	Harvesting period	Days stored before start of consumption
1	1 May - 15 Sept	1 May - 15 Sept	45
2	1 May - 15 Sept	1 May - 15 Sept	65
3	1 May - 15 June	1 May - 15 June	150
4	1 May - 15 June	1 May - 15 June	150

Notes:

1. Regions 1 - 4 are shown in Figure 2.3.
2. Whilst outdoors it is assumed that cattle and sheep graze pasture grass.
3. Whilst indoors it is assumed that cattle and sheep eat silage/hay.

Table 2.22: Activity concentrations in silage/hay when animals go indoors for each region(1)

a) Deposition on 1 January

	Activity Concentration (Bq/kg dry weight per 1000 Bq/ m^2)		
Region	Sr-90	Cs-137	I-131
1	51	6	0
2	51	6	0
3	48	6	0
4	48	6	0

b) Deposition on 1 May

	Activity Concentration (Bq/kg dry weight per 1000 Bq/ m^2)		
Region	Sr-90	Cs-137	I-131
1	260	220	2.8E-05
2	260	220	4.6E-06
3	480	440	2.4E-05
4	480	440	2.4E-05

c) Deposition on 1 July

	Activity Concentration (Bq/kg dry weight per 1000 Bq/ m^2)		
Region	Sr-90	Cs-137	I-131
1	240	220	5.3E-03
2	240	220	8.7E-04
3	0	0	0
4	0	0	0

Notes:

1. The regions are as defined in Figure 2.3.

For deposition in May and July the silage concentrations were similar for regions 1 and 2, the difference for iodine-131 being due to the length of time the fodder is stored before the start of consumption. For regions 3 and 4 deposition on 1 July occurs after the fodder has been harvested and, therefore, the predicted contamination was zero. The fodder fed to cattle during the winter whilst indoors in Mediterranean countries is from crops such as clover and lucerne. Although these may be different to grass in their uptake of radionuclides it is thought that the modelling of grass as a fodder crop will give a reasonable estimate of the likely contamination of these crops.

Figures 2.4 to 2.7 give some examples of the variation of activity concentration in milk and meat with time across the different regions for deposition at different times of the year. As can be seen from the Figures, there were, in general, only small differences between the concentrations in the different regions. These were mainly due to the different times at which the animals graze pasture and the differences in winter fodder concentrations. These small differences are reflected in the time-integrated concentrations given for milk and beef in Table 2.23.

There were two cases where very different concentrations were seen in the regions considered. These were for deposition on 1 January in region 2 and for deposition on 1 July in regions 3 and 4. The predicted concentrations in region 2 following deposition on 1 January were lower when the animals go out to graze in April because the only contamination of the grass was due to soil related pathways, as there is little grass at the time of deposition as discussed above. The effect on the integrated concentrations when compared with region 1, which is otherwise similar, was about a factor of 4 for caesium-137 and a factor of 2 for strontium-90, the concentrations in region 2 being lower. This also has implications for comparison with an intervention level, as the steep peak in concentration seen after the cows go out to pasture in the other regions whould not be seen for region 2.

The other major difference seen was in regions 3 and 4 for deposition in July, and occurs when the animals go indoors for the winter in the first year after deposition. The contamination of the winter fodder was predicted to be zero because it was harvested before deposition occurred and there was, therefore, no additional contribution to the concentrations in animal products other than that from grazing grass outdoors. The concentrations therefore dropped off rapidly as activity cleared from the animals and then rose again when the animals returned to pasture the next spring. The effect on the integrated concentrations can be seen in Table 2.23, the values for regions 3 and 4 about a factor of 2 - 3 lower than those seen in regions 1 and 2. No effect was seen for iodine-131 because the activity has decayed before the animals go indoors.

For an accident in January there were some small differences between the results for the different regions in the size of the peak concentration in milk and beef after the animals went outdoors. It could be argued that this could be important if the concentrations were near a banning criterion for that food. Some caution is needed here, however, as the variation between peak concentrations needs to be considered along with the accuracy of the foodchain models in predicting the concentrations and the former may be less than the latter.

The variation in concentration in sheep meat was found to be very similar to that seen in beef and so is not discussed here.

Table 2.23: Time-integrated concentrations in milk and beef for regions of the EC

a) Results for strontium-90

1 January		Time-integrated activity concentrations Bq y/kg per 1000 Bq/ m^2					
	Region	milk			beef		
		1y	2y	5y	1y	2y	5y
	1	4.7 E-01	1.1	2.0	1.0 E-01	2.3 E-01	4.2 E-01
	2	3.2 E-01	8.5 E-01	1.6	6.6 E-02	1.8 E-01	3.5 E-01
	3	5.8 E-01	1.1	2.0	1.2 E-01	2.4 E-01	4.2 E-01
	4	6.3 E-01	1.2	2.0	1.3 E-01	2.6 E-01	4.4 E-01
1 May	Region						
	1	2.6	3.7	4.6	5.6E-01	7.9E-01	9.9E-01
	2	2.5	3.2	4.5	5.3E-01	6.8E-01	9.7E-01
	3	3.5	4.9	5.8	7.5E-01	1.0	1.2
	4	3.4	4.7	5.6	7.3E-01	1.0	1.2
1 July	Region						
	1	2.6	3.5	4.4	5.5E-01	7.5E-01	9.5E-01
	2	2.5	3.4	4.4	5.4E-01	7.3E-01	9.3E-01
	3	1.3	1.8	2.7	2.7E-01	3.9E-01	5.9E-01
	4	1.3	1.8	2.8	2.7E-01	3.9E-01	5.9E-01

b) Results for caesium-137

1 January		Time-integrated activity concentrations Bq y/kg per 1000 Bq/ m^2					
	Region	milk			beef		
		1y	2y	5y	1y	2y	5y
	1	1.3	1.7	1.9	6.7	8.5	9.5
	2	2.3E-01	5.0E-01	6.3E-01	1.0	2.5	3.1
	3	1.6	1.9	2.0	7.8	9.4	1.0E+01
	4	1.8	2.1	2.2	8.8	1.0E+01	1.1E+01
1 May	Region						
	1	1.3E+01	1.4E+01	1.4E+01	6.0E+01	6.9E+01	7.0E+01
	2	1.2E+01	1.3E+01	1.3E+01	5.5E+01	6.2E+01	6.8E+01
	3	1.9E+01	2.0E+01	2.0E+01	8.7E+01	1.0E+02	1.0E+02
	4	1.8E+01	1.9E+01	1.9E+01	8.5E+01	9.7E+01	9.8E+01
1 July	Region						
	1	1.3E+01	1.3E+01	1.4E+01	6.5E+01	6.9E+01	7.0E+01
	2	1.3E+01	1.3E+01	1.3E+01	6.2E+01	6.6E+01	6.7E+01
	3	5.4	5.6	5.8	2.7E+01	2.8E+01	2.9E+01
	4	5.4	5.6	5.8	2.7E+01	2.9E+01	2.9E+01

Table 2.23 (continued)

c) Results for iodine-131

<u>1 May</u>	Time-integrated activity concentrations Bq y/kg per 1000 Bq/m^2					
Region	milk			beef		
	1y	2y	5y	1y	2y	5y
1	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01
2	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01
3	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01
4	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01
<u>1 July</u>						
Region						
1	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01
2	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01
3	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01
4	1.9	1.9	1.9	8.2E-01	8.2E-01	8.2E-01

Figure 2.4: Activity concentrations of strontium-90 in milk following deposition on 1 January in regions of the EC.

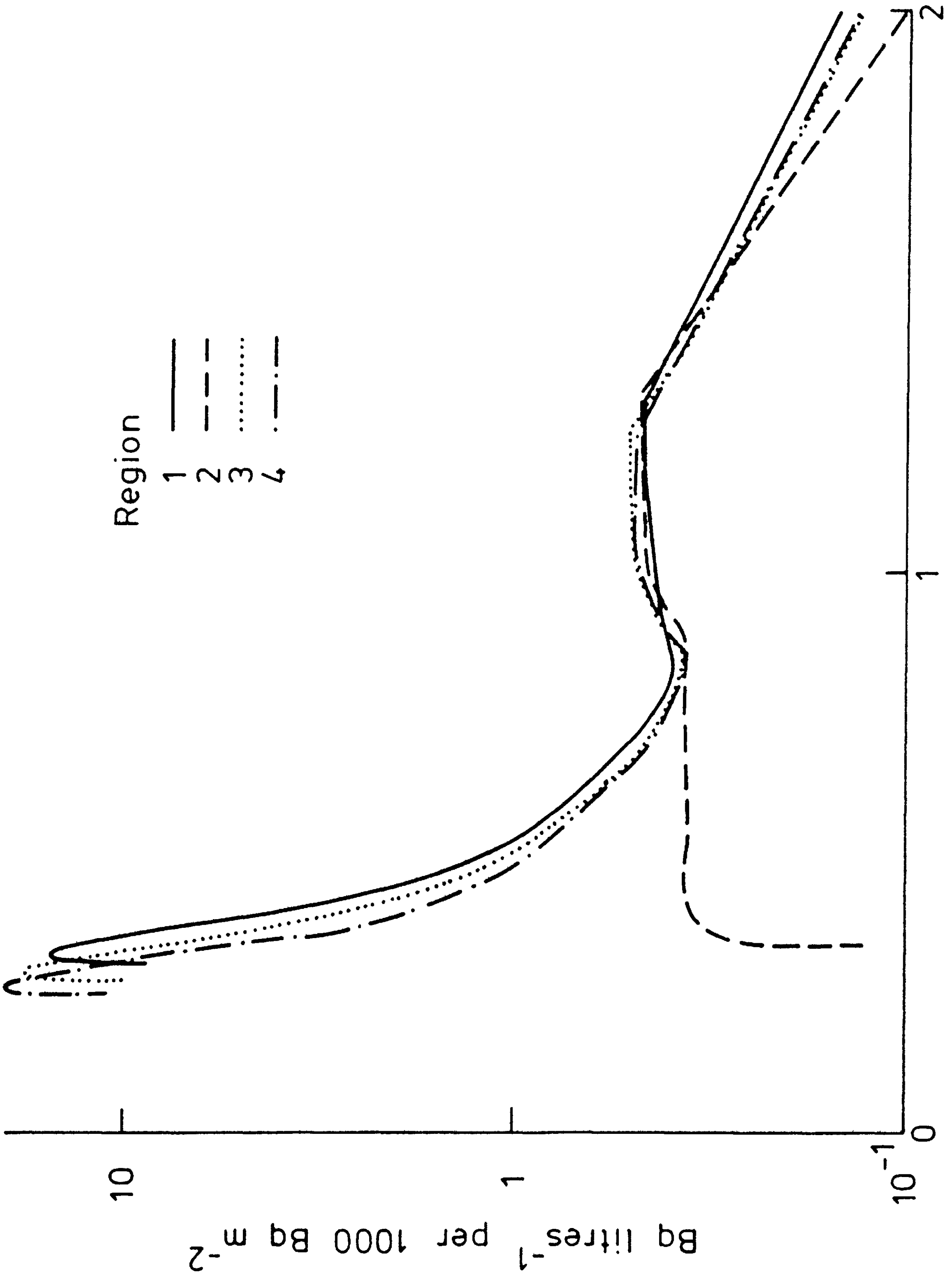


Figure 2.5: Activity concentrations of caesium-137 in milk following deposition on 1 May in regions of the EC.

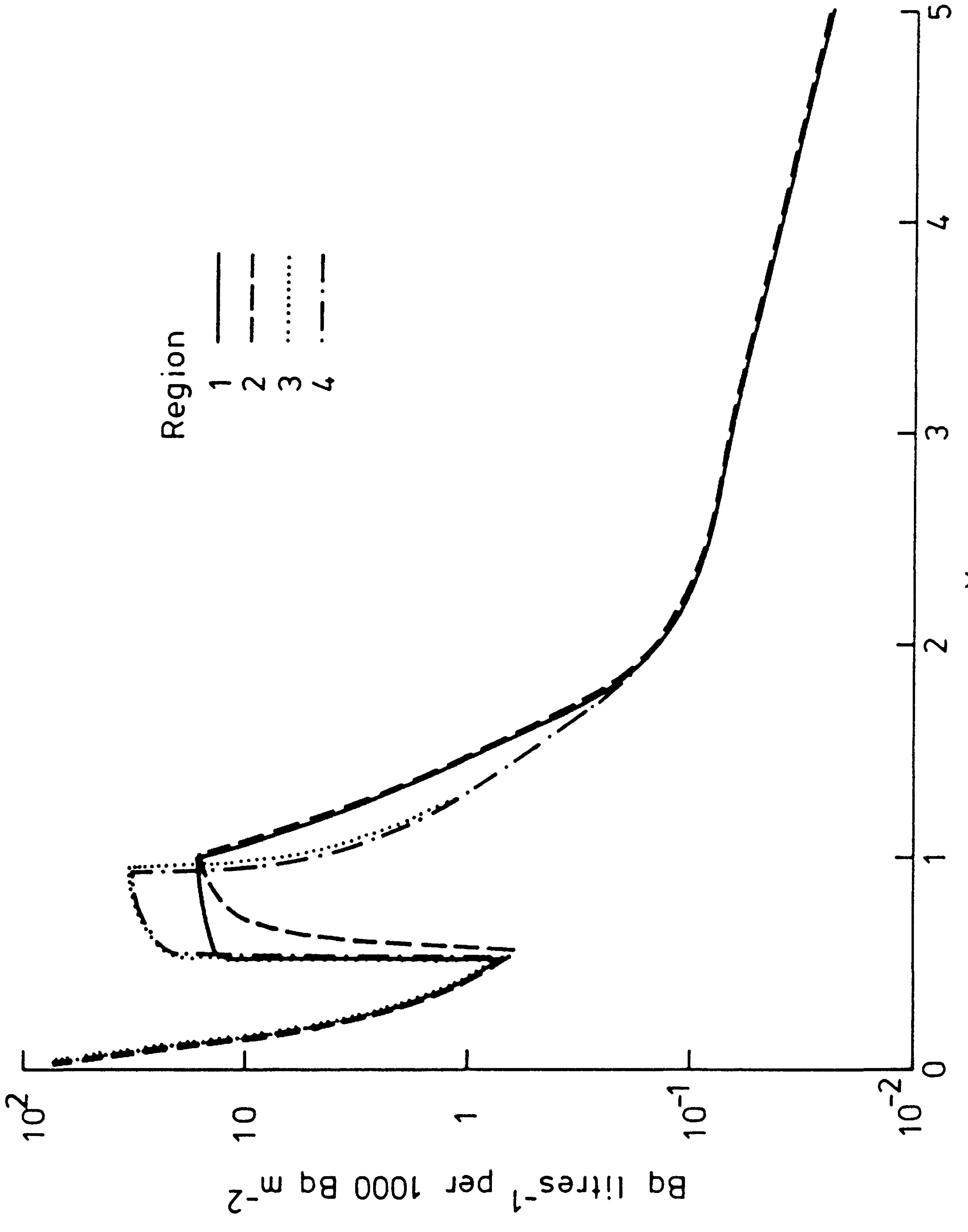


Figure 2.6: Activity concentrations of caesium-137 in milk following deposition on 1 July in regions of the EC.

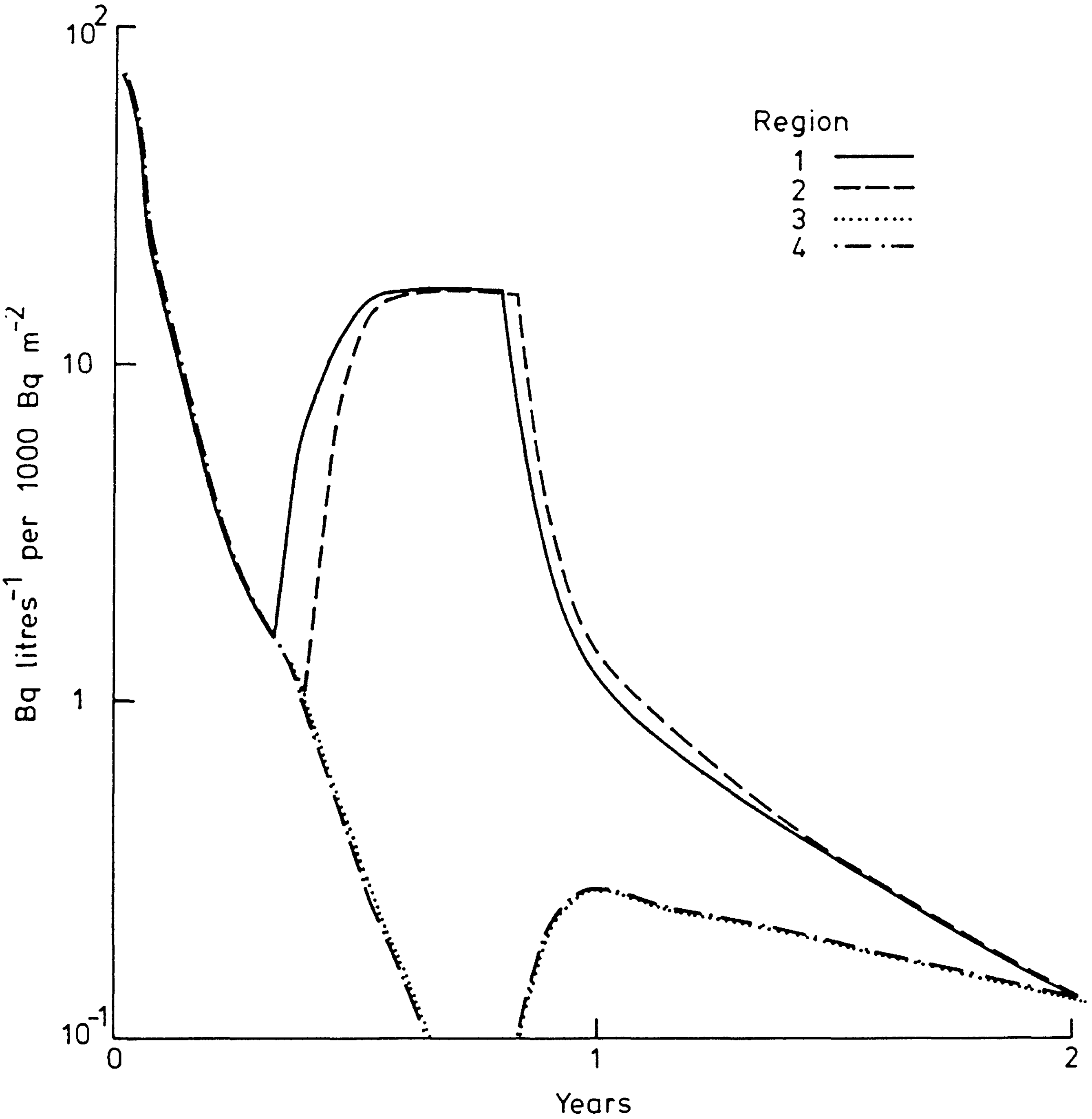
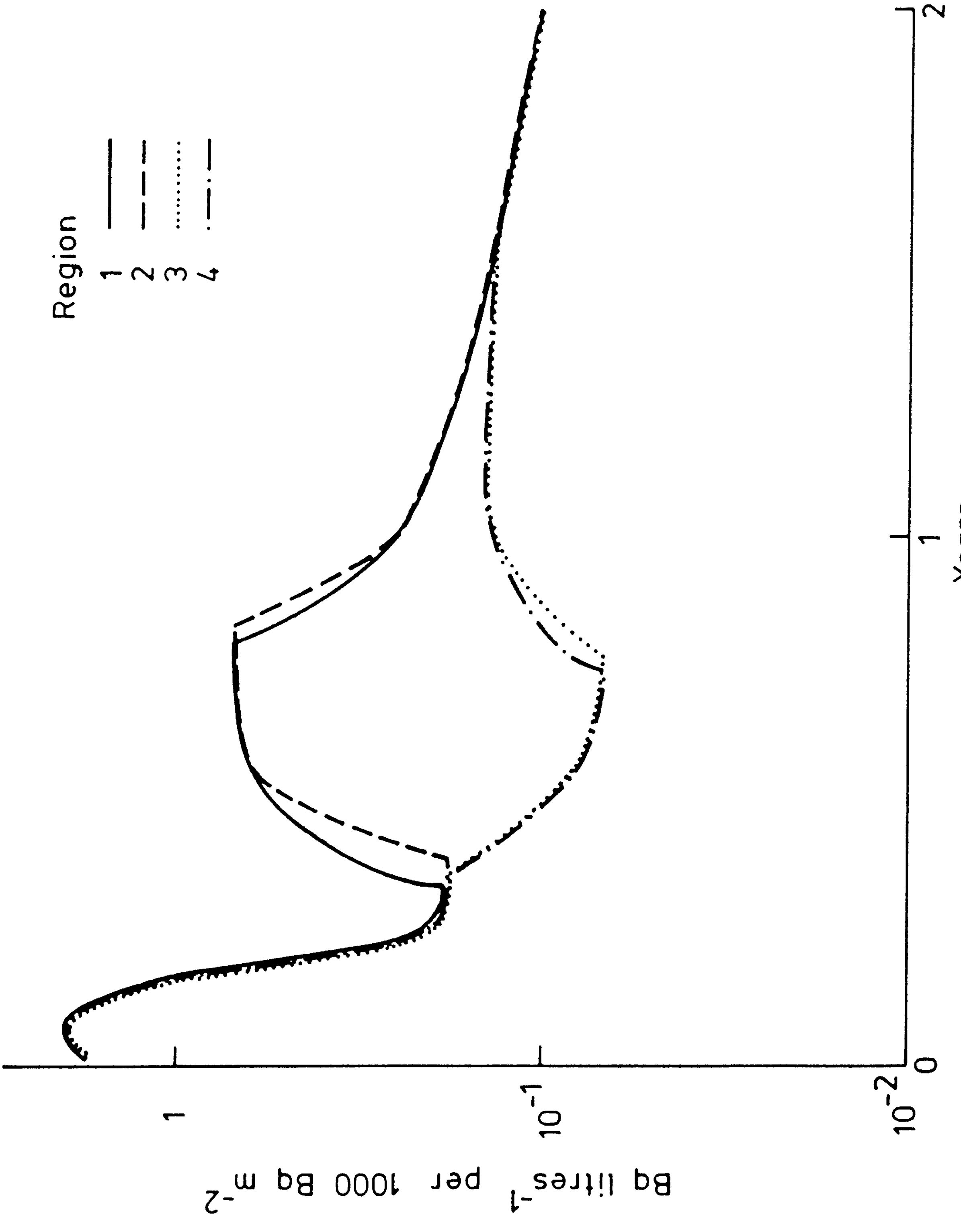


Figure 2.7: Activity concentrations of strontium-90 in beef following deposition on 1 July in regions of the EC.



2.4.2 Crops

The influence of growth conditions on concentrations of activity in crops has been evaluated by calculating concentrations of caesium-137, strontium-90 and iodine-131 following deposition at 3 times of the year in the four regions of the EC. The results of the calculations are given in the Tables 2.24 to 2.26 for winter and spring grain, potatoes and leafy vegetables.

For these calculations, again a wet deposition of 1000 Bq/m^2 during a precipitation of 3 mm is assumed.

After deposition on 1 May, the highest caesium-137 activities in cereals can be expected in the southern parts of Europe. The plants are already more or less fully developed, therefore the interception is high and the translocation is considerable, whereas in the north the growth - especially for spring grain - is just starting.

The situation is quite different after deposition on 1 July. In the very south the wheat is already harvested, so is not contaminated. In the other southern parts the interception is relatively low due to the decreasing leaf area and the translocation is reduced due to the decreasing metabolic activity.

In general, the strontium activity in grain is higher the shorter the period between deposition and harvest. Therefore, the Sr-90 activity is always highest in the southern parts of Europe due to the early times of harvest. An exception is deposition on 1 July, when the wheat is already harvested.

For potatoes, the situation is similar. After deposition in May the crop development is most advanced in the south, therefore the activities are highest. In July, in all countries the contamination is quite similar. It should be noted that there are numerous varieties of potatoes, with different requirements for their optimal growth and this may lead to considerably different activity concentrations in some cases than those given here for mean conditions.

Table 2.24: Cs-137 and Sr-90 activity in winter wheat, spring wheat and potatoes in the four different regions in the first year after deposition on 1 May and 1 July (deposition: 1000 Bq/m^2 during a precipitation of 3 mm)

Nuclide	Deposit	Region	Activity concentration (Bq y/kg per 1000 Bq/ m^2)		
			winter wheat	spring wheat	potatoes
Cs-137	1st May	1	6.0	0.36	4.7
		2	4.1	0.03	0.22
		3	26	24	8.9
		4	61	50	15
Cs-137	1st July	1	75	65	18
		2	73	63	18
		3	41	26	18
		4	0	0	10
Sr-90	1st May	1	0.57	0.57	0.14
		2	0.57	0.57	0.14
		3	0.91	1.3	0.14
		4	2.7	2.4	0.14
Sr-90	1st July	1	11	9.5	0.14
		2	12	11	0.14
		3	22	19	0.14
		4	0	0	0.14

Table 2.25: Cs-137, Sr-90 and I-131 activity in leafy vegetables in all four regions of Europe after deposition on 1st January (deposition: 1000 Bq/m^2 during a precipitation of 3 mm)

Time after deposition	Activity concentration (Bq y/kg per 1000 Bq/m^2) Cs-137	Sr-90	I-131
7d	200	310	61
14d	190	280	30
30d	150	220	5.5
0.5y	0.057	0.83	0
1y	0.054	0.80	0
50y	3.2E-4	0.018	0

Tab. 2.26: Cs-137 , Sr-90 and I-131 activity in leafy vegetables in all four regions of Europe after deposition on 1st May and 1st July (deposition: 1000 Bq/m^2 during a precipitation of 3 mm)

Time after deposition	Activity concentration (Bq y/kg per 1000 Bq/m^2) Cs-137	Sr-90	I-131
7d	140	210	41
14d	81	120	13
30d	18	29	0.71
0.5y	0.057	0.83	0
1y	0.054	0.80	0
50y	3.3E-4	0.019	0

Leafy vegetables are cultivated in all regions of Europe throughout the year. Therefore, the activity concentration of leafy vegetables is not significantly dependent on the region. In winter, due to longer weathering half-lives, a slower decrease of the activity can be expected.

2.5 DISCUSSIONS AND CONCLUSIONS

In this chapter a default terrestrial foodchain model has been described. This model was derived following a comparison of the predictions of FARMLAND and ECOSYS with environmental measurements and a comparison of the model predictions. The default model and its results are intended for use where more site specific information is not available. A relatively simple model is particularly appropriate for estimating representative doses from the ingestion of terrestrial foods over large areas. It is appropriate for use with probabilistic accident consequence codes like COSYMA (KfK and NRPB, 1990) which deal with a range of meteorological conditions and the consequences of postulated accidental releases over large areas. The default foodchain model is also useful for preliminary emergency planning to look at the likely extent of food countermeasures following accidental releases. The default model can also be used to pre-calculate food concentrations for use in the early phase after an actual accident before detailed meteorological data or measurements in food are available.

However, in any applications of the default model the variability in the results should be borne in mind. As shown in Section 2.2.2, the variation in the predicted concentrations in food in different meteorological conditions is particularly important. The variation due to releases at different times of year and due to different agricultural practices can also be significant. In addition, the uncertainty in the foodchain model resulting from a lack of knowledge of the parameter values should be recognised [Crick et al, 1988].

For post-accident analysis when full details of the meteorological conditions and other site specific data are available, a more detailed foodchain model, such as ECOSYS, is more appropriate. A more detailed model is also better if a knowledge of the likely range of possible food concentrations following a given accidental release is required, for example, for detailed emergency planning.

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3 FOOD CONSUMPTION

3.1 INTRODUCTION

In order to estimate internal doses caused by ingestion of radionuclides, the diet of the population groups involved needs to be known. In this chapter data on food consumption in the European Communities will be reported and discussed.

Firstly, information on average food consumption for the total population of each EC country will be given, in kilogram per caput per year. Secondly, the possibility of generalizing food intake to estimate EC diets which covers groups of countries was investigated.

In addition, differences in consumption between population groups within a given country were considered. Influences on food consumption of the following factors were studied: age, sex, social class, season, level of urbanisation, regional habits and level of self-support.

Apart from the factors mentioned above, food consumption within a population group can vary due to more individually characterized factors such as bodyweight, metabolism, occupation, and activities like sports, etc. Moreover, some people do not consume certain foodstuffs, because of personal taste or as a consequence of allergic reactions or adherence to a special diet because of illness. Others follow a diet because of a certain philosophy of life, e.g. vegetarians, macrobiotics. Immigrants consume different types of foodstuffs or foodstuffs from different origins. The resulting differences in consumption are very difficult to quantify and are therefore not taken into account.

In summary, only differences in food consumption between countries and between subgroups of the population are considered in this chapter. Individual variations were not taken into account.

As the information on food consumption was gathered to serve as underlying data to derive emergency reference levels, care should be taken when using it for any other purpose.

3.2 CHOICE OF CLASSES AND SUBCLASSES OF FOOD

The different foods were divided into classes and subclasses (Table 3.1). The choices and the arrangement of foodstuffs were such that nearly the entire human diet was covered and the subdivisions were relevant to radiation protection purposes. Details of the food products incorporated in each class or subclass are given in the extensive RIVM-CEA report on food consumption (van de Ven-Breken, 1990).

The same classification is used for each country. In general, the original data have not been processed. Some calculations were carried out in order to present all data as consumption of raw, unprepared products in $kg.person^{-1}.year^{-1}$. The conversion factors used are given in Tables 3.2, 3.3 and 3.4. Also, corrections were necessary when the classification of foods used in the original data did not match the classification used in this chapter.

Belgium and Luxembourg were combined. As usual, no separate data for Luxembourg are available. The diet in Luxembourg is generally very similar to that of Belgium.

Table 3.1 List of classes and subclasses of food used to present data on food consumption in EC countries

Foods (kg.person^{-1}.year^{-1})
1. Cereals
1.1 Wheat
1.2 Rye
1.3 Maize
2. Potatoes
3. Vegetables
3.1 Leafy vegetables
3.2 Fruit vegetables
3.3 Roots and tubers
3.4 Pulses
4. Fruit
4.1 Citrus fruit
4.2 Soft fruit + strawberries
4.3 Tropical fruit
4.4 Other fruit
4.5 Nuts
5. Milk and milk products, cow's milk
5.1 Drinking milk
5.2 Milk products
5.3 Butter
5.4 Cheese
5.5 Milk powder + condensed milk
6. Milk and milk products, goat + sheep
6.1 Drinking milk
6.2 Cheese
7. Meat
7.1 Beef
7.2 Veal
7.3 Pork
7.4 Lamb, mutton and goat
7.5 Poultry
7.6 Game
8. Fish
9. Eggs
10. Beverages
10.1 Drinking water
10.2 Non-alcoholic beverages
10.3 Beer
10.4 Wine

Table 3.2: Vegetables and potatoes: weight losses in culinary preparation (cleaning and cooking)

Subclass	Waste in cleaning (% of raw weight)	Shrinkage in cooking (% of raw weight)	Remaining part (% of raw weight)
VEGETABLES			
Leafy vegetables + cabbages	22	12	66
Fruit vegetables	17	4	79
Roots and tubers	16	11	73
Rest	23	26	51
All vegetables combined	20	13	67
POTATOES	20	NA	80

Table 3.3: Fruit: weight losses in culinary preparation (removing peel and stone)

Subclass	Waste in cleaning (% of raw weight)
Citrus	42
Soft fruit + strawberries	3
Tropical fruit	12
Rest	20
All fruit combined	20

Table 3.4: Meat: weight losses in culinary preparation (frying)

Subclass	Shrinkage in frying (% of raw weight)
Beef	25
Veal	30
Porc	35
Poultry	23
Sheep and goat	NA
All meat combined	30

Source Tables 3.2, 3.3 and 3.4: Westenbrink, 1987.

3.3 DATA SOURCES

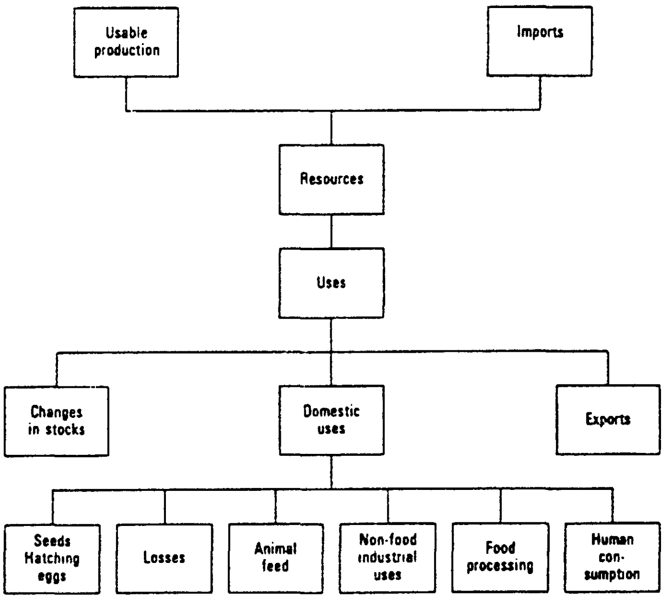
Where possible, the data collected were for 1986. This year was selected to ensure that most statistical data would be available but differences with the present situation were considered to be small.

The three sources of data available on food consumption are discussed below.

3.3.1 Food supply balance sheets

Food supply balance sheets are established at the national level. Using statistical data on food production, imports and exports and stock variations, the amounts available for human consumption for the entire population can be calculated (fig. 3.1). The available amounts are divided by the total number of inhabitants of the country to calculate average individual consumption, with no distinctions by age, sex, etc.

Schema for the supply balance sheets



This general schema can be modified depending on the balance sheet under consideration.
Resources = Usable production + Imports
Uses = Exports + Changes in stocks + Domestic uses

Figure 3.1: Scheme for the supply balance sheets (EUROSTAT, 1988)

Data from food balance sheets are usually readily available. The data refer to the raw, unprepared product. However, the calculated amounts per person usually overestimate actual consumption because losses at the retail shop and in the household (due to decay, damage, waste and use of foods for pets) are not taken into account. The published data are in general not very detailed, so extra work is necessary to distinguish between subclasses within classes of food. Furthermore, the data at this level apply to average citizens of the population (average by age, sex, etc.). Effects of the different factors can not therefore be studied.

The statistical data used are in general taken from EUROSTAT statistics (1988), and from national statistical yearbooks published in the different countries (CBS, 1987; Danmarks Statistik, 1987; Dennis, 1988; MAPA, 1985; SB, 1987). OECD data (1988) were used when data from other sources were not available.

3.3.2 Household budget surveys

In various EC countries household budget surveys, investigating household food consumption and expenditure in large samples (several thousands of households) are carried out on a regular basis. However, the year 1986 was not covered in all countries. Quantities recorded refer to the food products consumed by members of the household at home and outside. When consumption for separate individuals is given, it usually originates from an estimation using the following variables: total quantities available to the household during the reference period, the average number of people in the household and amounts consumed outside the home by the different members.

Several household budget surveys present information on influences of social class, geographical area, season and level of self-support. Also the information on food products consumed is much more detailed than with food balance sheets. The specific food consumption of separate individuals is not always given, in which case influences of age and sex cannot be assessed.

Data from this source usually concern the raw, unprepared products as bought. When data refer to prepared products, they have to be converted to unprepared amounts for reasons of comparability.

3.3.3 Food consumption research

Food consumption research is usually carried out for particular groups specified by age and sex and sometimes by other factors. Information on the kind of foodstuffs consumed is detailed.

When the number of participants is small, extrapolation of the results to the entire population may be unreliable. Due to the limited number of food consumption studies available, restriction to the year of reference (1986) was not always possible. Therefore in this research, studies from about 1980 until now were used.

In nutrition surveys, the amount of prepared product is usually registered. The recorded amounts were converted to amounts of raw, unprepared product in order to allow comparisons with data from other sources.

3.3.4 Use of data sources in this report

The three types of data sources each have advantages and disadvantages. Food consumption research is thought to be the best and most detailed approach to determine what people really eat and drink. However, these detailed data are not available for all countries studied. Also, food consumption research is often restricted to a relatively small part of the population or to subgroups of the population. For reasons of availability and comparability of data, food balance sheets have been used for Table 3.5 of Section 3.4. This table was used to group countries on a European scale. Tables on food consumption originating from household budget surveys and food consumption research can provide additional information (van de Ven-Breken, 1990).

3.4 FOOD CONSUMPTION IN SEPARATE EC COUNTRIES

In Table 3.5 the average annual food consumption based on food balance sheets is given for all EC countries for the reference year 1986. The data are the amounts available for consumption by individuals averaged by age and sex, which will in general be higher than the actual amounts consumed.

Total amounts (fresh plus preserved) of the individual classes and subclasses of food consumed are given in $kg.person^{-1}.year^{-1}$. The division of foodstuffs into the different subclasses is given where possible. For the food classes cereals, milk and milk products, meat and beverages, information on subclasses was available for most subclasses and countries. For vegetables and fruit, no information on consumption of the different subclasses was available. Using a special method described in the extensive report (van de Ven-Breken, 1990), this information was derived for France, Greece, Ireland, Italy, Portugal and Spain.

The consumption of fruit seems to be rather high, because fruit juices are included in total fruit consumption. The data on meat are expressed as carcass weight, in which waste (fat and bone) is included. The edible part of the carcass weight is usually obtained by applying the following waste percentages: bone, 20% of carcass weight, fat: 5%. The total value given for meat is higher than the sum of the subclasses. This is probably caused by the fact that certain kinds of meat (e.g. horse meat) and edible offals which are included in total meat are not given as a separate subclass.

In Table 3.6 the number of people living in each of the EC countries in 1986 is given.

The following abbreviations are used for the different countries:

BLEU: Belgium-Luxembourg Economic Union
DK: Denmark
FRG: Federal Republic of Germany
F: France
GR: Greece
IRL: Ireland
IT: Italy
NL: The Netherlands
P: Portugal
SP: Spain
UK: United Kingdom

Table 3.5: Food consumption of the EC countries in 1986

Foods (kg.person^{-1}.year^{-1})	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
1. CEREALS	71	66	71	80	105	91	115	58	101	75	80
1.1 Wheat	68	46	52	70	104	80	107	53	67	73	67
1.2 Rye	1.0	18	13	0.5	0.0	0.3	0.1	3.2	7	1.1	0.3
1.3 Maize	2.0	2.0	6	9	0.8	8	8	2.1	27	0.5	13
2. POTATOES	98	64	78	75	78	126	35	86	93	107	110
3. VEGETABLES	94	71	76	105	156	85	156	96	116	126	94
3.1 Leafy vegetables				36	25	34	56			39	
3.2 Fruit vegetables				41	109	12	84			56	
3.3 Roots and tubers				28	15	37	13			26	
3.4 Dried pulses	2.5	0.8	1.0	1.0	8	2.3	3.3	2.4	6	4.7	2.3
4. FRUIT	78	55	112	92	172	59	145	159	54	133	52
4.1 Citrus fruit	23	12	30	21	36	16	42	84	13	28	14
4.2 Soft fruit + strawberries	52	40	79	3.1	1.0	1.1	4.0	68	0.7	4.7	36
4.3 Tropical fruit				11	7	8	8		1.5	14	
4.4 Other fruit				54	120	32	87		36	80	
4.5 Nuts	2.7	2.0	3.3	2.0	8	1.1	3.9	8	2.9	7	1.0
5. MILK, MILK PRODUCTS, COW'S MILK	111	180	125	129	87	206	100	166	49	110	150
5.1 Drinking milk	69	136	70	74	65	194	83	108	43	95	127
5.2 Milk products	17	23	24	21				28		9	6
5.3 Butter	8	7	8	10	1.0	8	2.3	4.0	0.8	0.4	4.9
5.4 Cheese	13	12	16	20	21	4.0	14	14	4.5	2.4	7
5.5 Milk powder + condensed milk	4.7	0.2	8	3.6	0.5	0.3	0.5	12	0.8	3.4	4.8
6. MILK,MILK PRODUCTS, GOAT + SHEEP											
6.1 Drinking milk										3.3	
6.2 Cheese				1.0						1.6	
7. MEAT	101	101	102	106	78	83	84	79	55	83	75
7.1 Beef	21	16	22	25	20	24	24	14	11	8	22
7.2 Veal	3.0	0.4	1.7	7	2.4	0.0	4.0	2.1	0.9	3	0.1
7.3 Pork	46	64	61	35	22	34	28	43	19	37	24
7.4 Lamb, mutton and goat	1.8	0.6	0.8	4.3	12	7	1.5	0.5	2.4	6	7
7.5 Poultry	16	12	10	18	15	18	18	14	15	20	17
7.6 Game				0.4							
8. FISH	9	40	6	12	12	11	8	6	38	26	14
9. EGGS	15	14	16	16	12	14	11	12	6	17	13
10. BEVERAGES											
10.1 Drinking water											
10.2 Non-alcoholic beverages				67						53	
10.3 Beer	116	125	146	37	36	88	22	86	30	70	110
10.4 Wine	18	19	23	81	29	3.3	62	14	74	49	9

Table 3.6: Population of the EC countries in 1986

EC countries	Population
BLEU	10 228 000
DK	5 116 000
FRG	61 066 000
F	55 392 000
GR	9 960 000
IRL	3 537 000
IT	57 260 000
NL	14 529 000
P	10 210 000
SP	38 616 000
UK	56 763 000
TOTAL	322 677 000

3.5 FOOD CONSUMPTION IN GROUPS OF COUNTRIES

3.5.1 Methodology

In order to use the data in calculations, the national diets were generalized by grouping countries which have a relatively homogeneous diet together, using the following statistical techniques: Correspondence Analysis (Greenacre, 1984) and Cluster Analysis (Anderberg, 1973).

With Correspondence Analysis, differences in food consumption in the various EC countries were calculated. For each country the average consumption of the following eleven major classes of foodstuffs was used: cereals, potatoes, fresh and dried vegetables, fruit, fresh dairy products (drinking milk and fresh milk products), other dairy products (butter, cheese, milk powder and condensed milk), beef and veal, pork, lamb and poultry, fish and eggs (Table 3.7). In the last column the total amount consumed is given. Beverages are not taken into account.

Table 3.7: Average food consumption in EC countries in 1986 (kg. person^{-1} year^{-}). Classes of food as used for Correspondence Analysis

Country	CERE	POTA	VEGE	FRUI	MIFP	BCPC	BEVE	PORK	LAPO	FISH	EGGS	TOTAL
BLEU	71	98	94	78	85	26	24	46	18	9	15	564
DK	66	64	71	55	160	20	17	64	12	40	14	583
FRG	71	78	76	112	94	32	23	61	11	6	16	579
F	80	75	105	92	95	34	32	35	23	12	16	598
GR	105	78	156	172	65	23	22	22	28	12	12	696
IRL	91	126	85	59	194	12	24	34	25	11	14	675
IT	115	35	156	145	83	17	28	28	19	8	11	645
NL	58	86	96	159	136	30	16	43	15	6	12	658
P	101	93	116	54	43	6	12	19	18	38	6	504
SP	75	107	126	133	104	6	12	37	25	26	17	668
UK	80	110	94	52	133	17	22	24	24	14	13	584

The abbreviations, used for the classes of food are:

CERE: cereals
POTA: potatoes
VEGE: vegetables
FRUI: fruit
MIFP: drinking milk and fresh products
BCPC: butter, cheese, milk powder and condensed milk

BEVE: beef and veal
PORK
LAPO: lamb and poultry
FISH
EGGS
TOTAL: total of all foodstuffs

Using Correspondence Analysis, three major statistical indicators were obtained. The first one, EUROPE.C1, compares consumption of vegetables and fruit to that of fresh milk products. Greece and Italy have high values for vegetable and fruit consumption, while consumption of fresh milk products is low. On the contrary, UK, Ireland and Denmark have low consumption of vegetables and fruit, and high consumption of fresh milk products. All other countries show intermediate values of consumption on this indicator. The second indicator, EUROPE.C2, is based on the association of consumption of cereals and fish. This association clearly characterizes Portugal (high values for consumption of these two products). The third indicator, EUROPE.C3, indicates other particular patterns: high potato and low fish and pork consumption (a pattern typical for UK and Ireland), or low potato but high fish and pork consumption (a pattern observed for Denmark). The other countries do not conform to either of these two patterns. In Figure 3.2 the national diets described by the three statistical indicators are presented in a three-dimensional plot.

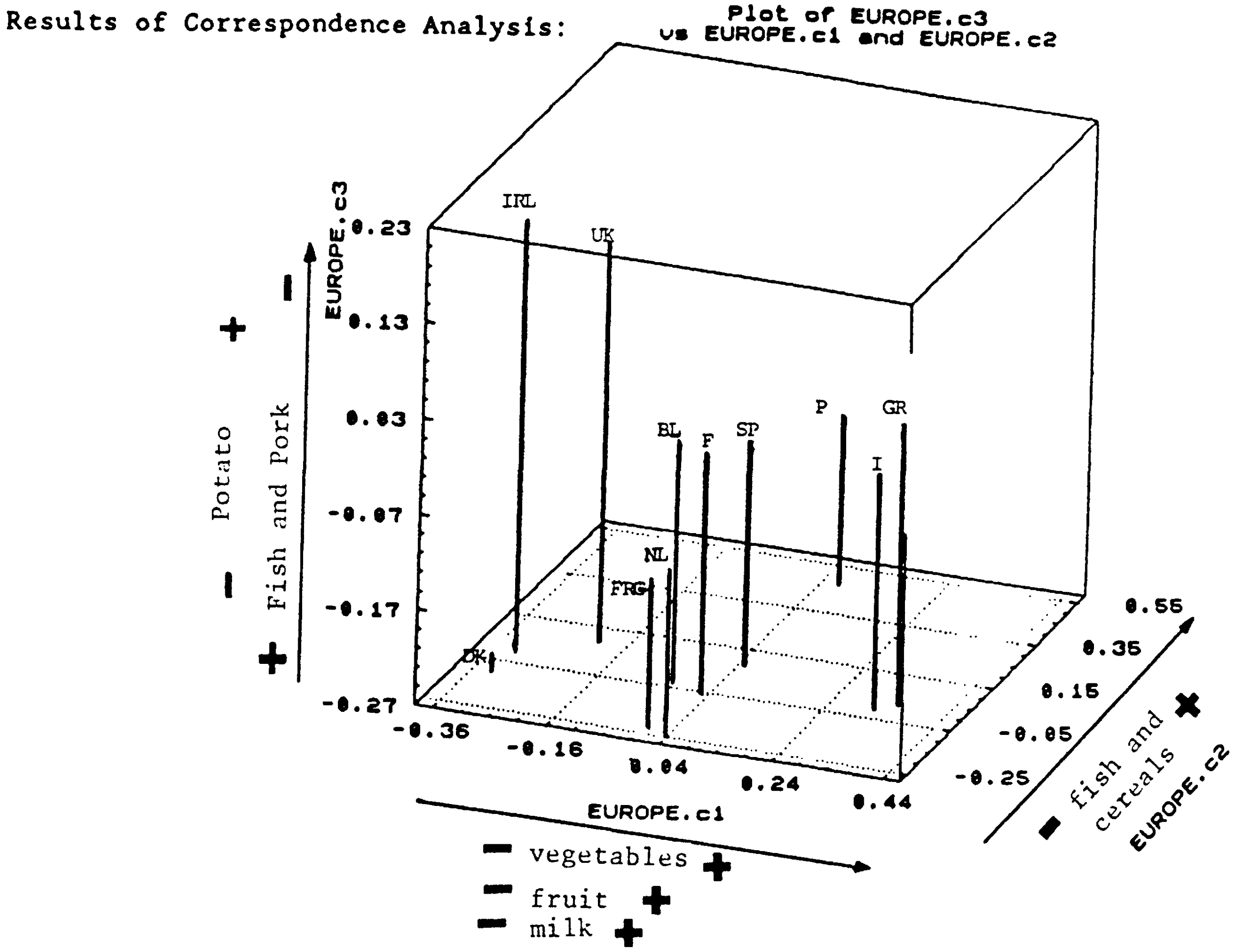


Figure 3.2: Grouping of EC countries using three statistical indicators of food consumption

Three groups of countries with similar diets can be observed in figure 3.2: Greece and Italy on the right; BLEU, France, Spain, the Netherlands and Germany in the middle, and UK and Ireland on the top left. Denmark and Portugal cannot easily be assigned to one of the groups. The grouping is confirmed when Cluster Analysis is applied to the data of Table 3.7. The results of this analysis are given in figure 3.3 as a clustering tree. On this clustering tree, national diets with 'union nodes' furthest to the left have the greatest similarities.

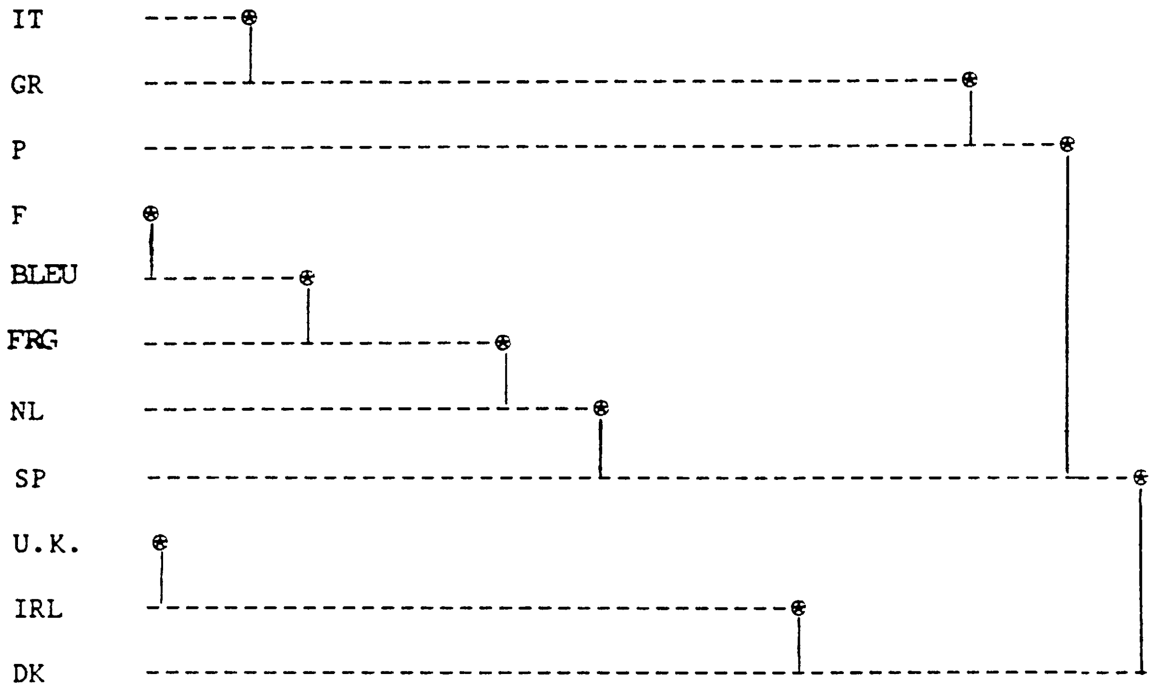


Figure 3.3: Grouping of EC countries with regard to food consumption
Clustering tree
⊛ : union node

3.5.2 Diets in groups of countries

EC diets were calculated per group of countries as the average of the clustered national diets weighted by population (Tables 3.8, 3.9 and 3.10). Applying the same procedure to all EC countries combined, the annual food consumption by an 'average citizen of the EC' was calculated. In Table 3.11 this average EC diet is given, together with the three EC diets for groups of countries and the national diets of Denmark and Portugal.

Table 3.8 Food consumption of group 1 of the combination of European countries and of the 2 constituing countries

Foods (kg.person^{-1}.year^{-1})	GROUP 1	IRELAND	UK
1. CEREALS	81	91	80
1.1 Wheat	67	80	67
1.2 Rye	0.3	0.3	0.3
1.3 Maize	13	9	13
2. POTATOES	111	126	110
3. VEGETABLES	94	85	94
3.1 Leafy vegetables			
3.2 Fruit vegetables			
3.3 Roots and tubers			
3.4 Dried pulses			
4. FRUIT	52	59	52
4.1 Citrus fruit			
4.2 Soft fruit + strawberries			
4.3 Tropical fruit			
4.4 Other fruit			
4.5 Nuts			
5. MILK AND MILK PRODUCTS, COW'S MILK	153	206	150
5.1 Drinking milk	137	194	133
5.2 Milk products			
5.3 Butter	16	12	17
5.4 Cheese			
5.5 Milk powder + condensed milk			
7. MEAT	71	83	71
7.1 Beef	22	24	22
7.2 Veal			
7.3 Pork	25	34	24
7.4 Lamb, mutton, goat	24	25	24
7.5 Poultry			
8. FISH	13	11	14
9. EGGS	13	14	13
POPULATION (thousands)	60300	3537	56763

Table 3.9 Food consumption of group 2 of the combination of European countries and of the 2 constituing countries

Foods ($kg.person^{-1}.year^{-1}$)	GROUP 2	GREECE	ITALY
1. CEREALS	113	105	115
1.1 Wheat	107	104	107
1.2 Rye	0.1	0.0	0.1
1.3 Maize	7	0.8	8
2. POTATOES	42	78	35
3. VEGETABLES	156	156	156
3.1 Leafy vegetables			
3.2 Fruit vegetables			
3.3 Roots and tubers			
3.4 Dried pulses			
4. FRUIT	149	172	145
4.1 Citrus fruit			
4.2 Soft fruit + strawberries			
4.3 Tropical fruit			
4.4 Other fruit			
4.5 Nuts			
5. MILK AND MILK PRODUCTS, COW'S MILK	98	87	100
5.1 Drinking milk	80	65	83
5.2 Milk products			
5.3 Butter	18	23	17
5.4 Cheese			
5.5 Milk powder + condensed milk			
7. MEAT	75	72	75
7.1 Beef	27	22	28
7.2 Veal			
7.3 Pork	27	22	28
7.4 Lamb, mutton, goat	21	28	19
7.5 Poultry			
8. FISH	9	12	8
9. EGGS	11	12	11
POPULATION (thousands)	67220	9960	57260

Table 3.10 Food consumption of group 3 of the combination of European countries and of the 5 constituing countries

Foods (kg.person^{-1}.year)$^{-1}$	GROUP 3	BLEU	FRG	F	NL	SP
1. CEREALS	74	71	71	80	58	75
1.1 Wheat	63	68	52	70	53	73
1.2 Rye	5	1.0	13	0.5	3.2	1.1
1.3 Maize	5	2.0	6	9	2.1	0.5
2. POTATOES	85	98	78	75	86	107
3. VEGETABLES	98	94	76	105	96	126
3.1 Leafy vegetables						
3.2 Fruit vegetables						
3.3 Roots and tubers						
3.4 Dried pulses						
4. FRUIT	112	78	112	92	159	133
4.1 Citrus fruit						
4.2 Soft fruit + strawberries						
4.3 Tropical fruit						
4.4 Other fruit						
4.5 Nuts						
5. MILK AND MILK PRODUCTS, COW'S MILK	126	111	125	129	166	110
5.1 Drinking milk	99	85	94	95	136	104
5.2 Milk products						
5.3 Butter	26	26	32	34	30	6
5.4 Cheese						
5.5 Milk powder + condensed milk						
7. MEAT	87	88	95	89	74	74
7.1 Beef	23	24	23	32	16	12
7.2 Veal						
7.3 Pork	46	46	61	35	43	37
7.4 Lamb, mutton, goat	18	18	11	23	15	25
7.5 Poultry						
8. FISH	12	9	6	12	6	26
9. EGGS	16	15	16	16	12	17
POPULATION (thousands)	179831	10228	61066	55392	14529	38616

Table 3.11 Food consumption of an 'average citizen of the EC', food consumption of all 3 groups of European countries and food consumption of Denmark and Portugal, countries not suitable for grouping.

Foods (kg.person^{-1}.year^{-1})	TOTAL EC	GROUP 1	GROUP 2	GROUP 3	PORTUGAL	DENMARK
1. CEREALS	84	81	113	74	101	67
1.1 Wheat	73	67	107	63	67	46
1.2 Rye	3.5	0.3	0.1	5	7	18
1.3 Maize	8	13	7	5	27	2.0
2. POTATOES	81	111	42	85	93	64
3. VEGETABLES	110	94	156	98	116	71
3.1 Leafy vegetables						
3.2 Fruit vegetables						
3.3 Roots and tubers						
3.4 Dried pulses						
4. FRUIT	106	52	149	112	54	55
4.1 Citrus fruit						
4.2 Soft fruit + strawberries						
4.3 Tropical fruit						
4.4 Other fruit						
4.5 Nuts						
5. MILK AND MILK PRODUCTS, COW'S MILK	124	153	98	126	49	180
5.1 Drinking milk	102	137	80	99	43	143
5.2 Milk products						
5.3 Butter	22	16	18	26	6	20
5.4 Cheese						
5.5 Milk powder + condensed milk						
7. MEAT	80	71	75	87	48	92
7.1 Beef	23	22	27	23	12	17
7.2 Veal						
7.3 Pork	37	25	27	46	19	64
7.4 Lamb, mutton, goat	20	24	21	18	18	12
7.5 Poultry						
8. FISH	13	13	9	12	38	40
9. EGGS	14	13	11	16	6	14
POPULATION (thousands)	322677	60300	67220	179831	10210	5116
(% of total EC)	100	19	21	56	3	2

3.5.3 Discussion on grouping of EC countries

Three groups of countries have a reasonable homogeneous food consumption.

In group 1 are the UK and Ireland. This group comprises 19% of the total population of the EC. The diet is characterized by a low consumption of fruit and a high consumption of potatoes and fresh dairy products. The only significant difference found between the two countries is in the consumption of fresh dairy products (133 and 194 $kg.person^{-1}.year^{-1}$ respectively). The Irish have the highest consumption of fresh dairy products in Europe.

Group 2 consists of Italy and Greece. The number of people in this group comprises 21% of the population of the EC. The diet is characterized by a high consumption of cereals, vegetables and fruit, and a low consumption of fresh dairy products. The two countries differ in the consumption of potatoes (35 and 78 $kg.person^{-1}.year^{-1}$ respectively). Consumption of fruit in Greece is the highest in Europe.

France, Belgium plus Luxembourg, FRG, the Netherlands and Spain belong to Group 3. This group comprises 56% of the total population of the EC. The diet is less homogeneous than for the first two groups, with intermediate consumption of most foodstuffs. Consumption of cereals, potatoes, meat and eggs does not differ very much between the five countries (variation less than 10% of the average). Consumption of the other foodstuffs shows larger discrepancies. For vegetables, fruit and milk plus milk products the differences are in the range of -30 to +30% of the average consumption. For fish, the differences are larger still (from half to twice the average), but absolute amounts consumed are small.

Two countries, Portugal and Denmark, cannot be classified with any of the three groups. Portugal has the lowest individual total consumption per year (80% of the 'average EC citizen'). Consumption of cereals, potatoes, vegetables and fish is high, consumption of fruit, milk plus milk products and meat is quite low. Danish people favour milk products, pork and fish, and consume few cereals, potatoes, vegetables and fruit.

The 'average citizen of the EC' consumes 621 kg of foodstuffs in total. Consumption of meat is 89 kg per year, including horse meat and offals. The average citizen consumes similar amounts of cereals and potatoes (84 and

81 kg respectively), and of vegetables and fruit (110 and 106 kg respectively). Consumption of milk and milk products is 124 kg, whereas the combined consumption of the other animal products, meat, fish and eggs is about the same, 116 kg (horse meat and offals included in total meat consumption).

In Table 3.12 the consumption by the average EC citizen is compared with the assumptions on food consumption by adults, adopted by the Article 31 Expert Group for deriving emergency reference levels (Kaul, 1988).

Table 3.12: Food consumption by age according to two different sources

	Annual ingestion (kg.person^{-1} year^{-1})			
	Article 31 Expert Group			Average EC citizen
	Age groups			
Foods	1-year-olds	10-year-olds	Adults	total population
1 Dairy produce	200	150	120	124
2 Meat	10	40	80	80 1)
3 Fruit and vegetables	20 2)	40 2)	100 2)	149 3)
4 Cereals	20	50	100	84
5 Drinking water	250	350	600	NA

1) without offals and horse meat
2) surface vegetables only
3) total fruit plus leafy vegetables and fruit vegetables

When comparing the data for the average EC citizen with the values adopted by the Article 31 Group for adults, it should be recognized that the EC data are averaged for all ages. The actual food consumption by adults will be greater, but quantification of the difference is not possible.

The data on consumption of dairy produce and meat seem to agree rather well. For cereals, the Article 31 assumption is about 20% higher than the value for the 'average EC citizen'. The value of Article 31 for consumption of vegetables and fruit is considerably lower than for the average citizen of the EC, which is about 50%. This could probably be explained by a rather high fruit consumption for the EC citizen due to inclusion of fruit juices in the total figure for fruit consumption.

3.6 FACTORS INFLUENCING FOOD CONSUMPTION

A description will be given here of the main features of the differences in food consumption due to differences in age, sex, social class, level of urbanisation, level of self-support, as well as regional and seasonal differences in food consumption. More details of the methodology used are given in the extensive report (van de Ven-Breken, 1990).

In general, limited information on the various factors is available. For some factors data are only available for a few EC countries. When information is scarce, application of data from one country to other countries is thought to be justified only for specific factors (like social class), while for the remaining factors extrapolation does not seem possible. For example, regional differences in food consumption in one country are not expected to be applicable to other countries.

Effects of the factors region, social class, level of urbanisation and level of self-support are often thought to be correlated. For example, the different social classes will probably be distributed inhomogeneously over the various regions of a country. In the following subsections, the factors are described separately. At the end of the section a table is given which summarizes all of the results. In Section 3.7 the effects of certain combinations of factors are discussed.

3.6.1 Age

Food consumption has been quantified for the following four age categories: 1-year, 5-year and 10-year-old children and adults.

Data on food consumption by age are usually obtained from nutrition research. Due to the limited number of studies available, the margins of the age classes cannot be applied too strictly and the age must be taken as an average over a wider period. For example, the group of 1-year-old children consists of infants from 10 to 16 months, and the group of 10-year-olds includes children of 9, 10 and 11 years.

The nutrition studies from which data are taken differ with regard to protocols, sample sizes and age classes. The various studies are therefore sometimes difficult to compare. The available data have been pooled for the entire EC. Plots of consumption versus age were constructed for the following foodstuffs: cereals, potatoes, fruit, milk, meat and vegetables (van de Ven-Breken, 1990). The ages range from 1 to 18 years old, with the age of 18 representing all adults. Correlation and regression coefficients were calculated, and the results are shown in Table 3.13.

For each class of products and for all age groups, the range of consumption can be large (about 50% of the average value). Nevertheless, clear relationships between age and food consumption were observed for all classes of food, except for milk and milk products. Regression lines were used to interpolate consumption between the ages of 1 and 18. From these lines, relative consumption with respect to adults, taken here as the 18-year-olds, was calculated for 1, 5 and 10-year-old children.

Table 3.13: Consumption (groups of products) related to age

		Regression coefficients 1)		Consumption at different ages compared with consumption of adults			
Foods	Corr. coeff.	a	b	1 year	5 years	10 years	18 years (Adults)
Cereals	0.83	3.4	25.0	0.33	0.49	0.68	1
Meat	0.90	4.0	15.6	0.22	0.40	0.63	1
Milk 2)	-0.19	-1.1	147.6				
Fruit	0.65	4.2	32.1	0.33	0.49	0.69	1
Potatoes	0.80	3.4	20.1	0.29	0.45	0.66	1
Vegetables	0.58	2.9	44.3	0.49	0.61	0.76	1
Total diet 3)	0.87	17.4	318.6	0.53	0.64	0.77	1

Sources: Boeijen, 1983; Deheeger, 1988; DGE, 1984; Hoffmans, 1987; INSERM; Rolland-Cachera, 1986; Rolland-Cachera, 1988; Wenlock, 1986.

1) Regression formula: Consumption ($kg.person^{-1}.year^{-1}$) = a . Age (years) +b

2) The correlation coefficient (corr. coeff.) does not differ significantly from zero. No clear relationship between age and consumption can be observed, and no ratios of consumption were calculated.

3) In the total diet milk was included.

To compare the data from Table 3.13 with the data adopted by the Article 31 Expert Group (Table 3.12), the values for milk were not taken into account when considering separate food classes, but milk was included in the total diet.

For 1-year-olds the relative consumption of separate food classes are in the order of about 0.2 to 0.3, with a value of 0.49 for vegetables. All values are higher than the values adopted by the Article 31 experts, which range from 0.1 to 0.2 . The relative values of ingestion of 5-year-olds range from 0.4 to 0.5, again with a higher value for vegetables. The Article 31 Group does not give data for 5-year-olds. The relative ingestion of 10-year-olds shows a small variation, from 0.63 to 0.69, with a value of 0.76 for vegetables. Compared with the Article 31 Group, the calculated value for 10-year-olds is higher for fruit and for vegetables, lower for cereals and about equal for meat. Concerning total diet (including milk), the calculated value for 10-year-olds of 0.77 is about equal to the Article 31 assumption of 0.7. For 1-year-olds, the difference between the calculated value of 0.53 and the Article 31 estimate of 0.62 is also small.

3.6.2 Sex

The effects of sex are related to age, as differences between men and women are expected to be smaller at lower ages. Because differences are expected to be smallest for 1-year-olds and data are scarce for this age category, effects of sex could not be taken into account for this age group.

Data on food consumption by men and women have to come from food consumption studies. Using the limited amount of data available, female consumption was compared to male consumption per class of age and the results are shown in Table 3.14. For intercomparison with values from the literature (CBS, 1982) adults were considered in two groups: people of 14 to 60 years old and people of 60 years and older.

Table 3.14: Relative consumption (total diet) of men and women at different ages

	Female consumption relative to male consumption		
	Classes of age		
	10+11 y.	14 - 60 y.	≥ 60 y.
Literature	1.0	0.8	1.0
Calculated			
France	0.8	NA	NA
FRG	0.8	0.8	0.8
NL	0.8	0.8	0.8
UK	0.9	NA	NA

NA: Not Available

Sources: Boeijen, 1983; DGE, 1984; EUROSTAT, 1988; Fehilly, 1984 MWVC, MLV, 1988; Rolland-Cachera, 1986; Wenlock, 1986.

For all three age groups the derived relative consumption shows that women consume on average 20% less than men. In the literature this difference was only given for the age group of 14 to 60 years.

Only differences in total food consumption have been considered so far. In Table 3.15 female and male consumptions are compared for different classes of food using data from FRG, the Netherlands and UK.

Table 3.15: Relative consumption (groups of products) of men and women at different ages

	Female consumption relative to male consumption						
	10 + 11-year-olds				adults (≥ 15 years)		
Foods	FRG	NL	UK	average	FRG	NL	average
Cereals	0.8	0.8	0.9	0.8	0.8	0.7	0.8
Potatoes	0.8	0.8	0.9	0.9	0.8	0.7	0.8
Vegetables	1.0	1.0	0.9	1.0	0.8	1.0	0.8
Fruit	1.0	1.2	1.2	1.1	0.9	1.1	1.0
Milk + milk products	0.7	0.9	0.8	0.8	0.9	0.9	0.9
Meat	0.8	0.8	0.9	0.9	0.7	0.8	0.7
Fish	1.0	2.0	0.9	1.1	0.7	0.7	0.7
Eggs	0.9	1.0	0.9	0.9	0.8	0.9	0.8

Sources: Boeijen, 1983; DGE, 1984; EUROSTAT, 1988; Fehilly, 1984
MWVC, MLV, 1988; Wenlock, 1986.

For most classes of food, the value of 0.8 found for total relative consumption is applicable for both 10 and 11-year-olds and adults. Vegetables and fruit are the only significant exceptions. Women consume the same or even higher amounts of fruit compared to men of both ages. Female consumption of vegetables is equal to male consumption at the age of 10 and 11, but for adults the general value of 0.8 is applicable again.

The consumption data of fish and eggs are less reliable as absolute consumption is usually small.

3.6.3 Social class

Variations in food consumption due to differences in social class may be explained to a large extent by differences in income. The upper and lower limits of income used to define different social classes may differ by country. A division of social classes applicable to all European countries will therefore be difficult to formulate. Within one country, consumption of well defined socio-economic classes can be compared. Between countries, nominally equal classes can be compared, even though the exact definition of these classes may differ.

When people have to reduce their expenditures on food, they can do so in several different ways. Den Admirant and Van Raay (1983) have developed a general model of ten strategies for economizing, applicable to all sorts of purchases. The strategies relevant to purchases of food can be summarized in the following three approaches:

1. consumers buy the same amount of a given product, but try to obtain it at a lower price (cheaper store, cheaper brand, bargains);
2. consumers substitute a given product with a cheaper one from the same or from another class of food;
3. consumers decrease the quantities used, or even stop consumption of the product.

The choice of strategy depends on the type of product, whether it is considered as basic, luxury or "in between" basic and luxury.

For basic products (like bread, potatoes, vegetables, drinking milk, eggs), the first strategy is generally chosen. For some products, strategy 2 is also used.

The choice of strategy 3 is typical for the consumption of luxury products (coffee, alcoholic beverages, sweets, cake + pastry, butter). Besides that, substitution of butter by (low-fat) margarine (strategy 2) is often one of the first measures taken in economizing.

For the remaining products, "in between" basic and luxury (fruit, certain milk products, cheese, meat), people decrease consumption until a certain minimum level is reached. Substitution of cheaper products (strategy 2) is used here as well.

Strategy 2, applied to fruit and vegetables, will often result in less fresh and more processed products being consumed. For specific kinds of vegetables and fruit the availability shows seasonal fluctuations. These kinds will be bought more often in the season of high availability, when prices are low. This might affect consumption per subclass of fruit more than total fruit consumption, as products might be exchanged between subclasses. For meat, there is a shift from beef to pork, a kind of meat which is less expensive. Total meat consumption might also be reduced.

The model described above may be applicable to all countries. The exact quantification per class of food will be different for each country, depending on the specific diet. In Table 3.16 consumption by people with low and high income is compared using data for two countries: United Kingdom and the Netherlands (for separate tables see van de Ven-Breken, 1990). Due to differences in the design of the two studies, the data are not completely comparable but can serve as an illustration.

Table 3.16: Differences in consumption (groups of products) between social classes in the Netherlands and UK

Foods	Consumption of people with low income relative to consumption of people with high income	
	Netherlands [1]	United Kingdom [2]
Dairy products (excl. cheese, butter)	1.1	0.9
Cheese	0.9	0.7
Meat, fish, eggs	0.9	0.9
Beef	0.5	NA
Bread, cereals	0.9	1.0
Margarine, oils, fats	1.1	NA
Potatoes	0.9	1.3
Vegetables, pulses	0.6	0.9
Fruit	0.9	0.5
Cake, pastry	0.7	NA
Alcoholic beverages	0.3	NA

Sources: van de Bergh, 1988; MAFF, 1987.

[1] The Netherlands: women aged 65 years and older, consumption of people with low and high income compared

[2] United Kingdom: consumption of households whose head was unemployed compared with consumption of total population

3.6.4 Level of urbanisation

Differences can be expected between urban and rural food consumption, both in total amounts consumed and in the origin of the food (from local production, or from national or international trade). The level of self-support is likely to be higher in the countryside. In this way, influences of the level of urbanisation are probably related to differences in the level of self-support. Also, there will probably be a correlation with social class, as the distribution of social classes over the rural and urban areas is likely to be uneven. In the past, when national and international trade were less important and the level of self-support was higher, the distinction urban versus rural was more important than it is now.

Data on this subject are available from household budget surveys carried out in France, Greece and the United Kingdom. Consumption in urban and rural areas was compared with the average national consumption for each country. The data on the three countries were then pooled and minimum plus maximum values are given for rural areas and for urban areas in Table 3.17. In the extensive report (van de Ven-Breken, 1990), the complete tables for each country are given. The definitions of urban and rural areas may differ by country.

Table 3.17: Consumption (classes of food) in urban and rural areas in France, Greece and the United Kingdom compared with the entire country

	Consumption in urban and rural areas relative to consumption in the entire country	
Foods	Urban area Minimum - Maximum	Rural area Minimum - Maximum
Cereals	0.7 - 0.9	1.0 - 1.5
Potatoes	0.7 - 1.0	1.1 - 1.2
Vegetables	0.9 - 1.1	1.0 - 1.3
Fruit	1.1 - 1.3	0.8 - 1.1
Milk and milk products	0.7 - 1.0	1.1 - 1.4
Meat	0.8 - 1.0	1.0 - 1.2
Fish [1]	0.8 - 1.2	0.9 - 1.3
Eggs	0.8 - 1.0	1.0 - 1.3

Sources: INSEE, 1983; MAFF, 1985; NSS, 1982.

[1] no data available on Greece

Consumption of cereals, potatoes, vegetables and milk plus milk products is lower in urban areas than in rural areas, whereas consumption of fruit is higher in urban areas.

Differences in consumption of the remaining products are less clear. Consumption of meat, fish and eggs tends to be lower in urban areas and higher in rural areas.

Differences between urban and rural areas are more distinct for France and Greece than for the UK. Information on more countries is necessary to investigate if differences between urban and rural regions could be larger in the southern part of the EC.

3.6.5 Level of self-support

For self-support the three most important population groups are:

- Farmers and their families, consuming foodstuffs from their own animal and/or vegetable production, plus people who buy products directly at the farm.

- Owners of kitchen gardens and/or allotments, who consume homegrown vegetables and fruit, and those with whom they share their production (relatives, neighbours, friends).

- Fishermen with their families, who consume fish from their own catch.

The foodstuffs concerned will, to a large extent, be of local origin. Also the amounts consumed of the specific foodstuffs may be larger than in the case of non-self-supporters.

Self-support is probably associated with regional consumption and with the level of urbanisation. Farmers live at the countryside, and people in rural areas have more opportunity to own or rent a kitchen garden or allotment.

Kitchen gardens and allotments

These kinds of gardens are mainly important for self-support in vegetables. In Table 3.18 data for the different countries are given. In general, 15 to

30% of total national vegetable consumption comes from kitchen gardens. For Denmark, Portugal and Spain the percentage is zero, for Greece and the UK no data were available.

Table 3.18: Self-support: production of vegetables in kitchen gardens

	Production of fresh vegetables from kitchen gardens		
Country	1000 ton	% of total production	% of total domestic use [1]
BLEU	194	15	19
FRG	664	31	13
F	1480	22	19
IRL	75	25	21
IT	1875	14	16
NL	200	6	13

Source: EUROSTAT, 1988.

[1] domestic use = production + imports - exports ± change in stocks

In households where people use a kitchen garden or allotment, the amount of vegetables consumed is also likely to increase, as the supply will be large. In a Dutch study among owners of kitchen gardens (Hulshof, 1988), total vegetable consumption of adults was 105 $kg.person^{-1}.year^{-1}$. This figure is 40% higher than the value of 75 kg found for vegetable consumption of the adult population in a comparable survey (MWVC, MLV, 1988).

Farmers

Farm production may lead to a considerable degree of self-support of the following products: cereals, potatoes, vegetables, milk and milk products, eggs, meat and wine. For wheat and milk and milk products, information on the level of self-support is available from EUROSTAT publications (Tables 3.19, 3.20). For some countries, no data were available, or direct consumption at the farm was negligible.

Table 3.19: Self-support: consumption of wheat at the farm

	Consumption at the farm					
	total wheat		soft wheat		durum wheat	
Country	1000 ton	% of national consumption 1)	1000 ton	% of national consumption 1)	1000 ton	% of national consumption 1)
BLEU	7	0.8	7	0.8	0	0
FRG	5	0.1	5	0.1	0	0
F	10	0.2	10	0.2	0	0
GR	370	26	300	25	70	28
IT	300	4	100	2	200	8
SP	101	3	95	3	6	3

Source: EUROSTAT, 1987.

1) consumption of total population, including consumption at the farm

For total wheat consumption, self-support is only significant for Greece, Italy and Spain. For Italy, self-support is highest for durum wheat, whereas for Greece and Spain self-support of soft and durum wheat is of the same order of magnitude.

Table 3.20: Self-support: consumption of milk and milk products at the farm

	Consumption at the farm					
	Drinking milk		Butter and cream		Cheese	
Country	1000 ton	% of national consumption 1)	1000 ton	% of national consumption 1)	1000 ton	% of national consumption 1)
BLEU	103	14.7	16.4	13.2	0.7	0.5
DK	75	10.7	0	0	0	0
FRG	723	16.9	1.8	0.2	0.4	0
F	820	20.1	14.1	2.0	28.5	2.3
GR	385	61.2	1.2	6.3	40.7	16.1
IRL	139	21.0	0.3	0.8	0	0
IT	1305	29.6	4.8	1.7	63.3	6.3
NL	88	5.6	0	0	7.4	3.5
UK	251	3.5	1.3	0.3	0	0

Source: EUROSTAT, 1988

1) consumption of total population, including consumption at the farm

The level of self-support is highest for drinking milk, 10 to 30% for most countries. The level is below 10% for the Netherlands and UK and is very high for Greece, about 60%. Belgium has the highest level of self-support for butter and cream. Self-support is of little importance in France (2%) and Greece (6%). The level of self-support for cheese is high in Greece. Self-support for milk and milk products seems to be more important in the Southern part of the EC.

Household budget surveys carried out in France and Greece provide information on average levels of self-support of a number of foodstuffs in rural areas. Data on the two countries have been combined, and minimum and maximum values are given in Table 3.21 .

Table 3.21: Self-support of different products in rural areas in France and Greece

	% of consumption coming from own production	
Foods	Minimum	Maximum
Cereals	1	22
Potatoes	20	84
Vegetables	56	61
Fruit	20	30
Milk and milk products	62	63
Meat	20	47
Fish	4	8

Sources: INSEE, 1982; NSS, 1982.

The level of self-support is quite constant and high (around 60%) for vegetables and milk plus milk products. For the other products self-support is more variable. For cereals, fruit and fish the maximum average levels are moderately high (30% and below), whereas for meat and potatoes the level of self-support can amount to high values (47 and 84% respectively). Only average values are given but the level of self-support might be higher in extreme cases. In the case of potatoes, vegetables, drinking milk, eggs and fish (fishermen) self-support might mount to 100%, in all other cases it is thought to be below 100%.

3.6.6 Region

Regional consumption patterns were considered only for those countries large enough to be divided into regions: United Kingdom, Federal Republic of Germany, France, Spain and Italy. Differences in food consumption between regions may result from different dietary habits as well as from differences in food production which influences the availability of foodstuffs. As mentioned before, regional consumption may be connected with the level of urbanisation and the level of self-support.

Information on regional differences in food consumption was scarce. Data came from household budget surveys carried out in France, Spain and the United Kingdom. Extrapolation of results from one country to another does not seem possible. Consumption per region was compared with national consumption for each country. Only regions with minimum and maximum consumption are given. In Table 3.22 the results for the three countries have been combined. This table may serve as an illustration of the order of magnitude of regional differences.

Table 3.22: Regional differences in consumption (classes of food) in France, Spain and the UK

	Consumption of regions relative to consumption of the entire country	
Foods	Region with lowest consumption Minimum - Maximum	Region with highest consumption Minimum - Maximum
Cereals	0.9 - 1.0	1.1 - 1.2
Potatoes	0.7 - 0.8	1.2 - 2.0
Vegetables	0.7 - 1.0	1.1 - 1.3
Fruit	0.8 - 0.9	1.2 - 1.3
Milk and milk products	0.8 - 0.9	1.1 - 1.3
Meat	0.8 - 0.9	1.1 - 1.2
Fish	0.7 - 0.8	1.1 - 1.3
Eggs	0.8 - 0.9	1.2 - 1.3

Sources: INSEE, 1983, MAFF, 1985; MAPA, 1987.

For cereals and meat the differences are not very pronounced; a value of 0.8 or 0.9 for lowest consumption and a value of 1.2 at the maximum for highest consumption. For all other products, consumption shows an important variation over the regions. Values of lowest consumption range from 0.7 to 1.0, for highest consumption the values range from 1.1 to 1.3 with a maximum of 2.0 for potatoes.

3.6.7 Seasonal differences in food consumption

The availability and price of specific foodstuffs are related to season and will influence food consumption. Also caloric requirements and therefore the amounts consumed, as well as the choice of products (within classes of food and between classes), may differ with season.

For animal products (meat, milk + milk products, eggs), production and supply is rather constant during the year, and no seasonal differences in consumption are expected.

For roots and tubers, cereals, potatoes and apples plus pears, harvesting takes place during a relatively short period of time. Storage qualities of these products are good enough to provide a continuous supply over the year. Storage is more difficult for fresh vegetables and certain European types of fruit, e.g. peaches, cherries. Seasonal changes in consumption of those two classes of food are therefore expected.

The assumption in relation to supply was confirmed by the results of a household budget survey carried out in the United Kingdom (MAFF, 1987). Differences in consumption of fish and eggs are not taken into account as absolute consumption is small. For potatoes, vegetables and fruit, changes of 10% or more between summer and winter consumption are shown (Table 3.23). Consumption of potatoes was 15% higher in winter, for fruit and vegetables consumption was higher in summer by 14% and 24% respectively.

Table 3.23: Consumption (groups of products) per season, UK.

Consumption (kg.person^{-1}.year^{-1}) in the four different seasons

Foods	January - March	April - June	July - September	October - December	Highest and lowest consumption compared	
					Ratio	difference in kg
Cereals	77.8	80.2	77.7	79.9	1.03	2.5
Potatoes	68.4	59.7	59.3	67.2	1.15	9.1
Vegetables	59.3	61.0	67.7	64.7	1.14	8.4
Fruit	31.3	35.2	38.8	33.3	1.24	7.5
Milk + milk products						
drinking milk						
fresh milk products	118.8	115.2	115.2	115.2	1.03	3.6
butter	3.4	3.2	3.2	3.5	1.09	0.3
cheese	5.9	6.3	6.2	6.1	1.07	0.4
Meat	54.7	54.1	54.5	55.3	1.02	1.2
Fish	7.3	8.0	8.0	7.2	1.11	0.8
Eggs	9.5	10.1	8.9	9.0	1.14	1.2

Source: MAFF, 1987

More quantitative data on seasonal variations were not available from food balance sheets or household budget surveys. Food consumption research in most cases only provides data on the intake of nutrients (carbohydrates, proteins, fats) and no data on consumption of specific foods. Only for the UK (Bingham, 1981; Fehilly, 1984) and the Netherlands (van Staveren, 1983) are data available from food consumption research. This information supports the assumption that consumption of vegetables and fruit is low during periods of low supply.

More information can be obtained from data on periods of harvesting and selling of specific kinds of vegetables and fruit (see van de Ven-Breken, 1990). During periods of high commercialization a rise in consumption of the product concerned can be expected.

In Tables 3.24 and 3.25 the results relating to the different factors have been summarized.

Table 3.24: The influence of the factors age, sex, social class, region and level of urbanisation on food consumption

Factor	Population groups distinguished	Reference group	Consumption of population groups	
			total diet	separate food classes
Age	1-year-olds		50%	vegetables: 50% rest:[1] 20-30%
	5-year-olds	adults	60%	vegetables: 60% rest:[1] 40-50%
	10-year-olds		80%	vegetables: 80% rest:[1] 60-70%
	adults			
Sex (10+11 years, adults)	women men	men	80%	vegetables, 10+11 y.: 100% fruit, both ages: 100-110% rest:[1] 70-90%
Social class	lower classes higher classes	higher classes		beef: 50% fruit: 60% potatoes: 120% rest: 70-100%
Level of urbanisation	rural area	entire country		fruit: 80-110% rest: 100-150%
	urban area	entire country		fruit: 110-130% rest: 70-110%
Region	different administrative regions	entire country		low cons.: all foods 70-100% high cons.: potatoes 200% rest: 110-130%

[1]: For all other food classes except milk for which no value could be calculated

Table 3.25: The influence of the factors season and level of self-support on food consumption

Factor	Population groups distinguished	Aspect of consumption studied	Consumption of population groups
Level of self-support	owners of gardens farmers	% of national consumption coming from local production	vegetables: 13-21% wheat: Greece 26% other countries ≤ 4% milk: Greece: 61%, other countries 4-30% butter + cream: BLEU 13% other countries 0-6% cheese: Greece: 16% other countries 0-6%
	fishermen		fish: max. expected of 100%
Season	total population	consumption during separate seasons	small differences between summer and winter for vegetables and fruit only (115-125% in summer as compared to winter)

3.7 EFFECTS OF COMBINATIONS OF FACTORS

In the previous section, the various factors influencing food consumption were described separately. In reality, combinations of factors will occur. For specific situations, when all factors are known, a rough estimate of influences on the average diet can be obtained. For example, for a 10-year-old girl living in the countryside in a particular region during a particular season, the most important factors are age, sex, region, season and level of urbanisation. For more general situations it may be more complicated to describe influences of combined factors.

Nevertheless, an attempt was made to describe the influences of combinations of factors for the main food products. The physiological factors of age and sex were not considered as they are assumed to have similar influences on all food products. Furthermore, because the different factors are thought to be correlated, only those factors that have the largest influences will be considered, which are level of urbanisation and region. The minimum and maximum values of the differences observed for the factors in section 3.6 were used to derive two coefficients. These two coefficients indicate the range of amounts consumed by specific population groups relative to the average consumption of the entire population. The derived coefficients should be used with great care, as they represent maximum influences of the combination of the factors region and level of urbanisation, using the most extreme values observed for the two factors and assuming that the influences of the factors are independent. In reality the factors may be correlated, and combined factors may have smaller effects than the maximum values presented here. The factor of self-support will be treated separately as it only marginaly influences absolute amounts consumed.

The different coefficients are given in Table 3.26.

Table 3.26: Influences of combinations of the factors region and level of urbanisation on food consumption.

	Consumption in urban and rural areas relative to consumption of the entire country (range)	
Foods	Urban area	Rural area
Cereals	0.6 - 0.8	1.4 - 1.8
Potatoes	0.5 - 1.4	0.8 - 2.4
Leafy vegetables	0.6 - 1.2	0.9 - 1.7
Fruit	0.6 - 1.2	0.9 - 1.7
Milk and milk products	0.6 - 0.9	1.1 - 1.8
Meat (fat and bone removed)	0.7 - 1.1	1.0 - 1.6

The data given in Table 3.26 for meat are for total meat consumption and cover different situations. Beef and veal are consumed more in urban areas than in rural areas whereas the reverse is true for poultry.

With regard to the factor self-support, the following remarks can be made.

Self-support of wheat is mainly important for Greece while for the other countries the level of self-support is low or even zero. For rural areas up to 80% of the total amount of potatoes consumed may come from peoples own production.

For both leafy vegetables and common European fruit (citrus and tropical fruit excluded), self-support in rural areas may amount to 60% of total consumption of vegetables and up to 30% for fruit. For specific kinds of vegetables or fruit the influence of self-support may be smaller. For example, 75% of peas are consumed as canned and only 25% as fresh. In this case the regional origin of the product is not important, as differences in origin are levelled out by distribution at the national level.

Another factor, not mentioned so far is the distinction between fresh and preserved products. For milk, the influence of storage life is important for some countries: e.g. milk is consumed primarily as pasteurized in Ireland, UK and the Netherlands, but in France 75% is consumed as UHT or sterilized milk.

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4 DISTRIBUTION OF FOOD

4.1 INTRODUCTION

4.1.1 Objective of the food distribution research

The Article 31 Group of Experts introduced the relative contamination factor when it established Derived Intervention Levels (DILs) for the level of activity in foodstuffs. The factor was assumed to be 0.1 and should be applied to the full value of the DIL. The factor is partly determined by the radio-active decay of the nuclides present, and partly by the dilution of contamination due to the distribution of foodstuffs. Dilution can occur in two ways: exportation of contaminated food, and decrease of local contamination by importation of uncontaminated food from other regions or countries. Scenarios for which the value of 0.1 is satisfactory are for instance: the annual intake of food is uncontaminated for 90% and for 10% only contaminated up to the DIL; or the activity concentration of the total diet does not surpass 10% of the DIL when averaged over the whole year.

When calculating doses due to ingestion, it is generally assumed that consumed amounts are all produced locally. This hypothesis is valid for a limited number of people living in rural areas with low population density and a large production of foodstuffs. It is less valid for most of the people living in areas with high population density, where local production is insufficient and foodstuffs must be imported from other regions from the same country, from other EC countries, or even from non-EC countries. Therefore, distribution and local production need to be studied, areas of production and consumption have to be determined, and the dilution factors have to be estimated. Another reason for studying transportation of foodstuffs is that the importance of exchanges within the European Community and with other countries needs to be known when authorities have to decide on countermeasures which might temporarily limit or ban food trade.

In literature (Obino, 1980a; Obino, 1980b; Obino, 1981; Stemmelen, 1984), data on food distribution patterns within the EC are given for milk and dairy products, the various kinds of meat, and for the irrigated vegetables that were exchanged during the 1976-1978 period. This data needs to be updated to take into account the entry of Spain, Portugal, and Greece into the Community, and the data collection must be extended to a larger number of food classes.

The objective of this chapter is to assess for each of the major foodstuffs consumed in a region or in a country the proportion imported and its origin. Using this data, the dilution factor may be estimated. For example, if uncontaminated imports represent 30% of the production in a particular region and when production is contaminated, one may consider as a first estimate that the radioactive concentration is reduced by a factor of 0.77. Regions that export their overproduction are considered as influencing regions, whereas importing regions are considered as affected regions. In general, influencing regions have a large production and low population density, whereas affected regions have a large demand due to a large population.

4.1.2 Self-sufficiency and exchanges at the country level

The agricultural policy of the European Community has been to achieve, as much as possible, self-sufficiency for the entire EC for basic foodstuffs. National production was stimulated when it was insufficient, and exchanges between the member states were encouraged. All these efforts resulted in a high level of self-sufficiency for the entire EC, and a moderately high level of self-sufficiency for most of the member states. As a consequence, imports from non-EC countries are few, and for most of the products exchanges between the member states are low when compared with national production.

4.1.3 Contents of this chapter

In Section 4.2 the methodology is described. The different levels of exchanges are explained from the international level to the interregional level. Choice of regions within countries is explained, and available data sources are presented. The classes of foods are defined. In Section 4.3 results are presented for each class of food. Exchanges between countries are always given. Exchanges which involve regions are described in the extensive report "Distribution of foodstuffs in the European Community" (Brenot, 1990); here, only general comments on regional exchanges will be introduced. Conclusions are given in Section 4.4.

4.2 METHODOLOGY

4.2.1 Different levels of exchanges

The trade of vegetable and animal products implies exchanges of products between regions of production and regions of consumption and/or marketplaces. Four levels of exchanges can be distinguished when countries are broken down by region. They are: a) international exchanges between countries that are summed at the country level; b) international exchanges that occur between a country and regions of another country; amounts that are imported (exported) are known for each region which imports (exports); c) international exchanges between regions of different countries; d) regional exchanges within a country. Exchange data are always known at the international level when it concerns countries, but are less reliable and even sometimes unknown when regions are involved.

As was done in Chapter 3, Belgium and Luxembourg are combined in BLEU. No regions are considered for BLEU, Denmark, Ireland, the Netherlands, and Portugal. Greece is not divided because to our knowledge no interregional exchanges exist for foodstuffs. With respect to Spain, there is also no division adopted because no regional data are in our possession. A breakdown into regions is considered only for the Federal Republic of Germany, France, Italy and the United Kingdom. The regions chosen are administrative entities, as listed in the Regions Statistical Yearbook (Eurostat 1987), or aggregates of such entities. In this way regions are large enough to avoid local particularisms and to deal with large enough amounts of exchanges. For FRG the 11 Länder are used. For France the 8 ZEAT's (Zone d'Etudes et d'Aménagement du Territoire) are selected, which are aggregates from the 21 French administrative regions. The same procedure is used for Italy: four large zones were defined as aggregates of the 20 Italian administrative regions. For the UK the four basic regions are England (made up of eight regions), Wales, Scotland and North-Ireland. For details on regions used, see the extensive report.

When describing exchanges, imports as well as exports can be discussed. In this document only importation is studied. For the countries or regions of destination (affected countries or regions), imported amounts and their origin are considered. With respect to the origin of food, a distinction is made between imports from EC countries and imports from outside the EC because of the importance of the Common Market. Also, there might be differences in the contamination levels, and in the values adopted for DILs.

For a country or region which imports, importations plus production make up the total amount of food available, i.e., the resources which can be used for different purposes (see Fig.3.1). It is not known whether a particular fraction of the resources is used for a specific purpose (for example, import of grain from outside the EC is only used for making bread). Therefore, the hypothesis is adopted that all the different components of the resources are mixed before they are used. As a consequence imports dilute the regional production. In 1986, for example, imports of French wheat by Nordrhein-Westfalen (647 x 1000 tons) represented 26% of the resources (2427 x 1000 tons); in this case, one may hypothesize that 26% of human consumption had a French origin when local production (1459 x 1000 tons) contributed 60%. To resume, for regulatory purposes it is necessary to know the quantities exchanged, but concerning the diet of an individual living in a particular region, the only valuable information that can be given is the relative contribution of countries or regions to the diet.

For vegetable products, exchanges depend on the period of the year, particularly for those products where harvesting periods differ from region to region. This is especially true for leafy vegetables which are produced mostly during summer in northern countries but earlier in the south. On the contrary, exchanges of animal products are less seasonally dependent. In this chapter the evaluation of exchanges is based on annual data because seasonal data are often not available and would involve an impressive workload to collect, whereas the benefit in relation to the scope of this project would be small.

4.2.2 Data sources

External trade between countries

All commodities that are exchanged between countries are registered as imports or exports by National Customs, which provide the data for statistical publications of international organizations. Detailed nomenclatures of the commodities are used for this purpose. OECD has the CTCI Revision 2 whereas EUROSTAT uses the NIMEXE nomenclature. In the OECD data bank of external trade (OECD, 1988), data of EC countries are the same as that reported in the EUROSTAT Nimexe data bank (Eurostat, 1986). Data given in this chapter comes from OECD and refers to 1986.

External trade between regions and countries

Exchanges at this level are also registered by National Customs. Within a country, Customs knows for each constitutive region, for imports and for exports, the commodities that are exchanged, their amounts and the countries of origin or of destination. Meanwhile, in the case of imports it is difficult to know whether a product coming from country B has been produced in B or is imported by B from country C. This phenomenon is supposed to be unimportant for the main foodstuffs. Moreover, in Customs data there is no information about what is exchanged between the regions of country A and the regions of country B. Such data does not exist and can only be estimated using models. The most common assumption then is the "independence hypothesis": each region of country B behaves as the entire country, that is each region of country B has a pattern of importation from regions of country A that is the same as the total importation pattern of country B. It must be mentioned also that nomenclatures used by National Customs are generally less precise than the NIMEXE nomenclature.

Internal trade - transportation data

Exchanges of commodities occur principally between regions of one country. They involve different transportation modes: truck, train, and boat. For some countries the corresponding traffic is registered by transport authorities and quantities are estimated by surveys realized with the assistance of transportation companies. Nomenclatures of products are not very detailed because domestic transport has practical constraints that make illusory the use of precise nomenclatures. Only very large classes of foodstuffs can be considered.

Internal trade - market data

In some cases regional exchanges can be estimated from statistical data describing the market of elimentary products. Vegetables and fruit, living animals and meats are produced and bred in certain regions and sent to large marketplaces from where they are dispersed. Origin and quantity of the products are known and therefore the flow of foodstuffs can be described.

4.2.3 Choice of foodstuffs

All considerations given previously lead to the choice of large classes of products in order to present all different types of exchanges as homogeneously as possible and to make comparable the tables at the different levels. The foodstuffs considered in this chapter are:

Wheat : including spelt and maslin, unmilled; when unavailable cereals total.
Potatoes : fresh or chilled.
Vegetables : total fresh, chilled, frozen and preserved.
Fruit : total fresh, chilled, frozen and preserved.
Milk products : - Milk and cream
  - Butter and cheese
Meat : total fresh, chilled, frozen and preserved; including offals and sometimes live animals.
Fish : fresh, chilled and frozen. include crustaceans ans molluscs
Eggs

4.3 FOOD DISTRIBUTION

4.3.1 Self-sufficiency at the country level

Self-sufficiency of a country is defined as the ratio of usable production and total domestic uses (usable production plus importation minus exportation) and is generally expressed as a percentage. It is calculated for each product and for each country by EC economical services, see EUROSTAT balance sheets (Eurostat, 1988). In Table 4.1 self-sufficiency of the seven major foodstuffs is given. A value greater than 100 means that total usable production is greater than the demand, and the country is able to export the product concerned. A value below 100 indicates a need to import.

Table 4.1 : Self-sufficiency (%) of 7 products in the countries of the European Community

		BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
Wheat	Soft wheat	72	105	99	239	82	56	58	47	33	97	108
	Hard wheat	-	-	39	114	194	-	131	-	53	92	40
Potatoes	Potatoes	101	99	93	104	108	80	97	132	92	100	94
Vegetables	Vegetables	119	71	39	92	139	75	128	200	145	134	61
Fruit	Fruit (excl. citrus)	60	36	52	92	128	14	131	47	97	118	23
	Citrus				3	188		114		99	261	
Milk Products	Raw milk	98	100	105	101	100	100	88	100	99	99	100
	Fresh milk products (excl. cream)	127	104	104	128	98	100	81	185	-	-	131
	Cream	88	100	113	114	107	105	64	104	-	-	97
	Butter	117	93	118	123	51	571	63	453	87	84	73
	Cheese	38	396	95	114	87	450	79	254	100	86	72
Meat	Total meat	124	304	93	99	68	277	71	247	95	97	80
	Bovine	128	283	121	118	33	678	58	219	86	95	80
	Pork	146	252	88	80	69	114	66	278	96	97	72
	Sheep and goats	22	33	45	71	86	196	57	225	100	99	79
	Poultry	80	193	61	129	96	91	98	212	100	99	95
Eggs	Eggs	114	101	72	98	97	77	92	357	100	101	96

At first view, for most countries, self-sufficiency is higher than 90% for all animal products and for potatoes, and then exchanges are of little importance. For vegetable products the situation is more contrasted.

In the EC, the wheat produced is basically soft (65 531 x 1000 tons, 92% of total EC wheat). France is the main exporter of wheat whereas BLEU, Ireland, Italy, the Netherlands and Portugal show large deficiencies. Regarding hard wheat (5 755 x 1000 tons, 8% of total production), only Greece and Italy, the biggest producers, have an important capacity for exportation.

For potatoes, all countries show a high level of self-sufficiency. In Ireland there is a need to import potatoes. The Netherlands can supply the major part of all imports to other EC countries.

The level of self-sufficiency of vegetables shows large discrepancies between the different member states. All southern countries have an excellent coverage of national needs, and all are exporters. The situation is similar for the Netherlands which has very efficient agriculture production. Denmark, Ireland, the UK, and especially the FRG need large imports to satisfy the national demand.

With regard to fruit, all northern countries, especially Denmark, Ireland, and the UK show a lack of fruit due to a low production of non-citrus fruit and no production at all of citrus fruit. The Mediterranean countries have a high production of both kinds of fruit and all have an excess. Spain and Italy are the main suppliers of fruit within Europe.

Most countries overproduce milk and milk products, except in Italy where all types of milk products are lacking. For butter and cheese the situation is more diverse, with large overproduction in some countries (Denmark, cheese; Ireland and the Netherlands for butter and cheese), and need for importation in other countries (Greece, Italy, Spain, the UK).

Supply balance sheets are established for the specific kinds of meat (cattle, pigs, sheep and goats, and poultry), as well as for the sum of all kinds (named total meat). Self-sufficiency is high in BLEU, Denmark, Ireland, and above all in the Netherlands; it is low in the UK and even lower in Greece and Italy, whereas the FRG and France overproduce some kinds of meat and underproduce other kinds.

No supply balance sheet is available for fish.

Finally, for eggs self-sufficiency is rather high in all countries except in the Federal Republic of Germany and to a lesser degree in Ireland. The Netherlands with their large overproduction supplies a large percentage of the demand within the EC.

International exchanges at the country level are given by product in the following tables (Table 4.2 to 4.10). The countries of origin make up the lines and the countries of destination the columns. For each product two subtables appear. In the first subtable, data are expressed as 1000 ton. The symbol '0' is used when there is no importation or production, and the symbol ':' when the amount concerned is less than 1000 tons. This subtable also gives information on the relative contribution of importations to the resources (the total amount available). This information is useful in estimating dilution factors; therefore data are provided for productions and importations of EC countries as well as for total importations (sum of importations from countries within and outside the EC, called 'world'). In the second subtable, data are given as profiles, that is importations by country A from country B are expressed as percentages of total importations by country A. Percentages greater than 1 are expressed as integers; below 1 they are not indicated.

4.3.2 Exchanges of wheat

According to Table 4.2, 81% of the imports by EC countries comes from within the EC, and all imports do not represent more than 20% of EC production. As mentioned in the previous chapter, BLEU, Ireland, Italy and the Netherlands import large quantities of wheat (soft wheat principally), their suppliers being France and the UK.

Table 4.2: Wheat (including spelt) and maslin, unmilled; international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	:	84	1	1	1	0	83	0	0	33	203
Denmark	:	0	124	0	0	7	0	4	0	0	29	165
Germany	84	48	0	19	0	9	49	116	:	:	98	423
France	793	41	1055	0	413	185	3239	709	35	284	697	7452
Greece	5	:	0	0	0	:	244	0	0	0	0	249
Ireland	:	1	5	0	0	0	0	0	0	0	99	106
Italy	:	0	1	5	7	0	0	:	0	0	1	15
Netherlands	51	0	200	:	0	:	0	0	0	:	29	280
Portugal	0	0	0	0	0	0	0	0	0	0	0	0
Spain	2	0	0	:	28	0	62	7	1	0	7	107
United Kingdom	171	113	891	109	1	141	757	223	0	568	0	2973
EEC	1106	204	2359	135	450	343	4352	1142	36	852	993	11972
World	1202	213	2393	318	453	377	5259	1258	642	882	1708	14705
Production	1325	2177	10455	26587	2389	424	9070	940	500	4298	13910	72075
EEC/World %	92	96	99	42	99	91	83	91	6	97	58	81
EEC/World+Production %	44	9	18	1	16	43	30	52	3	16	6	14

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU			4					7			2
Denmark			5			2					2
Germany	7	23		6		2	1	9			6
France	66	19	44		91	49	62	56	5	32	41
Greece							5				
Ireland		1									6
Italy				2	2						
Netherlands	4		8								2
Portugal											
Spain					6		1	1			
United Kingdom	14	53	37	34		37	14	18		64	
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, OECD

Productions : 1986, Harvested productions, EUROSTAT Statistical yearbook.

From the analysis of regional exchanges of wheat within France, as estimated by transportation data, two comments of general value can be made. Firstly the transported amount and the national production are almost equal, so there is no double counting of transported amounts. Wheat is transported only once from the grain elevator to the mill. Secondly, transfers are of small distance (less than a hundred kms) and are, for the most part, realized in the region of production or between two adjacent regions.

4.3.3 Exchanges of potatoes

Of all EC imports, 90% comes from within the EC (Table 4.3). Imports from outside the EC represent less than 10% of the Community production. The Netherlands is by far the largest supplier for most of the countries.

Belgium has a particular pattern which is due to an important triangular exchange with France and the Netherlands.

Table 4.3: Potatoes fresh or chilled, international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	0	17	96	:	:	2	286	4	2	47	453
Denmark	0	0	:	2	0	:	1	:	4	:	0	7
Germany	11	3	0	2	1	0	53	453	1	2	1	528
France	162	1	41	0	:	:	162	18	6	33	25	449
Greece	:	:	8	:	0	:	:	:	0	0	8	17
Ireland	0	0	0	0	:	0	0	:	:	6	12	18
Italy	14	18	221	36	0	1	0	14	0	:	6	308
Netherlands	260	8	641	68	5	48	164	0	52	53	143	1441
Portugal	0	0	0	:	0	0	0	0	0	3	0	3
Spain	:	1	8	20	0	:	:	1	2	0	39	71
United Kingdom	1	0	:	:	0	48	:	1	26	53	0	130
EEC	448	31	936	224	6	97	383	773	95	152	279	3424
World	460	34	964	303	8	104	436	782	99	154	467	3810
Production	1692	1129	7390	6021	971	619	2547	6854	1114	4857	6445	39639
EEC/World %	97	91	97	74	75	93	88	99	96	99	60	90
EEC/World+Production %	21	3	11	4	1	13	13	10	8	3	4	8

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU			2	32				37	4	1	10
Denmark				1					4		
Germany	2	9		1	13		12	58	1	1	
France	35	4	4				37	2	6	22	5
Greece		1	1								2
Ireland					1					4	3
Italy	3	52	23	12		1		2			1
Netherlands	56	23	66	22	65	46	38		52	34	31
Portugal										2	
Spain		2	1	6					2		8
United Kingdom						46			26	35	
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, OECD

Productions : 1986, Harvested productions, EUROSTAT Statistical yearbook.

4.3.4 Exchanges of vegetables

For vegetables (Table 4.4), imports come from within the EC for 91% and they represent 11% of total EC production. In general, imports come mainly from the Netherlands and secondly from Spain. This is particularly the case for the FRG which is the major importer. All southern countries have very few imports, as almost all are produced in the country itself.

Table 4.4: Vegetables fresh or chilled, international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	:	96	171	:	:	8	49	:	:	6	332
Denmark	:	0	1	0	0	:	:	:	0	:	:	2
Germany	6	6	0	5	:	:	1	33	0	:	10	61
France	51	5	174	0	:	6	13	53	:	1	98	400
Greece	:	:	56	:	0	:	:	1	0	0	:	57
Ireland	0	:	0	0	0	0	:	:	0	0	11	11
Italy	18	11	305	135	:	3	0	25	0	:	27	523
Netherlands	202	30	828	223	:	21	13	0	1	1	278	1597
Portugal	:	:	:	:	0	:	:	1	0	:	1	4
Spain	25	22	344	355	0	10	16	142	2	0	368	1285
United Kingdom	:	:	8	:	0	8	:	7	0	:	0	24
EEC	302	73	1813	889	:	49	52	309	3	2	800	4293
World	307	80	1991	1007	:	56	67	337	4	2	882	4734
Production	1057	278	1511	5254	3690	228	11081	2936	1700	9262	3639	40636
EEC/World %	98	91	91	88		88	78	92	75	100	91	91
EEC/World+Production %	22	20	52	14		17		9			18	9

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU			5	17	1		12	14		8	1
Denmark											
Germany	2	7			1	1	2	10		1	1
France	17	6	9			10	19	16	1	51	11
Greece			3								
Ireland											1
Italy	6	13	15	13	18	6		7			3
Netherlands	66	38	42	22	14	37	20		32	31	32
Portugal										5	
Spain	8	27	17	35		18	24	42	59		42
United Kingdom						14		2			
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, OECD
Productions : 1986, Harvested productions in agricultural holdings, EUROSTAT Statistical yearbook.

Regional exchanges within a country involve, in general, multiple loadings. This important point is observed in transportation data of vegetables in France. Transported quantities are twice as large as the quantities produced. This is due to the existence of large marketplaces where all fresh products are gathered to be sold and sent to other destinations.

4.3.5 Exchanges of fruit

Contrary to the vegetable products discussed so far, imports of fruit are large with respect to EC production (35%) and only 50% coming from within the EC (Table 4.5). Thus, a large place is made for non-EC products. Imports by country are about equally divided over the different exporting countries, and it is difficult to distinguish one or two major suppliers of fruit; Italy and Spain are major exporters in certain cases.

Table 4.5: Fruit and nuts (not inc. oil nuts), fresh or dried, international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	1	25	24	:	:	9	85	:	1	42	187
Denmark	:	0	2	0	:	:	:	:	:	0	:	3
Germany	11	21	0	6	:	:	27	32	:	:	13	110
France	85	21	173	0	1	31	49	101	1	13	302	776
Greece	5	8	199	26	0	4	48	57	:	:	97	444
Ireland	:	:	0	0	0	0	0	:	0	0	20	20
Italy	76	32	883	230	:	7	0	43	0	1	131	1404
Netherlands	70	5	57	25	2	3	10	0	:	5	82	259
Portugal	1	:	1	2	0	:	:	4	0	1	1	10
Spain	140	32	648	842	:	14	37	200	6	0	320	2238
United Kingdom	3	:	1	:	:	15	:	10	:	:	0	31
EEC	392	120	1990	1154	3	74	181	533	7	21	1008	5482
World	671	220	3542	2393	6	157	694	1199	21	82	2045	11032
Production	418	83	3584	3481	3499	13	11029	586	536	7782	501	31512
EEC/World %	58	55	56	48	50	47	26	44	33	26	49	50
EEC/World+Production %	36	40	28	20		44	2	30	1		40	13

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU			1	1	1		1	7		1	2
Denmark											
Germany	2	9			6		4	3			1
France	13	10	5		10	19	7	8	3	15	15
Greece	1	3	6	1		2	7	5	1		5
Ireland											1
Italy	11	15	25	10	5	4		4		1	6
Netherlands	10	2	2	1	27	2	1		1	6	4
Portugal										1	
Spain	21	14	18	35		9	5	17	28		16
United Kingdom	1					10		1			
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, (Juices preparations not included), OECD

Productions : 1986, Total table fruits, harvested production, EUROSTAT Statistical yearbook.

From the analysis of exchanges concerning regions, three general comments can be made. Firstly, in all highly urbanized regions, as for example Hambourg, Bremen and Ile de France (Paris area), the exchanged quantities of fruit are important because of a large demand and the existence of large installations for trade; thus on the average, more than 70% of the fruit imported comes from non-EC countries. Secondly, the phenomenon of multiple loadings is once again illustrated with French data on the transportation of fruit where the amount transported is twice the national production. Thirdly, the major transportations of fruit occur always from southern regions to northern ones.

4.3.6 Exchanges of milk and milk products

Almost all imports of fresh milk come from within the EC, and they are very few compared to production (3%). Only in Italy are there large imports coming from Germany (80%), with the remaining 20% coming from France (Table 4.6).

Table 4.6: Milk and cream, fresh, not concentrated or sweetened, international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	0	84	106	9	:	29	282	0	21	4	535
Denmark	:	0	2	0	:	0	1	:	:	:	:	3
Germany	96	3	0	9	2	0	1412	201	0	17	1	1741
France	58	:	66	0	3	:	334	:	0	169	:	630
Greece	:	0	:	:	0	0	:	:	0	0	2	3
Ireland	0	0	:	:	:	0	:	0	0	:	27	28
Italy	:	0	:	:	:	0	0	:	0	:	:	:
Netherlands	16	0	5	:	1	:	1	0	0	1	1	25
Portugal	0	0	0	0	0	0	0	0	0	0	0	0
Spain	0	0	:	6	0	0	1	0	0	0	0	8
United Kingdom	:	:	0	:	:	34	:	:	:	:	0	34
EEC	170	3	156	121	15	34	1779	484	:	208	35	3007
World	170	3	159	123	15	34	1780	484	:	209	35	3012
Production	3451	4899	24196	26257	949	5585	8476	12331	880	7046	15587	109657
EEC/World %	100	100	98	98	100	100	100	100		100	100	100
EEC/World+Production %	5		1		2	1	17	4		3		3

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU			53	86	57		2	58		10	10
Denmark			1		1				61		1
Germany	57	99		7	14		79	42		8	2
France	34		42		19		19			81	
Greece											6
Ireland					1						78
Italy											
Netherlands	9		3		7						2
Portugal											
Spain				5							
United Kingdom		1				99			39		
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, OECD

Productions : 1986, Raw milk delivered to dairies. EUROSTAT Statistical yearbook
1985, Raw milk delivered to dairies. OECD Food consumption statistics.

Butter and cheese exchanges are more diverse. Imports from within the EC amount to 90%. Major importers are, relative to population size, BLEU (imports from the Netherlands and Germany), Italy (imports from Germany), the UK, and Germany (imports from the Netherlands). Major exporters are the Netherlands, FRG, and France (Table 4.7). For cheese many countries are both importers and exporters, importers of certain varieties of cheese and exporters of other varieties.

Table 4.7: Butter and cheese, international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	4	13	26	2	:	35	49	0	:	19	148
Denmark	5	0	39	1	9	:	11	3	:	3	43	114
Germany	74	3	0	36	19	:	164	21	:	5	26	347
France	41	4	76	0	2	1	68	15	:	5	15	226
Greece	:	:	2	:	0	0	:	:	0	0	:	2
Ireland	11	0	14	2	2	0	1	17	0	1	83	130
Italy	2	:	9	10	:	:	0	4	:	:	3	29
Netherlands	96	8	216	62	12	:	33	0	1	14	35	477
Portugal	:	0	0	0	0	0	0	:	0	:	:	1
Spain	:	:	:	1	0	0	:	:	:	0	:	1
United Kingdom	8	2	5	8	:	8	2	24	:	1	0	58
EEC	237	21	375	146	45	10	314	131	2	29	224	1534
World	248	22	391	162	46	10	355	134	7	35	317	1727
Production	148	366	1491	1937	187	223	740	776	50	170	460	6548
EEC/World %	96	95	96	90	98	100	88	98	29	83	71	89
EEC/World+Production %	60	5	20	7	19	4	29	14	4	14	29	19

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU		18	3	16	5	3	10	36		1	6
Denmark	2		10	1	19	2	3	2	4	8	14
Germany	30	11		22	41	3	46	16	2	14	8
France	17	17	19		4	6	19	11	2	13	5
Greece											
Ireland	5		4	1	4			12		3	26
Italy	1	1	2	6				3			1
Netherlands	39	36	55	38	25	5	9		13	40	11
Portugal										1	
Spain											
United Kingdom	3	11	1	5		80	1	18	4	2	
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, OECD

Productions : 1986, EUROSTAT Statistical yearbook,
1985, OECD Food consumption statistics.

4.3.7 Exchanges of meat

In Table 4.8, imports when compared to EC production are rather low (14%), and come for the most part (80% on the average) from EC countries. The Netherlands exports large quantities of meat to FRG, France, and Italy. Italian imports, that rise up to 25% of the Italian production, are covered 30% by the Netherlands, 20% by Denmark, 20% by Germany, and 20% by France. The UK has a particular pattern of importation with Ireland as the main country of origin, and 43% of its imports coming from non-EC countries.

Table 4.8: Total Meat, fresh, chilled or frozen (inc. offals), international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	:	60	158	6	:	70	50	1	8	4	357
Denmark	3	0	105	71	10	1	132	1	4	12	52	391
Germany	8	9	0	114	85	:	185	21	7	7	15	449
France	18	1	101	0	13	:	124	12	3	27	54	354
Greece	:	0	:	:	0	0	:	:	0	:	:	1
Ireland	4	1	18	73	:	0	4	5	:	2	141	248
Italy	1	:	16	11	15	0	0	2	:	4	:	50
Netherlands	63	6	473	207	49	:	307	0	4	31	45	1185
Portugal	0	0	:	0	0	0	:	0	0	0	0	:
Spain	:	0	1	7	:	:	1	1	1	0	1	11
United Kingdom	13	1	51	125	1	24	6	10	:	7	0	239
EEC	109	19	826	766	180	25	829	100	20	99	312	3285
World	143	24	972	877	216	26	984	132	32	154	550	4110
Production	1348	1576	5814	5734	537	754	3892	2505	535	3108	3426	29229
EEC/World %	76	79	85	87	83	96	84	76	63	64	57	80
EEC/World+Production %	7	1	12	12	24	3	17	4	4	3	8	10

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU		2	6	18	3		7	38	4	5	1
Denmark	2		11	8	5	3	13		13	8	9
Germany	5	40		13	39		19	16	21	4	3
France	13	5	10		6		13	9	9	17	10
Greece											
Ireland	3	3	2	8				3		1	26
Italy	1	1	2	1	7			2		3	
Netherlands	44	26	49	24	23		31		12	20	8
Portugal											
Spain				1					3		
United Kingdom	9	5	5	14		94	1	8	1	5	
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986,OCDE

Productions : 1986, usable production (slaughterings), EUROSTAT Statistical Yearbook.

In the analysis of regional data, the largest imports occur for highly urbanized regions. In France, one region, the Ile de France which has the largest demand (more than 10 million consumers), has as many imports as all the other regions, imports coming almost equally from BLEU, the Netherlands and the UK. In Germany, Nordrhein-Westfalen (16 million consumers) occupies a similar situation and its major supplier is the Netherlands. Concerning Italian regions, the northern ones are the largest producers. The Northwest region (Piemonte) is self-supporting and only the Northeast region has the capacity to export to the Centre and South.

4.3.8 Exchanges of fish

Imports of fish, crustaceans and molluscs, listed under the heading 'fish', rise to 40% of the catches reported by EC countries (Table 4.9). Half of the imports are covered by EC countries, principally Denmark, the Netherlands and the UK. For Germany and BLEU, catches are much lower than imports, the difference is covered only partially by Denmark and the Netherlands respectively. The exchanges of fish are more difficult to use than those discussed previously because imports from a country do not contain information on the actual origin of the catches (catch areas for fish are extremely large and all coastal waters are concerned for crustaceans and molluscs).

Table 4.9: Fish, crustaceans, and molluscs, fresh, chilled or frozen, international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	3	2	4	:	:	:	11	:	:	4	25
Denmark	12	0	124	29	:	:	21	47	:	5	37	277
Germany	3	21	0	8	:	:	3	26	0	:	4	66
France	12	1	14	0	1	:	38	5	1	22	6	99
Greece	:	:	:	2	0	0	1	:	0	2	:	6
Ireland	1	1	12	25	:	0	:	9	:	6	29	83
Italy	1	:	4	23	4	0	0	1	:	23	1	57
Netherlands	42	21	41	45	5	:	28	0	1	5	19	206
Portugal	:	2	1	3	:	:	1	:	0	11	1	20
Spain	:	:	3	20	1	:	51	:	42	0	2	120
United Kingdom	5	23	12	57	:	13	3	43	1	28	0	183
EEC	75	72	212	216	13	14	146	143	45	103	104	1142
World	96	300	376	415	43	15	358	156	72	273	287	2391
Production	38	1825	186	660	115	193	399	479	255	1098	762	6010
EEC/World %	78	24	56	52	30	93	41	92	63	38	36	48
EEC/World+Production %	56	3	38	20	8	7	19	23	14	8	10	14

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU		1	1	1		1		7			1
Denmark	12		33	7	1		6	30	1	2	13
Germany	3	7		2	1		1	16			2
France	13		4		2	2	11	3	1	8	2
Greece				1						1	
Ireland	1		3	6	1			6		2	10
Italy	1		1	5	10			1		8	
Netherlands	44	7	11	11	11	1	8		1	2	7
Portugal		1		1						4	
Spain			1	5	3	1	14		59		1
United Kingdom	5	8	3	14		88	1	27	1	10	
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, Live or dead , OECD

Productions : 1986, Catches live weight, EUROSTAT Statistical yearbook.

4.3.9 Exchanges of eggs

As shown in Table 4.10, almost all imports come from within the EC (97%). They are low compared with production (9%) and come almost totally from the Netherlands. The FRG is the major importer of eggs.

Table 4.10: Eggs and yolks, fresh, dried or otherwise preserved, international exchanges

IMPORTATIONS (1000 TONS)

Origin	Destination											
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK	EEC
BLEU	0	0	27	23	0	:	3	3	0	:	:	57
Denmark	:	0	1	:	:	0	:	:	0	:	1	1
Germany	1	1	0	1	:	:	18	3	:	:	2	27
France	5	:	2	0	:	0	5	:	:	1	2	17
Greece	0	0	0	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	:	:	:
Italy	0	0	:	:	0	0	0	:	0	:	0	:
Netherlands	35	2	273	9	:	:	28	0	:	1	18	366
Portugal	0	0	0	0	0	0	0	0	0	:	0	:
Spain	:	0	:	:	0	0	:	:	:	0	0	1
United Kingdom	1	0	2	1	0	7	1	2	:	:	0	14
EEC	43	3	306	35	:	7	56	9	:	2	23	484
World	44	5	312	35	:	7	58	13	:	2	23	500
Production	174	75	728	848	116	34	596	607	69	641	722	4610
EEC/World %	98	60	98	100		100	97	69		100	100	97
EEC/World+Production %	20	4	29	4		17	9	1			3	9

IMPORTATIONS (Profiles %)

Origin	Destination										
	BLEU	DK	FRG	F	GR	IRL	IT	NL	P	SP	UK
BLEU			9	65			6	26		5	
Denmark											2
Germany	3	24		4	24		32	23	3		8
France	12	1	1		3		9	3	38	56	10
Greece											
Ireland										1	1
Italy										1	
Netherlands	80	37	87	26	20		49		49	34	77
Portugal											
Spain				1					5		
United Kingdom	2		1	3		100	1	15	1	1	
World	100	100	100	100	100	100	100	100	100	100	100

Importations : 1986, OECD

Productions : 1986, Eggs for consumption, EUROSTAT Statistical yearbook.
1985, Eggs for consumption, OECD Food consumption statistics.

4.4 CONCLUSIONS

The European Community has achieved a high level of self-sufficiency for the main foodstuffs with its voluntarist policy for agriculture. In general most countries have an overproduction of the different products, in which case they are self-supporting. A low percentage of the imports comes from countries outside the European Community.

National self-sufficiency is higher than 80% for all animal products (milk and milk products, butter and cheese, meat, and eggs) in almost all countries. As a consequence imports are low relative to production, in general less than 25%. More than 80% of imports come from within the EC. There are a few countries which show large deficits for a given product: Italy for all dairy products, the United Kingdom for butter and cheese, Greece and Italy for meat, and the Federal Republic of Germany for eggs.

Self-sufficiency varies much more for the different vegetable products. It rises to 90% for potatoes in all countries with the one exception of Ireland (80% only). Moreover 90% of the potatoes imported in each country come from within the EC. On first analysis for the EC as a whole, the situation concerning vegetables appears to be satisfactory; indeed imports represent no more than 10% of production, and more than 90% of the imports come from within the EC. There are, however, large discrepancies at the national level: overproduction in the southern countries and the Netherlands, large deficiencies in Denmark, Ireland, the UK, and in FRG (more than 50% of the usable amount of fresh vegetables is imported in FRG). For fruit there is a general deficit in the EC: imports represent one-third of the production and are equally supplied by non-EC countries and EC countries (Greece, Italy and Spain respectively). With regard to wheat, importation amounts for a maximum of 20% of production. BLEU, Ireland, Italy, the Netherlands, and Portugal show severe deficiencies that are provided for largely by wheat coming from EC countries (80%, principally from France and the UK).

The Netherlands has a very efficient agriculture production which makes them the largest exporter of potatoes, vegetables, all dairy products, all kinds of meat, and eggs. The other countries show a more complex situation: they are exporters for certain products and importers for others. For instance, all southern countries export vegetables and fruit but they lack meat or certain dairy products, France is the major exporter of wheat but lacks pork.

A general deficit of foodstuffs exists in all regions that are highly urbanized and industrialized. They represent areas without agricultural production, but with well developed trade and distribution networks. Their imports generally show less preference than is commonly given to EC products.

The analysis of regional exchanges estimated by transportation data (herewith the French situation) leads to some conclusions about loading practices. Fresh vegetables and fruit are transported twice on the average, at first from the region of production to the region with market installations, and then from the market to the region of consumption. For raw milk, the ratio of transported to produced amounts is 3:2. For the other dairy products numerous loadings must be expected and the same holds true for meat. On the contrary, grain is transported once from the grain elevator to the region of milling and transportation distances are short.

In summary, the first approximation for all EC countries and for all foodstuffs is that imports for a given foodstuff represent 20% of the corresponding production, and 80% of the imports come from within the EC. This means that, on average, 84% of the resources is provided for by national production, 13% by production of other EC countries, and only 3% coming from outside the EC. On the basis of these average figures, in a country where national production is contaminated, imports of uncontaminated food from foreign countries are unlikely to decrease the contamination level by more than 20% . However, contamination will probably not be homogeneous for large countries. Regional exchanges, that always take place, will therefore have considerable more importance. Thus high dilution factors can be reasonably expected for foodstuffs consumed regionally; they will depend on regional self-sufficiency and they can be estimated by national authorities on a case by case basis. Such considerations for large regions do not hold for small areas that can be severely affected as could occur in the near-field of an installation after a large accident.

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5. AGE-DEPENDENT DOSES PER UNIT INTAKE OF RADIONUCLIDES BY INGESTION

5.1 INTRODUCTION

The International Commission on Radiological Protection in Publication 30 (1979) recommended biokinetic parameters and dosimetric models for calculating radiation doses for occupationally exposed adults following intakes of radionuclides by inhalation and ingestion. These parameters are, however, not necessarily appropriate for calculating radiation doses to members of the public following the release of radionuclides into the environment. For the calculation of doses to the general public it is necessary to take account of the effect of age on the biokinetics of radionuclides as well as on anatomical and physiological parameters. Incorporation of radionuclides into foodstuffs may also result in changes in their absorption from the gastrointestinal tract. Information is also needed on the transfer of radionuclides to the developing embryo and fetus following intakes of radionuclides by the mother.

A number of organisations (ORNL, ISH/BFS, NRPB) have developed age-dependent values of dose per unit intake for some radionuclides, but there are at present no generally accepted values. The International Commission on Radiological Protection (ICRP), has set up a Task Group on age-dependent dosimetry. The objectives of the Task Group are to review biokinetic data on selected radionuclides, to adopt dosimetric models that may be used for calculating age-dependent doses following intakes by ingestion and inhalation, and to provide representative values for population doses. The first report is now available as ICRP Publication 56, Part 1 (1989). The information included in this report for ingested radionuclides is consistent with the ICRP report but limited to the radionuclides likely to be of most concern after an accident: isotopes of strontium, ruthenium, iodine, caesium, plutonium and americium.

To provide representative values for a population, doses to age 70 years are calculated for intakes by the 3-month-old infant, for 1-, 5-, 10- and 15-year-old children, and for adults. Estimates of doses to the developing embryo and fetus following intakes of a number of radionuclides by the mother are also given for each element; fetal doses have not yet been considered by the ICRP Task Group but are within its remit. Variability and uncertainty in the calculation of dose per unit intake are also considered for caesium-137, iodine-131 and plutonium-239. Details of the general approach adopted are given below, followed by biokinetic and dosimetric data for the individual elements.

5.2 INTAKES BY INGESTION

The model used for calculating doses to the gastrointestinal tract from ingested radionuclides is that described by ICRP in Publication 30. Due to lack of sufficient age-specific information the mean residence times taken for the four compartments (stomach, small intestine, upper large intestine, lower large intestine) are taken to be the same as adults. This may lead to some over-estimation of the dose to different parts of the gastrointestinal (GI) tract for long-lived radionuclides. The values of gut absorption (f_1) recommended by ICRP in Publication 30 apply specifically to intakes of chemical forms of the elements expected to be encountered in the workplace and are not necessarily appropriate for radionuclides associated with food and drinking water. Consideration has therefore been given to the most appropriate f_1 values for intakes of radionuclides in foodstuffs.

The absorption of radionuclides tends to be greater in the newborn, although the results of animal studies suggest the enhancement of gut transfer progressively decreases with increasing age, reaching adult values by about the time of weaning in most cases. For most elements f_1 values for adults can therefore be considered to apply to children of one year of age or over. For younger children, an NEA Expert Group (NEA, 1988) has recently recommended f_1 values for infants for the first year of life. Where no human or animal data are available, a general approach has been suggested. For fractional absorption values between 0.01 and 0.5 in the adult an increase by a factor of 2 is assumed for the first year of life, but for elements with a fractional absorption in the adult of 0.001 or less, a value ten times the adult value is assumed. This approach has been adopted in this report as a reasonable interpretation of the available data.

After translocation from the GI tract into body fluids, a radionuclide is assumed to be cleared into organs and tissues, or to be excreted according to first order kinetics. In the absence of specific data a half-time in body fluids of 0.25 days is assumed which is taken to be independent of age. Radionuclides in the transfer compartment are taken to be distributed uniformly throughout the whole body.

Distribution and retention in body tissues is element specific and this report reviews available biokinetic information for strontium, ruthenium, iodine, caesium, plutonium, americium.

5.3 BONE SEEKING RADIONUCLIDES

The standard ICRP models are not considered appropriate for determining age-specific doses to red bone marrow and cells on bone surfaces following the deposition in the skeleton of bone volume and bone surface seeking radio nuclides.

The actinides plutonium and americium are assumed by ICRP to be bone surface seeking radionuclides and to be retained on the bone surfaces throughout life. This is likely to be a conservative assumption for adults. In practice, evidence from animal studies and human data indicate that a fraction of plutonium and other actinides become buried as a result of bone growth and turnover, whilst a fraction is reabsorbed, of which some may redeposit in the bone marrow. These processes are more important in infants and young children than in adults because of their faster bone turnover rate. To allow for these features of actinide metabolism in the skeleton, the age-dependent model developed by Leggett and his colleagues (Leggett and Eckerman 1984, Leggett and Warren, 1987) has been adopted.

For the bone volume seeking element strontium, again bone turnover will affect deposition and retention in the skeleton. The age-dependent bone model for strontium developed by Leggett (1982, 1984) which is based on physiological data and information on the concentrations of weapons fallout strontium in human bones from persons of various ages, has been applied in the report.

5.4 DOSIMETRIC MODELS

5.4.1 Adults

Models for use in internal dosimetry generally describe the transfer of radionuclides between different compartments in terms of first order kinetics. The organs of the body are represented by one or more compartments, each with its own retention half-time. The radionuclide is simultaneously undergoing radioactive decay to isotopes which may themselves be radioactive. The resulting model is equivalent to a large number of linear chains of compartments represented by the general equation (Bateman, 1910; Skrable et al, 1974):

$$\frac{dn_i}{dt} = \lambda_{i-1}\, n_{i-1} - \lambda_{i-1} - \lambda_R n_i$$

where n_i = number of atoms in compartment i at time t
λ_i = biological rate constant for transfer to the next compartment
λ_R = physical rate constant for radioactive decay.

The biokinetic model for any nuclide allows the calculation of the number of nuclei which disintegrate in each of the organs of the body in a specified period. The energy released in each decay may be absorbed in the organ in which the decay takes place, the "source" organ, or in another "target organ". The total dose to a target organ T is given by the sum of contributions from all source organs.

$$H_T = \Sigma_s\, U_s\, \mathrm{SEE}\ (T \leftarrow S)$$

where the summation is over source organs S and

U_s = number of transformations in S

SEE(T ← S) = specific effective energy, i.e., the contribution to the dose to target organ T per decay in S.

The specific effective energy absorbed in T per decay in S is given by

$$\mathrm{SEE}(T \leftarrow S) = \Sigma_i\ \frac{Y_i E_i Q_i\ AF_i\ (T \leftarrow S)}{M_T}$$

where the summation is over the different decay modes of the nuclide (in many instances there is only one mode) and

Y_i = fraction of decays in the particular mode
E_i = energy released
Q_i = quality factor
AF_i (T ← S) = fraction of this energy which is absorbed in T
M_T = mass of the target T.

The details of the decay of most nuclides of importance in radiological protection are well known and have been documented in ICRP Publication 38 (ICRP, 1983). The absorbed fractions for a variety of source/target pairs and types of radiation have been published in ICRP Publication 23 (ICRP, 1973). For the calculations presented here the adult is taken to be age 20 years and doses are calculated to age 70 years.

Note: The normal ICRP assumption is that radioactive decay products adopt the chemical characteristics of their parents (but iodine and rare gas daughters adopt their own behaviour). This assumption is also used in the calculations reported here.

5.4.2 Children

The basic ICRP Publication 30 (ICRP, 1979) scheme for calculating doses to tissues from internal emitters is that for adults. As described in Section 5.4.1, this leads to the equation for dose to target organ T.

$$H_T = \sum_S U_S \sum_i \frac{Y_i E_i Q_i \; AF_i \; (T \leftarrow S)}{M_T}$$

Modifications are needed for calculating doses to children. The smaller body size will affect organ masses (M_T above) and for all but non-penetrating radiation it is likely that absorbed fractions (AF above) will change. SEE values have been computed for individuals of various ages considered in the anthropomorphic phantom series of Cristy and Eckermann (1987). Total body mass as a function of age is given in ICRP Publication 23 (1975). It is also possible that materials will display different biokinetics in children than in adults. Very often the turnover of radionuclides in children will be faster than in adults and this will lead to differences in the number of transformations in source organs (U_S above). Differences in biokinetic parameters are considered on an element specific basis.

5.4.3 The embryo and fetus

Intakes of radionuclides before or during pregnancy may lead to irradiation of the fetus (taken here for brevity to apply to embryo and fetus). No international consensus on a scheme for calculating fetal doses has yet emerged although this is within the remit of the ICRP Task Group on Age-dependent dosimetry. A number of problems have to be considered.

(a) The fetus will take up material from maternal blood. Shortly after conception a placenta starts to form which provides a selective barrier and results in lower concentrations of many radionuclides in the fetus than in maternal tissues. Much less commonly, there is evidence for higher concentrations in the fetus than in the mother. Little is known about the ability of the human placenta to discriminate against many radionuclides and information must be obtained from experimental animals. However, different animal species have different types of placenta so care is needed in extrapolating to humans.

(b) As well as direct uptake by the fetus of radionuclides when they first enter the maternal blood from the GI tract, there is some evidence for redistribution of material from maternal to fetal organs.

(c) The fetus grows very rapidly, increasing from a single cell at conception to about 10^9 cells at birth, when the infant weighs about 3.5 kg. This rapid growth will dilute any radionuclides taken up by the fetus and will tend to reduce doses, although this dilution is, to some extent, offset by the transfer to the fetus of radionuclides deposited in maternal tissues. The function and importance of different groups of cells in the fetus changes with time as organs develop. This means that the consequences of an intake may depend very much on its timing. The rate of development of the fetus in experimental animals will also differ from that in humans and may need to be allowed for. A number of ad hoc schemes for calculating the dose to the fetus have been developed. Details may be found elsewhere (Stather et al, 1984; NRPB, 1987). The present position on the development of models for the elements considered in this report is given in the following sections.

5.5 BIOKINETIC DATA FOR STRONTIUM

5.5.1 Uptake to blood after ingestion

Adults

The behaviour of strontium in the body is qualitatively very similar to, but quantitatively different from, that of calcium (Comar, 1963; Comar and

Wasserman, 1964). The absorption of calcium is generally greater than that of strontium by up to a factor of 2, although in ICRP Publication 30 (ICRP, 1979) they are assigned the same f_1 value of 0.3. Human studies of strontium absorption have given average values for dietary forms and soluble salts in the range from about 0.2-0.5. Results for other animal species are generally similar (Coughtrey and Thorne, 1983). Factors found to increase absorption include fasting and low dietary levels of calcium, magnesium and phosphorus. Milk diets and vitamin D may also increase absorption. Spencer et al (1972) showed that overnight fasting of human volunteers results in an increase in strontium absorption from about 0.25 to 0.55. The ICRP f_1 value of 0.3 has recently been endorsed by an NEA Expert Group on gut transfer (NEA, 1988).

Infants and children

Results obtained by Widdowson et al (1960) suggested that absorption in 7-day-old infants fed with cow's milk was greater than 70%. Bedford et al (1960) reported that absorption in 5 - 15-year-old children was the same as in adults. However, studies on beagles and rats have shown that the period of increased absorption of strontium extends beyond the time of weaning. In the beagle, results for the retention of strontium at 3-9 days after ingestion were 20%, 15% and 8% in 48, 80 and 140 day-old animals, respectively (Della Rosa et al, 1965). The absorption of strontium in 35-day-old and 75-day-old rats was estimated as 70-90% by Gran (1960), compared with 12% in 270-day-old rats. Comparisons of the absorption of calcium and strontium suggest there is no discrimination against strontium in the immediate postnatal period (Rosenthal, 1969; Taylor, 1967). Based on the available data, an f_1 value of 0.6 for strontium would appear reasonable and moderately conservative as an average for the first year of life. The ICRP adult value of 0.3 would appear to be sufficiently conservative to allow for increased absorption continuing after the first year. These are the values recommended by NEA (1988).

5.5.2 Distribution and retention

Adults, infants and children

Strontium substitutes for calcium in bone mineral and is classified by ICRP (1979) as a bone-seeker. Based on human data including fallout measurements, stable isotope determinations and injection experiments, ICRP has developed a comprehensive model for alkaline earth metabolism (ICRP, 1973) in adults which was used in ICRP Publication 30 (ICRP, 1979). This model is not considered appropriate however for calculating age dependent doses from intakes of strontium isotopes since it takes no account of changes in uptake and retention with age.

Papworth and Vennart (1973, 1984) and Leggett et al (1982) have described age-related changes in the accumulation and retention of strontium in bone. Uptake is greater and retention shorter in infants and young children than in adults. Several age-dependent biokinetic models for Sr have been derived from these data (Kulp and Schulert, 1972; Bennett, 1972; Papworth and Vennart, 1984). Another age-dependent model for Sr was derived primarily from considerations of age-specific changes in skeletal Ca, together with information on age-specific discrimination between Ca and Sr by the human body (Leggett et al, 1982, 1984). This model proved to be a reliable predictor of fallout data for Sr-90 and has the advantage for consideration of acute exposures that parameter values were derived to a large extent from basic physiological information on the human skeleton rather than from curve fits to Sr-90 data for chronic exposure. The biokinetic model used here is essentially that of Leggett et al (1982, 1984) and is described in detail elsewhere (ICRP, 1989).

Embryo and fetus

The method adopted for the calculation of doses to the fetus from Sr isotopes by the mother has been described in detail (Stather et al, 1984). The estimated uptake by the fetus was based on evidence that the calcium content of the fetus is about 2% of its dry tissue mass from age 5-months to full-term (and assumed to apply from conception), together with evidence that discrimination by the placenta yields a Sr/Ca ratio for uptake by the fetus that is about one-half the ratio applying to adults (Simkiss, 1967; Schulevt et al, 1969; Twardock, 1967; Twardock et al, 1969). Of strontium reaching the fetus from current intakes by the mother, the fraction retained in bone was taken to be 0.27 as in adults (ICRP, 1973). The dose rate to both bone marrow and bone surfaces was taken as equal to the average dose rate in the fetal skeleton. The remaining fraction of 0.73 retained in soft tissue was assumed to be distributed throughout the whole fetus and to contribute a dose to all tissues (including red bone marrow and bone surfaces) equal to the average dose rate to the fetus.

5.5.3 Dose per unit intake

Values of dose per unit intake for Sr-90 data are given in Table 5.1. The committed effective dose equivalent (CEDE) is dominated by the contributions from the dose equivalents to bone surfaces and red bone marrow. Dose per unit intake is greatest for 3-month-old infants and 1-year-old children because of their lower skeletal mass and high Sr-90 uptake during rapid bone growth. Dose per unit intake is lower in older children and adults but a peak value at 15 years of age corresponds to a renewal of rapid bone growth during adolescence.

Estimates of doses to the fetus from Sr-90 are given in Table 5.22, together with values for the other radionuclides considered in this chapter. For chronic ingestion of Sr-90 by the mother for the year including pregnancy, and taking account of activity present in the child at birth, the total CEDE is similar to that of the mother. The in utero dose contributes about half of the total CEDE.

Table 5.1: Committed dose equivalent (Sv/Bq) to age 70y for ingested Sr-90

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	1.1E-08	8.6E-09	3.8E-09	2.5E-09	1.6E-09	1.3E-09
Testes	1.1E-08	8.6E-09	3.8E-09	2.5E-09	1.6E-09	1.3E-09
Breast	1.1E-08	8.6E-09	3.8E-09	2.5E-09	1.6E-09	1.3E-09
R.B.M.	7.1E-07	4.5E-07	1.7E-07	1.8E-07	2.4E-07	1.8E-07
Lungs	1.1E-08	8.7E-09	3.8E-09	2.5E-09	1.6E-09	1.4E-09
Thyroid	1.1E-08	8.6E-09	3.8E-09	2.5E-09	1.6E-09	1.3E-09
Bone Surf	1.0E-06	7.4E-07	3.9E-07	5.5E-07	1.2E-06	3.8E-07
Stomach	1.4E-08	1.0E-08	4.6E-09	2.9E-09	1.9E-09	1.6E-09
S.I.	1.4E-08	1.1E-08	5.5E-09	3.4E-09	2.1E-09	1.8E-09
U.L.I.	3.7E-08	3.3E-08	1.9E-08	1.1E-08	5.9E-09	5.4E-09
L.L.I.	1.3E-07	1.1E-07	7.1E-08	3.9E-08	2.1E-08	1.9E-08
Liver	1.1E-08	8.6E-09	3.8E-09	2.5E-09	1.6E-09	1.3E-09
Uterus	1.1E-08	8.6E-09	3.8E-09	2.5E-09	1.6E-09	1.3E-09
C.E.D.E.	1.3E-07	9.1E-08	4.1E-08	4.3E-08	6.7E-08	3.5E-08

5.6 BIOKINETIC DATA FOR RUTHENIUM

5.6.1 Uptake to blood after ingestion

Adults

There are some published data on the absorption of ruthenium in man. Yamagata et al (1969) measured the uptake of ruthenium from contaminated clams in a male volunteer and estimated absorption of about 1%. A similar level of absorption was found for chlorocomplexes of ruthenium (III and IV) but this increased by a factor of about three following administration of nitrosyl ruthenium (III).

A number of studies in experimental animals have been reported and values of absorption obtained are reasonably consistent with the limited human data. Values for gastrointestinal absorption depend on the physical and chemical form administered and the nutritional status of the animal, uptake tending to be elevated in fasted animals. Thus, Thompson et al (1958) estimated that for Ru chloride given chronically to rats, absorption was 3%, Burykina (1962) reported 5% absorption in guinea pigs, Bruce and Carr (1961) obtained values of about 3% in rabbits and 2% in rats, and Stara et al (1971) reported 6% in cats.

Furchner et al (1971) gave a value of 3.5% absorption as an average value for four species of fasted animals (mice, rats, monkeys and dogs) given the chloride. When given in the absence of carrier, uptake of the oxide by rabbits is similar to that following administration of the chloride (2.5 3.5%) (Bruce, 1963). Nitrate derivatives of nitrosyl ruthenium appear to be absorbed to a greater extent. Bruce and Carr (1961) reported values of about 13% in rabbits and 6% in rats, while Stara et al (1971) found values of about 13% in cats. A value of 4% was obtained for the absorption of ruthenium administered to rats as a nitro-nitrosyl (Bruce and Jackson, 1963).

On the basis of these data, a fractional absorption value (f_1) of 0.05, as recommended in ICRP Publication 30 (ICRP, 1979) and by the NEA (1988), appears to be an appropriate value for ruthenium ingested in food or drinking water by adults in the general population.

Infants and children

Few data are available on the absorption of ruthenium in the young. Newborn mice absorbed about 7% of Ru administered as the chlorocomplex in dilute HCl (Matsusaka et al, 1969) but 21-day-old and adult mice absorbed less than 1%. Inaba et al (1984) found 0.8% absorption of carrier free Ru-103 in suckling (5-day-old) rats after administration as the chloride compared with 0.5% in adults. These results suggest that for infants in the first year of life the f_1 value may be twice that applied to adults, but for children of 1 year and older an f_1 value of 0.05 is appropriate. This is consistent with the recommendations of an NEA Expert Group (NEA, 1988).

5.6.2 Distribution and retention

Adults

Studies in experimental animals have shown that following the entry of ruthenium into the blood it becomes fairly uniformly distributed throughout the body with differences in concentration between most tissues by a factor of about three (Furchner et al, 1971; Thompson et al, 1958). Distribution and retention of the soluble component of ruthenium that has entered the blood seems to be largely independent of the form of the initial intake (Thompson et al, 1958; Bruce and Carr, 1961). In an interspecies study on the retention of Ru-106 intravenously administered as the chloride to rats, mice, monkeys and dogs (Furchner et al, 1971) it was concluded that retention in all the species could be best represented by the sum of four exponential components. With the exception of the long-term component, the retention parameters in all the species were broadly similar and provided the basis for the values recommended by ICRP (1979) for adults and used in the dose calculations reported here. Ruthenium is assumed to be retained in the transfer compartment with a biological half-time of 0.3 day. A proportion, 15%, is assumed to go directly to excreta and the remainder is assumed to become uniformly distributed throughout all organs and tissues of the body. Of Ru leaving the transfer compartment, 35% is assumed to be retained with a biological half-time of 8 days, 30% with a biological half-time of 35 days and 20% with a biological half-time of 1000 days. These retention parameters are considered to be appropriate for calculating radiation doses to adults in the general population.

Infants and children

No data appear to have been published on the retention of ruthenium in the body as a function of age. In the absence of such information, the retention parameters recommended for adults are also applied to infants and children. Table 2 summarises the biokinetic data used in calculating doses from ruthenium.

Embryo and fetus

There have been few published reports on the transfer of ruthenium to the fetus. Nelson et al (1962) in an autoradiographic study failed to demonstrate appreciable fetal concentrations of Ru-103 in the mouse at various times up to 16 days after intravenous injection as the chloride. However, high concentrations of Ru-103, persisting up to about 4 days after administration, were accumulated by the fetal membranes. Stather et al (1987) administered Ru as chlorocomplexes to pregnant rats at varying stages of gestation and measured the relative concentrations of Ru in maternal and fetal tissues at birth. The results showed that the greatest transfer of ruthenium to the fetus occurred following intravenous administration to the dam towards the end of pregnancy. Thus, after administration in the week before conception and at 14 and 19 days of gestation, relative concentrations on the fetus and mother (C_F/C_M) at birth were 0.0037, 0.015 and 0.051, respectively. These data suggest that the radiation dose to the fetus should not be underestimated, and may be substantially overestimated, if it is assumed that the concentration in fetal tissues is one-tenth that of the mother (i.e., $C_F/C_M = 0.1$). It is therefore assumed that the dose to fetal organs is the dose to the maternal organ multiplied by the placental discrimination factor of 0.1. The concentration in the organs of the newborn child will on this basis be one-tenth that of the mother.

5.6.3 Doses per unit intake

Values of doses per unit intake for Ru-103 and Ru-106 derived from the biokinetic data summarised in Table 5.2 are given in Tables 5.3 and 5.4. In the absence of information on the effect of age on the tissue distribution and retention of ruthenium, the greater values of dose per unit intake for younger children are due solely to their lower body mass. The values of dose per unit intake for 3-month-old infants also take account of increased gut transfer to 0.1 compared with 0.05 in children of one year of age and older. However, this change results in only a small increase in dose per unit intake because 70-80% of the CEDE in each case is due to doses from unabsorbed Ru-103 and Ru-106 in the large intestine.

Doses to the fetus after chronic maternal intake of Ru-103 and Ru-106 during the year including pregnancy are given in Table 5.22. For Ru-106, the CEDE to the child is about 70 times less than the maternal CEDE. This estimate includes both in utero irradiation based on a placental discrimination factor of 0.1 and the dose from activity present at birth. For Ru-103, because of its penetrating photon emissions, fetal irradiation is very largely from activity in the maternal tissues and the discrimination factor does not apply. On this basis, the estimated dose to the child is similar to the maternal dose.

Table 5.2: Biokinetic data for ruthenium

Age	f_1	Distribution (%)				Biological half-time (days)			
		Total body			Excretion	Total body			Transfer-compartment
		Comp. A	Comp. B	Comp. C		Comp. A	Comp. B	Comp. C	
3 Months	0.1	35	30	20	15	8	35	1,000	0.3
1 Year	0.05	35	30	20	15	8	35	1,000	0.3
5 Years	0.05	35	30	20	15	8	35	1,000	0.3
10 Years	0.05	35	30	20	15	8	35	1,000	0.3
15 Years	0.05	35	30	20	15	8	35	1,000	0.3
Adult	0.05[a]	35[a]	30[a]	20[a]	15[a]	8[a]	35[a]	1,000[a]	0.3[a]

a) Value from ICRP Publication 30 (1979)

Table 5.3: Committed dose equivalent (Sv/Bq) to age 70y for ingested Ru-103

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	4.1E-09	2.9E-09	1.7E-09	1.1E-09	7.6E-10	5.7E-10
Testes	1.4E-09	7.1E-10	3.5E-10	2.3E-10	1.3E-10	1.1E-10
Breast	9.3E-10	3.6E-10	1.9E-10	1.1E-10	7.1E-11	5.8E-11
R.B.M.	1.6E-09	6.4E-10	3.9E-10	2.8E-10	2.0E-10	1.6E-10
Lungs	1.1E-09	4.3E-10	2.2E-10	1.4E-10	9.0E-11	7.1E-11
Thyroid	1.1E-09	4.1E-10	2.2E-10	1.3E-10	8.2E-11	6.5E-11
Bone Surf	1.4E-09	6.2E-10	3.2E-10	2.1E-10	1.4E-10	1.1E-10
Stomach	3.2E-09	1.7E-09	9.3E-10	5.7E-10	3.8E-10	3.1E-10
S.I.	6.8E-09	4.6E-09	2.5E-09	1.6E-09	9.7E-10	7.9E-10
U.L.I.	2.5E-08	1.7E-08	8.8E-09	5.4E-09	3.1E-09	2.5E-09
L.L.I.	6.5E-08	4.5E-08	2.3E-08	1.4E-08	8.1E-09	6.6E-09
Liver	1.5E-09	6.9E-10	3.8E-10	2.3E-10	1.4E-10	1.1E-10
Uterus	2.6E-09	1.6E-09	9.3E-10	5.9E-10	3.7E-10	2.9E-10
C.E.D.E.	7.7E-09	5.1E-09	2.7E-09	1.7E-09	1.0E-09	8.1E-10

Table 5.4: Committed dose equivalent (Sv/Bq) to age 70y for ingested Ru-106

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	2.4E-08	9.7E-09	5.3E-09	3.2E-09	2.0E-09	1.7E-09
Testes	2.3E-08	8.7E-09	4.7E-09	2.8E-09	1.7E-09	1.5E-09
Breast	2.2E-08	8.5E-09	4.6E-09	2.8E-09	1.7E-09	1.4E-09
R.B.M.	3.6E-08	1.2E-08	5.8E-09	3.5E-09	2.2E-09	1.8E-09
Lungs	2.3E-08	8.7E-09	4.7E-09	2.8E-09	1.7E-09	1.4E-09
Thyroid	2.3E-08	8.6E-09	4.7E-09	2.8E-09	1.7E-09	1.4E-09
Bone Surf	2.7E-08	1.0E-08	5.4E-09	3.2E-09	2.1E-09	1.7E-09
Stomach	4.3E-08	2.0E-08	1.0E-08	5.9E-09	3.9E-09	3.1E-09
S.I.	6.7E-08	3.9E-08	2.0E-08	1.2E-08	6.8E-09	5.5E-09
U.L.I.	2.8E-07	1.9E-07	9.3E-08	5.5E-08	3.1E-08	2.5E-08
L.L.I.	7.8E-07	5.2E-07	2.6E-07	1.5E-07	8.8E-08	7.1E-08
Liver	2.3E-08	8.8E-09	4.8E-09	2.8E-09	1.7E-09	1.5E-09
Uterus	2.3E-08	9.2E-09	5.0E-09	3.0E-09	1.9E-09	1.5E-09
C.E.D.E.	8.9E-08	5.3E-08	2.7E-08	1.6E-08	9.2E-09	7.5E-09

5.7 BIOKINETIC DATA FOR IODINE

5.7.1 Uptake to blood after ingestion

Absorption of iodine following administration in aqueous solution is almost complete in both adult animals and man (Wood et al, 1963; Bustad et al, 1963; Ramsden et al, 1967) and similar results have been obtained in both young children and adolescents (Van Dilla and Fulwyler, 1963; Cuddihy, 1966). The major source of iodine in the diet is milk and milk products and no differences in uptake between iodine in aqueous media and milk have been found (Comar et al, 1963; Cuddihy, 1966). Very limited data are available on the uptake of iodine associated with food but, for example, Wayne et al (1964) have shown that it is completely absorbed when incorporated in watercress. It is therefore assumed that for all ages absorption of iodine is complete when incorporated in foodstuffs or in drinking water (i.e., $f_1 = 1.0$).

5.7.2 Distribution and retention

ICRP (1979) has recommended a simple three compartment model based on that described by Riggs (1952) for the behaviour of iodine in adults after its entry into the blood. This basic model has been used here for calculating radiation doses to adults and children following intakes of radioiodine. The development of models for calculating doses from intakes of iodine isotopes has been reviewed by Stather and Greenhalgh (1983).

Adults

In the dosimetric model recommended for adults (ICRP, 1979) the normal adult gland is taken to contain 10,000 μg of stable iodine which is retained with a biological half-time of 80 days. This value is consistent with information on the retention of I-131 in the thyroid of adults reviewed by Dunning and Schwarz (1981). The fractional uptake of iodine by the gland after its entry into the blood is taken to be 0.3, although this will vary considerably between individuals and in different countries as a result of different levels of stable iodine in the diet (Stather and Greenhalgh, 1983). In the UK the levels of dietary iodine are relatively high, averaging about 225 μg per day in adults, and, in most individuals, the thyroid is not enlarged. The discussion will concentrate on such normal 'euthyroid' individuals. Dietary deficiency, resulting in thyroid enlargement, does occur in some European countries. The low level of iodine in the diet will, however, have resulted in a compensatory increase in the mass of the thyroid with the result that the concentration of radioiodine in the thyroid will be similar to that calculated using the standard model (Henrichs et al, 1983).

Most organic iodine that enters the blood from the thyroid is metabolised in tissues and is returned to the plasma pool as inorganic iodide. Thus, some iodine will be recycled back to the gland. About 20% is excreted in the faeces in organic form (although a value of 10% was adopted by ICRP (1979)). The level of organic iodine in the body has been variously reported to lie between about 500 and 1200 μg (Ingbar and Woeber, 1981; Colard et al, 1965; Wayne et al, 1964). A level of 1000 μg is adopted in the model proposed by ICRP (1979). The turnover of iodine in the body is taken to be 12 days, which is reasonably consistent with the half-times for thyroxine - the predominant organic form of iodine released from the thyroid - reported in the literature (6.5 days - Ingbar, 1960; Nicoloff and Dowling, 1988; Sterling et al, 1954; Anbar et al, 1965). Most of the iodine entering the body is excreted in the urine.

Because iodine is recycled through the thyroid, monitoring the gland after an intake of radioiodine will not reveal a single exponential clearance. Fell and Adams (1979) have shown that for the ICRP model the fractional retention R(t) in the thyroid gland is approximately described by the sum of two exponentials

$$R(t) = Ae^{-0.693t/T_1} + (1-A)e^{-0.693t/T_2} \qquad (1)$$

T_1 and T_2 may be termed observed half-times to distinguish them from the biological half-times used in the models.

Retention data are largely obtained from studies using I-131. Because of the short physical half-life of this isotope (8 days), retention in the gland is normally followed for about 2 weeks, which is too short a time to enable resolution of the two exponentials in equation (1). As a consequence many investigators report a single exponential clearance from the thyroid; the half-time of this retention will here be called the "apparent" half-time.

In a review of the literature, Dunning and Schwarz (1981) estimated a mean "apparent" half-time in adults of 85 days based upon data from 47 cases published by Rosenberg (1958), Cuddihy (1966), Burns et al (1951) and Solomon (1956). Similar results have also been published by Van Dilla and Fulwyler (1963). These results are reasonably consistent with the model parameters adopted by ICRP (1979) which give an "apparent" half-time of 91 days between 2 and 16 days after iodine administration.

Infants and children

Uptake of radioiodine by the thyroid gland is enhanced in the newborn. Van Middlesworth (1954) obtained an uptake of 70% (range 46%-94%) in 7 newborn infants given an intramuscular injection of I-131, and Morrison et al (1963) also found an uptake of about 70% in 19 newborn infants after intramuscular injection and 50% in 8 infants after intravenous injection. Fisher et al (1962) have published data showing that thyroid uptake of I-131 in newborn infants is higher than in adults, reaching a maximum 2 days after birth but then declining to values at or below that accepted for adults by 5 days of age.

After the first few weeks of life uptake appears to change very little with increasing age. Cuddihy (1966) found similar levels of accumulation of I-131 by the thyroid in adolescents and adults between 7 and 49 years of age. Comparable results were obtained by Van Dilla and Fulwyler (1963) in children and adults between 4 and 46 years of age. Oliner et al (1957) found that in 60 children and adolescents aged between 2 months and 18 years living in the Chicago area, the 24-hour uptake of I-131 ranged between 17% and 50% with a mean of 31.1 + 7.6% (one standard deviation). This range did not differ from that for euthyroid adults. There did not appear to be any variation between the sexes nor was there any consistent trend with age. Karhausen et al (1973) also reported little significant difference between children and adults in Belgium, although in this study results were very variable and uptake in all ages was increased (uptake about 50%) reflecting low dietary iodine levels. The fractional uptake by the gland in young infants and children is therefore taken to be the same as the ICRP value for adults (0.3) although a higher uptake would be expected in newborn infants in the first few days of life.

Information on age related changes in retention of radioiodine in the thyroid has been reviewed by Dunning and Schwartz (1981) and Stather and

Greenhalgh (1983). Although the data available are very variable they indicate that the turnover of iodine in the thyroid decreases with increasing age. On the basis of the information available "apparent" half-times of about 15, 20, 30, 70 and 80 days are indicated for 3-months and for 1-, 5-, 10- and 15-year-old children, respectively. These "apparent" half-times have been used to calculate the biological half-times for iodine in the thyroid given in Table 5.5 using as a basis the biokinetic model for the adult. For the calculation of half-times the following assumptions are made:

a) fractional uptake by the thyroid is independent of age (0.3);
b) extrathyroidal iodine is equal to 1/10 thyroid iodine at all ages;
c) faecal excretion is 20% of extrathyroidal organic iodine at all ages;
d) the amount of iodine in the thyroid is determined by the requirement of consistency with measured "apparent" half-times.

The implication of these assumptions is that the turnover rate of organic iodine will be faster in children than in adults and that the circulating hormone level will be similar in adults and children. This is consistent with the literature on the rate of utilisation of thyroid hormone and measurements of hormonal concentrations in tissues (Wayne et al, 1964; Hoddard et al, 1960).

Embryo and fetus

Radioiodine is readily translocated across the placenta and accumulates in the fetal thyroid from about 11 weeks after conception (Moore, 1977). Published data are available on measurements of I-131 activity in the fetal thyroid after diagnostic administration prior to therapeutic abortions, as well as after nuclear weapons fallout. These data have been reviewed (Book and Goldman, 1975; Roedler, 1987) and indicate a ratio of activity concentrations in the fetus and mother (C_F/C_M) of about two. Some data are also available on the turnover of radioiodine in the fetal thyroid (Aboul-Khair et al, 1966) but the data are insufficient for use in dose calculations. For calculating radiation doses the concentration of radioiodine in the fetal thyroid is taken to be twice that of the maternal thyroid from the beginning of the 11th week of gestation.

5.7.3 Variability in dose per unit intake for I-131

The most important iodine isotope is normally I-131. As noted above the effective dose equivalent from 131I is dominated by the dose to the thyroid from activity in the thyroid. This isotope has a relatively short physical half-life (8 days) compared with the biological half-life, and as a result the variability in the period of retention has a small effect on the dose, particularly in the case of adults. The main factors which will affect the variability in dose per unit intake are:

(a) mass of the thyroid gland,
(b) fractional uptake by the thyroid.

ICRP Publication 23 (ICRP, 1973) presents data on the mass of the thyroid but does not give standard deviations or other measures of the variability of thyroid mass. However, Dunning and Schwarz (1981) have reviewed the data and concluded that the distribution is approximately log-normal. The 95% confidence interval is spanned by a factor between 6 and 7 and the upper 95th percentile is about 2-2.5 times the mean. The same authors have investigated the variability in fractional uptake by the thyroid. This was also found to be log-normally distributed. Here the 95% confidence interval spanned a factor of 3-4 for 1-year-old infants and adults and a factor of between 5 and 6 for 10-year-old children. The upper 95th percentile was about twice the mean for all ages. When the contributions from thyroid mass and from fractional uptake are combined, the 95% confidence intervals for dose per unit intake span about an order of magnitude for all three age groups considered here. The upper 95th percentile of the distribution is higher than the mean by a factor of between 2 and 3.

5.7.4 Dose per unit intake

Values of dose per unit intake for I-129, I-131 and I-132 derived from the biokinetic data summarised in Table 5.5 are given in Tables 5.6 to 5.8. As discussed above, the dose is delivered very largely to the thyroid with much lower doses to other tissues. For the long-lived isotope, I-129 (half-life of 1.6 x 10^7 years), the reduction in dose at younger ages due to shorter biological half-times (Table 5.5) counteracts the effect of smaller thyroid mass. This results in similar values of dose per unit intake for 3-month-old infants and 1-, 5- and 10-year-old children with slightly lower values for 15-year-old children and adults. For I-131, because of its shorter half-life (8 days), the effect of changes in retention times is reduced and the dominant factor determining the age-dependence of dose per unit intake is thyroid mass. Values of dose per unit intake are therefore progressively greater in younger children with about an order of magnitude difference between adults and 3-month-old infants. Similarly, for I-132 (half-life of 2.4 hours) the effect of thyroid mass results in an order of magnitude greater values of dose per unit intake in infants than adults.

Estimates of fetal doses after chronic maternal intake of iodine isotopes throughout the year including pregnancy are given in Table 5.22. The assumption that the concentration of radioiodine in the fetal thyroid will be twice that of the maternal thyroid from the 11th to 38th week of gestation results in fetal doses very similar to annual maternal doses.

Table 5.5: Biokinetic data for iodine

Age	f_1	Uptake by Thyroid %	Faecal Excretion %	Biological half-time (days)			"Apparent" half-time (days)
				Blood T[a]	Thyroid T[b]	Rest of Body T[c]	Thyroid[a]
3 Months	1	30	20	0.25	11.2	1.12	15
1 Year	1	30	20	0.25	15	1.5	20
5 Years	1	30	20	0.25	23	2.3	30
10 Years	1	30	20	0.25	58	5.8	70
15 Years	1	30	20	0.25	67	6.7	80
Adult	1[b]	30[b]	20	0.25[b]	80[b]	12[b]	91

a) Between 2 and 16 days after intake to the thyroid

b) Value from ICRP Publication 30 (1979)

Table 5.6: Committed dose equivalent (Sv/Bq) to age 70y for ingested I-129

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	2.0E-10	1.5E-10	1.0E-10	1.3E-10	8.9E-11	1.2E-10
Testes	1.8E-10	1.4E-10	9.7E-11	1.2E-10	8.5E-11	1.1E-10
Breast	2.3E-10	1.8E-10	1.1E-10	1.3E-10	8.6E-11	1.1E-10
R.B.M.	3.4E-10	2.3E-10	1.4E-10	1.8E-10	1.3E-10	1.6E-10
Lungs	4.2E-10	3.4E-10	2.1E-10	2.3E-10	1.3E-10	1.6E-10
Thyroid	3.7E-06	4.3E-06	3.5E-06	3.8E-06	2.8E-06	2.1E-06
Bone Surf	5.7E-10	4.4E-10	3.2E-10	4.4E-10	3.5E-10	4.2E-10
Stomach	1.2E-09	7.0E-10	3.7E-10	2.8E-10	1.9E-10	2.0E-10
S.I.	2.0E-10	1.5E-10	1.0E-10	1.3E-10	8.8E-11	1.2E-10
U.L.I.	1.9E-10	1.5E-10	1.0E-10	1.2E-10	8.6E-11	1.1E-10
L.L.I.	1.9E-10	1.5E-10	9.9E-11	1.2E-10	8.7E-11	1.2E-10
Liver	2.1E-10	1.6E-10	1.1E-10	1.3E-10	9.0E-11	1.2E-10
Thymus	1.4E-09	1.2E-09	5.6E-10	4.1E-10	1.7E-10	1.7E-10
Uterus	2.0E-10	1.5E-10	1.0E-10	1.3E-10	9.0E-11	1.2E-10
C.E.D.E.	1.1E-07	1.3E-07	1.0E-07	1.1E-07	8.4E-08	6.4E-08

Table 5.7: Committed dose equivalent (Sv/Bq) to age 70y for ingested I-131

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	3.9E-10	2.7E-10	1.4E-10	7.8E-11	4.7E-11	4.0E-11
Testes	3.4E-10	2.3E-10	1.1E-10	6.6E-11	4.0E-11	3.4E-11
Breast	5.6E-10	4.1E-10	2.3E-10	1.5E-10	7.3E-11	5.8E-11
R.B.M.	7.0E-10	4.4E-10	2.3E-10	1.6E-10	1.2E-10	1.0E-10
Lungs	8.9E-10	6.5E-10	3.8E-10	2.4E-10	1.4E-10	1.2E-10
Thyroid	3.7E-06	3.6E-06	2.1E-06	1.1E-06	6.9E-07	4.4E-07
Bone Surf	6.6E-10	4.8E-10	3.0E-10	2.1E-10	1.5E-10	1.3E-10
Stomach	3.4E-09	2.0E-09	9.8E-10	5.6E-10	3.8E-10	3.0E-10
S.I.	4.0E-10	2.7E-10	1.3E-10	8.3E-11	4.9E-11	4.0E-11
U.L.I.	4.0E-10	2.7E-10	1.4E-10	8.1E-11	4.8E-11	4.0E-11
L.L.I.	3.8E-10	2.5E-10	1.3E-10	7.6E-11	4.4E-11	3.9E-11
Liver	4.6E-10	3.2E-10	1.7E-10	9.8E-11	5.9E-11	4.7E-11
Thymus	2.3E-09	1.7E-09	8.5E-10	4.7E-10	2.3E-10	1.5E-10
Uterus	3.9E-10	2.7E-10	1.4E-10	7.9E-11	4.8E-11	4.0E-11
C.E.D.E.	1.1E-07	1.1E-07	6.3E-08	3.2E-08	2.1E-08	1.3E-08

Table 5.8: Committed dose equivalent (Sv/Bq) to age 70y for ingested I-132

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	2.0E-10	1.4E-10	7.6E-11	4.8E-11	3.1E-11	2.5E-11
Testes	1.6E-10	1.1E-10	5.7E-11	3.6E-11	2.3E-11	1.9E-11
Breast	1.8E-10	1.2E-10	6.4E-11	3.9E-11	2.5E-11	2.0E-11
R.B.M.	2.4E-10	1.4E-10	7.2E-11	4.8E-11	3.2E-11	2.6E-11
Lungs	3.0E-10	2.0E-10	1.0E-10	6.7E-11	4.3E-11	3.4E-11
Thyroid	4.1E-08	3.6E-08	1.9E-08	8.5E-09	5.6E-09	3.5E-09
Bone Surf	2.1E-10	1.4E-10	7.4E-11	4.7E-11	3.1E-11	2.6E-11
Stomach	6.7E-09	3.8E-09	1.9E-09	1.1E-09	8.0E-10	6.3E-10
S.I.	2.4E-10	1.7E-10	9.2E-11	5.8E-11	3.7E-11	3.0E-11
U.L.I.	2.5E-10	1.7E-10	9.6E-11	5.9E-11	3.8E-11	3.1E-11
L.L.I.	2.0E-10	1.3E-10	7.7E-11	4.8E-11	2.9E-11	2.5E-11
Liver	2.4E-10	1.7E-10	9.3E-11	5.6E-11	3.5E-11	2.7E-11
Thymus	2.3E-10	1.6E-10	8.0E-11	5.0E-11	3.1E-11	2.4E-11
Uterus	2.0E-10	1.4E-10	7.7E-11	4.9E-11	3.1E-11	2.5E-11
C.E.D.E.	1.8E-09	1.5E-09	7.7E-10	3.8E-10	2.5E-10	1.7E-10

5.8 BIOKINETIC DATA FOR CAESIUM

5.8.1 Uptake to blood after ingestion

Human data and the results of animal experiments indicate that soluble compounds of caesium are rapidly and almost completely absorbed from the gastrointestinal tract (ICRP, 1979). Thus Rundo (1964) observed an average fractional absorption of 0.99 in ten normal subjects following ingestion of Cs-137. Similar results have been reported by Rosoff et al (1963). Henrichs et al (1989) measured the uptake of Cs-137 in 10 volunteers following the consumption of venison contaminated as a result of the Chernobyl accident. Absorption varied from about 56% to 90% (mean 78%) indicating uptake of caesium from food may not always be complete. However, since there are insufficient data on the uptake of caesium incorporated in foods, an f_1 of 1.0 is adopted for caesium in food for all ages.

5.8.2 Distribution and retention

Adults

Caesium behaves similarly to potassium after its entry into the blood, being accumulated by all body tissues. Higher concentrations of caesium have been reported for muscle than for other tissues but differences in concentration between tissues are relatively small. It is therefore assumed, for the purposes of dosimetry, that caesium is uniformly distributed throughout the body tissues after its clearance from the blood (Harrison et al, 1963; ICRP, 1979; Muller and Scheffel, 1982).

Retention of caesium in the body is best described by the sum of two exponential components. ICRP (1979) recommended half-times of retention for the two components of 2 days (10%) and 110 days (90%).

The fast component is thought to mainly represent excretion in the urine of caesium accumulated by the kidney within a few hours of its entry into the blood (Stather, 1970). The long-term component of retention largely reflects the progressive loss in the urine and faeces of caesium accumulated by the muscle and other tissues. A third, intermediate component of retention has sometimes been separated (Lloyd et al, 1973) which probably reflects the loss of caesium from tissues with a higher turnover rate than muscle.

Results obtained for the half-time of the long-term component of retention in adults have been reviewed by a number of authors (Rundo, 1964; Leggett, 1986; Baverstock, 1987) and indicate values for adult males in the range 50-150 days. Similar results have been obtained by Henrichs et al (1989) for 5 male adults after ingestion of Cs-137 in venison (T_2:85 to 206 days; mean: 120 days). These data are consistent with the half-time of retention of 110 days recommended by ICRP (1979) for workers.

A shorter half-time of retention in females than in males has been reported (Clemente et al, 1971; Miltenberger et al, 1981). Retention half-times for the long-term component in females are reported to be less than in males (Clemente et al, 1971; Miltenberger, 1981). Henrichs et al (1989, priv. comm.) has reported for this component half-times of 45 to 86 days (mean: 61 days) in 5 females. Schwartz and Dunning (1982) reported a mean equivalent biological half-time in adult females (29 cases) of 65 days (range 30-141 days). The retention parameters recommended by ICRP for adults are likely, therefore, to be conservative if applied for calculating radiation doses to adult females in the population.

Children

There is substantial evidence that the rate of loss from the body is increased in children compared with adults. In four newborn infants the average half-time of retention between birth and 6 months was about 12 days (Wilson and Spiers, 1967), in a 10-month-old infant it was 25 days (Cahill and Wheeler, 1968) and in three children aged between 4 and 11 years it ranged from 36 to 61 days (Ruwei et al, 1984). This change in retention half-time probably reflects the decreasing turnover of caesium in muscle tissue with increasing age.

Variations in the retention of caesium in the body with age have been related to changes in body mass (Eberhardt, 1967; Baverstock, 1987) and body potassium (Leggett, 1986). Both methods of analysis are restricted by the limited data available on very young persons (1-5 years) and on the size and rate of clearance of the short-term component.

Baverstock (1987) has suggested that, for radiological protection purposes, age-related changes in the long-term component of caesium retention can be represented by a simple linear equation:

$$T_{1/2} = 1.27m + 11.9$$

where m is the body mass in kg.

Leggett (1986) has based estimates of the short and long-term components of retention of caesium in children and young persons on observed relationships between the mass of total body potassium and the parameters in the two exponential retention models for caesium. The retention half-times of the long-term component for 5-15 year old children are similar to those given by Baverstock (1987).

The model developed by Leggett gives the most comprehensive analysis of retention data for caesium currently available and has been adopted for this report. The parameters predicted by the model for 1-, 5-, 10- and 15-year old children are given in Table 5.9. They are similar to age dependent parameters given in ICRP Publication 53 (1988), although there are minor differences due to some changes in estimates of body potassium (see Leggett and Warren 1987). The body content of potassium used in these calculations is: 11.4g (3-months), 20.8g (1-year), 42.7g (5-years), 71.0g (10-years) and 131.4g (15-years).

Infants

A number of authors have reported measurements of the half-time of retention of Cs-137 in newborn children. Wilson and Spiers (1967) reported values for 4 subjects (0-183 d) of about 12 days, Bengtsson et al (1964) gave values for 2 subjects (2-12 d) of about 23 days (range 21-25 days) and Pendleton et al (1965) found values for 5 subjects (17-143 d) of about 19 days (range 12-33 d). Results from experimental animals suggest that the rate of loss of caesium from the body in newborn children can be influenced by the concentration of potassium in the diet (Inaba, 1988). This may explain the faster rate of loss of caesium in bottle fed infants measured by Wilson and Spiers (1964) compared with that obtained by Bengtsson et al (1964) in breast fed infants with a lower dietary potassium intake. No information was given in these reports on the presence of a short-term component of retention, but information from experimental animals suggests that caesium retention in newborn animals does not show two components of clearance (Stather et al, 1970; Matsusaka et al, 1967). This may reflect a slower rate of loss of potassium in young animals associated primarily with a slow development of kidney function (Bell et al, 1961). It is recommended that for young infants (taken to be 3 months of age) the retention of caesium is described by a single exponential component with a half-time of 16 days (Table 9). This approach is consistent with information on the physiological development of the human kidney.

Embryo and fetus

Wilson and Spiers (1967) reported Cs-137 concentrations arising from weapons fallout in nine newborn children and their mothers obtained within 3 days of birth. The results indicated very similar concentrations in the mother and newborn. Similar observations have been made by other authors (McDonald et al, 1963; Bengtsson et al, 1964; Kaul et al, 1966; Iinuma et al, 1969).

No direct information is available on the transfer of caesium to the human fetus during gestation, although animal studies indicate ready exchange of Cs-137 between maternal and fetal tissues. As a result, a fairly constant fetal/maternal concentration ratio occurs at birth which is largely independent of the time of administration of Cs-137 to the mother during pregnancy (Stather et al, 1987). These data therefore indicate that the radiation dose to the developing fetus can be taken to be the same as that for the mother. Doses to the fetus are therefore based on the dose calculated for the mother over the period of pregnancy using retention parameters in the reference adult. There is evidence that this is conservative. Bengtsson et al (1964) and Zundel et al (1969) have reported that during pregnancy the rate of loss of Cs-137 from the mother has a half-time of approximately 50 days. This is rather less than the rate found in the adult females generally, and about 50% of the half-time in adult males. On the basis of a reduced half-time in pregnant women and a comparable dose to the mother and fetus the fetal dose from incorporated Cs-137 will be lower by a factor of about two than that calculated for the reference adult. The calculation of fetal doses using reference adult parameters is therefore be expected to provide a degree of conservatism.

5.8.3 Variability in dose per unit intake

Variability in dose per unit intake can arise from three sources (see Section 5.4): absorbed fractions, organ masses and retention half-times.

Caesium is taken to be uniformly distributed throughout the body and the first of these factors, variability in absorbed fractions, does not contribute significantly. It also follows from this assumption that the dose per unit intake for a given retention half-time is inversely proportional to body mass. The effect of variability in retention is more complex and is considered in more detail.

Leggett (1983, 1986) has presented data on retention for 19 adult males. Using these data the half-time in the short-term compartment was calculated to be 1.3 ± 0.7 (mean ± standard deviation) days and that in the long-term compartment 98 ± 30 days. The fraction clearing with the shorter half-time was 11.3% ± 4.2%. Monte Carlo techniques were used to calculate the resulting variability in dose per unit intake. It was assumed here that all Leggett's data points carried the same weight and that the parameters entering into the calculation were independent. Neither assumption is strictly true but they probably do not affect the conclusion that variability in the retention function introduces a variability of one-quarter to one-third in the values of dose per unit intake for long-lived isotopes of caesium. These would include Cs-134 and Cs-137, the isotopes of greatest practical importance. The coefficient of variation for body mass of adult males is about 15% (ICRP, 1973). There is some evidence for correlation between body mass and retention time for caesium (Baverstock, 1987) so a reasonable estimate for the coefficient of variation for these long-lived isotopes of caesium might be about one-third for adult males. This estimate is in reasonable agreement with those of Schwarz and Dunning (1982) and Henrichs and Paretzke (1985). The latter authors give a rather larger variability (60%), but this arises from the fact that they are particularly concerned to assess the upper 95th percentile of the distribution and that they have considered both men and women together. Schwarz and Dunning also consider both sexes but arrive at an estimate of variability not much larger than that given here (less than 40%). Published data on retention in women and children are much more sparse than for adult males but it is probably not unreasonable to assume that the coefficient of variation is similar to that for adult males.

5.8.4 Dose per unit intake

Values of dose per unit intake for Cs-134 and Cs-137 derived using the biokinetic data in Table 5.9 are given in Tables 5.10 and 5.11. In general, shorter biological half-times at younger ages counteracts the effect of lower body mass, resulting in values of dose per unit intake that are largely independent of age; the maximum difference being about a factor of two.

Doses to the fetus from chronic maternal intakes of Cs-134 and Cs-137 throughout the year including pregnancy are given in Table 5.22. In utero doses are taken to be the same as the greatest doses to maternal tissues during the 38 weeks of pregnancy. The overall dose estimates for the child are very similar to maternal doses from the years intake.

Table 5.9: Summary of biokinetic data for caesium

		Distribution (%)		Biological half-time (days)	
		Total Body		Total Body	
Age	f_1	A	B	A	B
3 months	1	-	100	-	16
1 Year	1	-	100	-	13
5 Years	1	45	55	9.1	30
10 Years	1	30	70	5.8	50
15 Years	1	13	87	2.2	93
Adult	1[a]	10[a]	90[a]	2[a]	110[a]

a) Value from ICRP Publication 30 (1979); appropriate for males; conservative if applied for calculating dose factors for females (see text).

Table 5.10: Committed dose equivalent (Sv/Bq) to age 70y for ingested Cs-134

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	2.7E-08	1.6E-08	1.4E-08	1.6E-08	2.2E-08	2.2E-08
Testes	2.2E-08	1.3E-08	1.1E-08	1.2E-08	1.7E-08	1.7E-08
Breast	1.8E-08	1.1E-08	8.9E-09	9.8E-09	1.4E-08	1.4E-08
R.B.M.	2.7E-08	1.5E-08	1.2E-08	1.4E-08	1.9E-08	1.9E-08
Lungs	2.2E-08	1.3E-08	1.1E-08	1.3E-08	1.8E-08	1.7E-08
Thyroid	2.5E-08	1.5E-08	1.3E-08	1.4E-08	1.9E-08	1.8E-08
Bone Surf	2.6E-08	1.5E-08	1.3E-08	1.5E-08	2.0E-08	2.0E-08
Stomach	2.7E-08	1.6E-08	1.4E-08	1.4E-08	2.0E-08	2.0E-08
S.I.	2.7E-08	1.6E-08	1.4E-08	1.6E-08	2.2E-08	2.1E-08
U.L.I.	2.6E-08	1.5E-08	1.4E-08	1.5E-08	2.1E-08	2.1E-08
L.L.I.	2.5E-08	1.4E-08	1.3E-08	1.5E-08	1.9E-08	2.1E-08
Liver	2.5E-08	1.5E-08	1.3E-08	1.4E-08	2.0E-08	1.9E-08
Uterus	2.7E-08	1.6E-08	1.4E-08	1.6E-08	2.2E-08	2.2E-08
C.E.D.E.	2.5E-08	1.5E-08	1.3E-08	1.4E-08	2.0E-08	1.9E-08

Table 5.11: Committed dose equivalent (Sv/Bq) to age 70y for ingested Cs-137

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	1.9E-08	1.1E-08	9.4E-09	1.0E-08	1.4E-08	1.4E-08
Testes	1.7E-08	9.9E-09	8.0E-09	8.9E-09	1.2E-08	1.2E-08
Breast	1.6E-08	9.1E-09	7.3E-09	8.0E-09	1.1E-08	1.1E-08
R.B.M.	2.7E-08	1.3E-08	9.5E-09	1.1E-08	1.5E-08	1.4E-08
Lungs	1.8E-08	1.0E-08	8.2E-09	9.2E-09	1.3E-08	1.2E-08
Thyroid	1.9E-08	1.1E-08	8.9E-09	9.7E-09	1.3E-08	1.3E-08
Bone Surf	2.1E-08	1.2E-08	9.5E-09	1.1E-08	1.5E-08	1.5E-08
Stomach	2.2E-08	1.2E-08	9.8E-09	1.0E-08	1.4E-08	1.4E-08
S.I.	1.9E-08	1.1E-08	9.4E-09	1.0E-08	1.4E-08	1.4E-08
U.L.I.	1.9E-08	1.1E-08	9.1E-09	1.0E-08	1.4E-08	1.4E-08
L.L.I.	1.8E-08	1.0E-08	9.0E-09	9.9E-09	1.3E-08	1.4E-08
Liver	1.9E-08	1.1E-08	8.9E-09	9.7E-09	1.3E-08	1.3E-08
Uterus	1.9E-08	1.1E-08	9.4E-09	1.1E-08	1.4E-08	1.4E-08
C.E.D.E.	2.0E-08	1.1E-08	9.0E-09	9.8E-09	1.4E-08	1.3E-08

5.9 BIOKINETIC DATA FOR PLUTONIUM AND AMERICIUM

5.9.1 Uptake to blood after ingestion

Adults

ICRP recently revised its biokinetic models for plutonium and related elements in ICRP Publication 48 (ICRP, 1986). On the basis of an extensive review of the available animal data on gut transfer, together with limited human data, an f_1 value of 10^{-3} was recommended for intakes of plutonium in food and drinking water. In the specific cases of occupational exposures to plutonium as the nitrate and as insoluble oxides, no changes were recommended from ICRP Publication 30 (ICRP, 1979) values of 10^{-4} and 10^{-5}, respectively. The value of 10^{-3} was taken to apply, however, to occupational exposures to other compounds and to unknown mixtures of plutonium. The same f_1 value of 10^{-3} was also recommended for occupational and population exposures to all forms of americium.

In recommending the f_1 value of 10^{-3}, ICRP (1986) concluded that: "Since the reported experimental data suggest a value for f_1 larger than 10^{-4} but not greater than 10^{-3}, the latter would appear to give a sufficient margin of safety for radiological protection purposes in all situations where the intake cannot be described precisely. The use of the cautious value of 10^{-3} may not be considered appropriate in all situations where a best estimate of absorption is required, either for a critical group or in estimating population doses. In such cases, if a different value can be justified, it should be employed.". An f_1 of 10^{-3} has been used in this report.

Infants and children

The uptake of plutonium and other actinides in newborn animals is greater than in adults (ICRP, 1986). Animal experiments have shown that absorption is greatest immediately after birth and decreases quite rapidly to reach adult values by about the time of weaning. On the basis of the available data, ICRP recommended the use of an f_1 value of 10^{-2} for the first year of life, with the adult value of 10^{-3} applying to all succeeding years. An NEA/OECD Expert Group (1988) proposed an f_1 of 10^{-2} as an average value for the first year of life. This value is consistent with findings of the ICRP Task Group (1986) and is adopted in this report.

5.9.2 Distribution and retention

Adults

The principal sites of deposition of plutonium and americium are the liver and skeleton. In ICRP Publication 30 (ICRP, 1979) it was assumed that the fractional deposition from the blood was 0.45 for both the liver and skeleton. In addition, the gonads were assumed to accumulate a fraction of $3.5\ 10^{-4}$ in males and $1.1\ 10^{-4}$ in females. These parameters were not changed in ICRP Publication 48 (ICRP, 1986). The half-times of retention in the liver and skeleton were taken as 40 years and 100 years, respectively, in ICRP Publication 30. Taylor (1984 a,b) has used measurements of fallout plutonium from human autopsies to re-estimate half-times. Based on these studies, the values recommended in ICRP Publication 48 were 20 years for the liver and 50 years for the skeleton (Table 5.12).

In adopting the value of 0.45 for the initial fractional uptake of plutonium by the liver and skeleton, it was noted in ICRP Publication 48 that the available human data for short-term distribution after intravenous injection would be better represented by fractions of 0.3 to liver, 0.5 to skeleton, 0.1 to other tissues and 0.1 excreted. However, recognising the considerable variations in the distribution between the liver and skeleton in autopsy samples, it was considered that a change from ICRP Publication 30 assumptions was not warranted.

For most tissues of the body, it is assumed for the purposes of dosimetry that the distribution of both sensitive cells and the retained activity are homogeneous throughout the tissue (ICRP, 1979). For the skeleton, the situation is more complex and plutonium and americium are classified by ICRP as bone-surface seeking elements (ICRP, 1979), i.e., they are assumed to be uniformly distributed on endosteal bone surfaces at all times after their deposition in the skeleton, with equal amounts depositing in cortical and trabecular bone. Details of the model are given in ICRP Publication 30 (1979).

Animal studies have shown that, in practice, bone-surface actinide deposits are progressively buried by the formation of new bone and become distributed throughout bone mineral as remodelling continues. Limited information from human autopsies is consistent with these observations. Consequently, the assumption of a bone-surface deposit may result in an over estimate of the absorbed dose to the target cells on bone surfaces and in the red bone marrow. However, there is also evidence that some activity may transfer to the marrow in macrophage cells.

It is pointed out in ICRP Publication 48 that the assumption that all skeletal plutonium and americium is retained on bone surfaces may result in overestimates of dose to bone surfaces and bone marrow because restructuring of bone leads to a gradual volume distribution of a portion of the skeletal burden. Because explicit consideration of bone remodelling processes is particularly important in the estimation of age-specific doses to bone surfaces from intake of actinides, a model proposed by Leggett (Leggett and Eckerman 1984, Leggett and Warren 1987) that is generally consistent with the conclusions of ICRP Publication 48, but which depicts redistribution of plutonium and americium due to bone restructuring and recycling among organs, was also used for the calculation of tissue doses. This model and the parameter values adopted for age-specific dose calculations are described elsewhere (ICRP, 1989).

Infants and children

It is well established that the distribution of plutonium and related elements between the liver and skeleton varies as a function of age at intake (ICRP, 1986), with a greater deposition of plutonium in the skeleton at younger ages. The age dependent plutonium model proposed by Leggett et al (1984, 1987), based on animal and human data, assumes 10% deposition in the liver and 70% deposition in the skeleton in the infant, 20% deposition in the liver and 60% in the skeleton from 1 year until 15 years and 30% deposition in the liver and 50% in the skeleton in adults (ICRP, 1989).

In addition to the age dependence in the uptake of plutonium and related elements by the skeleton, there will also be differences in their distribution and retention in bone. Owing to the very high turnover and growth rate of bone in the skeletons of children, any radionuclide deposited on bone surfaces will quickly either become buried by new bone deposited on to the contaminated bone surfaces or be removed from surfaces during bone resorption. The age dependent model developed by Leggett has been used in this report for calculating doses to infants and children. For comparison doses are also calculated for the biokinetic data recommended by ICRP in Publication 48 (Table 5.12). The model for plutonium has also been adopted to apply to americium and is described in detail elsewhere (ICRP, 1989). A difference in the model for americium is that although the initial deposition in the liver and skeleton of the infant are taken to be 10% and 70% as for plutonium, the initial deposition from 1 year to 15 years is taken to be 30% and 50% in the liver and skeleton, respectively, and the values for adults are 50% and 30%, respectively.

Embryo and fetus

Most published data on the transfer of plutonium and americium across the placenta have been obtained in rats, although some data are available for baboons and mice. For both rats and baboons, the ratios of concentrations of plutonium in the fetus and mother are highest for intakes early in gestation (up to 9 days in the rat and 22 days in the baboon), when these ratios approach unity for rats (Sikov and Andrew, 1979) and even exceed unity for baboons (Sikov et al, 1978). Higher concentrations of plutonium are accumulated in the yolk sac membranes but it is not clear whether doses to stem cells in this tissue have any significance for the fetus and newborn. Much lower average concentrations in the fetus relative to the mother (C_F/C_M about 0.1 or less) are observed for intakes of plutonium later in gestation (more than 14 days in the rat and 40 days in the baboon) when the placenta appears to provide a barrier to actinide uptake by the fetus. In the case of americium lower C_F/C_M values (about 0.02) are obtained.

Several studies have examined the distribution of plutonium within the tissues of the fetus. They have shown that it deposits preferentially in the liver and skeleton, as in adults (Sikov and Andrew, 1979; Sullivan, 1980). It is assumed for the estimation of doses that the distribution pattern of plutonium and americium in the fetus from about the end of major organ development is the same as that in young persons. In the human this corresponds to about 60 days of pregnancy.

The model adopted to calculate in utero doses from isotopes of plutonium and americium is described in detail in Stather et al (1984). Essentially, estimates of the doses to fetal organs (i.e., from the completion of organogenesis at 8 weeks to full-term at 38 weeks) were taken to be one-tenth of the doses accumulated by the corresponding maternal organs during the 30-week period. No attempt was made in these estimates to include doses to the fetus before distinct fetal organs exist. Revised models are currently being developed which take account of earlier doses to developing haemopoietic tissue.

5.9.3 Variability and uncertainty in dose per unit intake for plutonium isotopes

The main factors affecting doses from the ingestion of plutonium isotopes are the f_1 value, the deposition in individual organs and retention times in these organs and the fraction of the alpha energy which is absorbed by sensitive cells. Differences in diet and the chemical form ingested can affect absorption and, in addition, variability between individuals given the same chemical form can be as great as an order of magnitude. Taking account of uncertainties in applying animal data to man, the range in f_1 value for environmental forms of plutonium might reasonably be taken as 10^{-4} - 10^{-3}, as concluded by ICRP (1986), with a best estimate of 5.10^{-4}. However, to ensure that doses are not underestimated, the higher value of 10^{-3} was recommended by ICRP when no specific information is available.

The variability in the fractions of plutonium and americium retained in different body organs has been considered by Kathren et al (1988) using autopsy data. For the 43 cases for which data were analysed, the fractional retention was about 0.45 ± 0.2 (mean ± SD) for the liver and about 0.55 ± 0.2 for the skeleton. If this distribution is taken to apply to 90% of plutonium reaching the circulation, as in the ICRP model (1979, 1986), the deposition fractions would be about 0.4 (range of 0.2-0.6) for the liver and 0.5 (range of 0.3-0.7) for the skeleton.

The analyses of autopsy data on which the revised half-times of retention in the liver and skeleton were based do not allow the associated ranges to be simply defined. Excretion data for human subjects given plutonium intravenously suggest that the overall half-time in the body is about 40-100 years (ICRP, 1986). It would appear reasonable to assume ranges of about 10-40 years for the liver and 25-100 years for the skeleton.

The ICRP (1979, 1986) values for actinide uptake by the gonads of 3.5 10^{-4} for testes and 1.1 10^{-4} for ovaries were based on a review by Richmond and Thomas (1975) which concluded that plutonium deposition was about 10^{-5} per gram of gonadal tissue. The available data show considerable variability, both within and between species. High values of about 10^{-3} have been obtained for the retention of fallout plutonium in human ovaries and testes. However, these values could be unreliable because of the very low levels of activity involved and the difficulties associated with their measurement. The limited data from human injection studies (Durbin, 1972) support the ICRP values. The available data suggest that a reasonable assumption for the range in uptake might be an order of magnitude for both testes and ovaries.

The ICRP (1979, 1986) assumption of infinite retention in the gonads is based on observations of long-term retention of plutonium in testes and ovaries with no appreciable loss of activity in a number of species including rats and dogs. However, a retention half-time of 1 year has been reported for plutonium in the testes of the Macaque monkey (Durbin et al, 1983). Females of the same species similarly showed a half-time of about 1 year for a residual component of activity after rapid clearance of the major fraction. Data for baboons have shown a similar decrease in retention of americium in ovaries over a period from about 1 month to 2 years (Guilmette et al, 1980). It might be argued that the data from monkeys and baboons would be more applicable to humans because of the marked dissimilarity in structure and function of primate and non-primate gonads.

In order to investigate the likely variability in doses from the more important plutonium isotopes, calculations were carried out using ranges of parameters based on the evidence discussed above. The ranges chosen are summarised in Table 5.13. The data on which these distributions are based were limited and it was generally difficult to select a 95% confidence interval. The data were inadequate for determining a functional form for the distribution and the choice of a normal distribution for most parameters was somewhat arbitrary. It can be seen that the central values of the distributions used are sometimes slightly different from the reference values of ICRP Publication 48 (e.g., a retention half-time in liver of 25 years instead of 20). This is in order to reproduce the best estimate of 95% confidence interval; such small discrepancies will not significantly affect the results. The mean value for fractional uptake by bone (0.55) is somewhat higher than the ICRP Publication 48 value (0.45). Conversely, the mean f_1 value used, 5 10^{-4}, is lower than the ICRP Publication 48 value of 10^{-3}. A log-normal distribution was selected for the absorbed fraction of alpha energy in the sensitive red bone marrow and endosteal cells. The mean of this distribution was set at the ICRP value of 0.25. The log-normal distribution was truncated and absorbed fractions greater than 0.5 were rejected. This reduces the mean to about 0.22. This is substantially higher than bone re-modelling studies would indicate (Priest and Birchall, 1985). However, until a consensus emerges on the calculation of dose to bone marrow it is thought prudent to err on the side of conservatism.

When all the sources of variability are taken into account the 95% confidence interval for effective dose per unit intake by ingestion spans about an order of magnitude. The upper 95th percentile lies about a factor of two above the mean value. These estimates of variability may be taken as applying to the most important isotopes of plutonium, Pu-239 and Pu-241. There is little evidence on the variability of doses from intakes of americium but such data as exist are consistent with the ranges calculated for plutonium.

5.9.4 Dose per unit intake data

Values of doses per unit intake for Pu-238, Pu-239, Pu-241 and Am-241 derived from the Leggett models for plutonium and americium are given in Tables 5.14-5.16. For comparison, doses per unit intake calculated using the parameters recommended in ICRP publication 48 are given in Tables 5.17-5.19. In each case, the CEDE is due largely to doses received by bone surfaces, red bone marrow, liver and gonads. Using the Leggett model to take account of recycling of activity in bone has little effect on dose per unit intake for adults; the greatest effect is for infants with a maximum reduction in dose of about a factor of two for Am-241. The dose per unit intake values for infants take account of greater gut transfer at 10^{-2}, compared with 10^{-3} for children of one year of age and older. This results in a proportional increase in the doses to the skeleton, liver and gonads.

Estimates of doses to the fetus after chronic maternal intakes of Am-241 and isotopes of plutonium are given in Table 5.22. Calculating fetal doses on the basis of a placental discrimination factor of 0.1 between the 8th and 38th week of gestation, and taking account of activity in the child at birth, the CEDE to the child is about two orders of magnitude less than the maternal CEDE.

Table 5.12: Biokinetic parameters for plutonium and americium[a]

Age	f_1	Uptake by body organ or tissue Organ or tissue	Fractional uptake	Retention half-time, yrs
3 months	10^{-2}			
1 year	10^{-3}	Bone	0.45	50
5 years	10^{-3}	Liver	0.45	20
10 years	10^{-3}	Testes	0.00035	∞
15 years	10^{-3}	Ovaries	0.00011	∞
adult	10^{-3}			

a) ICRP Publication 48 (1986)

Table 5.13: Range of parameters used in analysis of variability for plutonium

Parameter[a]	95% confidence interval	Parameters of distribution	
		Mean	Standard deviation
Gut uptake factor (f_1)	10^{-5} - 10^{-3}	$5\ 10^{-4}$	$2\ 10^{-4}$
Retention time			
bone[b]	25 - 100	50 years	20 years
liver[b]	10 - 40	25 years	7 years
gonads	1 - ∞	50 years	25 years
Fractional uptake			
bone[c]	0.3 - 0.8	0.55	0.125
liver[c]	0.1 - 0.6	0.35	0.125
testes	10^{-4} - 10^{-3}	$5\ 10^{-4}$	$2\ 10^{-4}$
ovaries	$3\ 10^{-5}$ - $3\ 10^{-4}$	$1\ 10^{-4}$	$1\ 10^{-4}$
Absorbed fraction[d] of alpha energy in endosteal cells and red bone marrow	0.07 - 0.5	-1.56	0.58

Notes:

a) All are parameters of normal distribution except for absorbed fraction where a log-normal distribution was used.

b) A constraint was applied to the sum of retention times in bone and in liver ≤ 50 RT (bone) + RT (liver) ≤ 100.

c) A constraint was applied on fractional uptakes by bone and liver such that $0.8 <$ FU (bone) + FU (liver) < 0.95.

d) A log-normal function was used with a mean at absorbed fraction 0.25. However, the distribution was truncated at 0.5, reducing the effective mean to about 0.22.

Table 5.14: Committed dose equivalent (Sv/Bq) to age 70y for ingested Am-241. Based on Leggett model for americium (ICRP, 1989).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	3.3E-06	3.4E-07	3.7E-07	3.8E-07	4.0E-07	3.9E-07
Testes	5.1E-06	5.0E-07	4.5E-07	4.1E-07	4.1E-07	3.9E-07
Breast	7.1E-07	6.1E-08	3.8E-08	2.5E-08	2.0E-08	1.9E-08
R.B.M.	2.3E-05	1.9E-06	1.3E-06	9.4E-07	7.8E-07	7.1E-07
Lungs	7.1E-07	6.1E-08	3.8E-08	2.5E-08	2.0E-08	1.9E-08
Thyroid	7.1E-07	6.1E-08	3.8E-08	2.5E-08	2.0E-08	1.9E-08
Bone Surf	2.0E-04	1.9E-05	1.9E-05	1.9E-05	2.1E-05	2.0E-05
Stomach	7.3E-07	7.0E-08	4.3E-08	2.8E-08	2.1E-08	2.0E-08
S.I.	7.5E-07	8.6E-08	5.1E-08	3.3E-08	2.4E-08	2.2E-08
U.L.I.	9.4E-07	2.1E-07	1.1E-07	7.0E-08	4.4E-08	3.8E-08
L.L.I.	1.4E-06	5.0E-07	2.6E-07	1.5E-07	9.3E-08	7.8E-08
Liver	2.4E-05	2.6E-06	1.8E-06	1.4E-06	1.2E-06	1.3E-06
Uterus	7.1E-07	6.1E-08	3.8E-08	2.5E-08	2.0E-08	1.9E-08
C.E.D.E.	1.2E-05	1.2E-06	1.0E-06	9.0E-07	9.1E-07	8.9E-07

Table 5.15: Committed dose equivalent (Sv/Bq) to age 70y for ingested Pu-238. Based on Leggett model for plutonium (ICRP, 1989).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	2.0E-06	2.0E-07	2.1E-07	2.2E-07	2.4E-07	2.2E-07
Testes	3.3E-06	3.2E-07	2.8E-07	2.4E-07	2.4E-07	2.1E-07
Breast	6.0E-07	4.9E-08	3.0E-08	1.9E-08	1.3E-08	1.2E-08
R.B.M.	2.2E-05	1.8E-06	1.3E-06	9.3E-07	8.1E-07	8.2E-07
Lungs	6.1E-07	4.9E-08	3.0E-08	1.9E-08	1.4E-08	1.2E-08
Thyroid	6.0E-07	4.9E-08	3.0E-08	1.9E-08	1.3E-08	1.2E-08
Bone Surf	1.6E-04	1.6E-05	1.5E-05	1.5E-05	1.6E-05	1.7E-05
Stomach	6.2E-07	5.7E-08	3.4E-08	2.1E-08	1.5E-08	1.3E-08
S.I.	6.4E-07	7.3E-08	4.2E-08	2.6E-08	1.7E-08	1.5E-08
U.L.I.	8.2E-07	1.9E-07	1.0E-07	6.1E-08	3.7E-08	3.1E-08
L.L.I.	1.2E-06	4.7E-07	2.4E-07	1.4E-07	8.4E-08	6.9E-08
Liver	6.5E-05	6.8E-06	5.1E-06	4.0E-06	3.4E-06	3.6E-06
Uterus	6.0E-07	4.9E-08	3.0E-08	1.9E-08	1.3E-08	1.2E-08
C.E.D.E.	1.3E-05	1.2E-06	1.0E-06	8.8E-07	8.7E-07	8.8E-07

Table 5.16: Committed dose equivalent (Sv/Bq) to age 70y for ingested Pu-239. Based on Leggett model for plutonium (ICRP, 1989).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	2.3E-06	2.4E-07	2.5E-07	2.5E-07	2.7E-07	2.4E-07
Testes	3.6E-06	3.5E-07	3.1E-07	2.7E-07	2.7E-07	2.4E-07
Breast	6.0E-07	4.9E-08	3.0E-08	1.9E-08	1.4E-08	1.3E-08
R.B.M.	2.2E-05	1.8E-06	1.3E-06	1.0E-06	8.8E-07	8.9E-07
Lungs	6.0E-07	4.9E-08	3.1E-08	2.0E-08	1.4E-08	1.3E-08
Thyroid	6.0E-07	4.9E-08	3.0E-08	1.9E-08	1.4E-08	1.3E-08
Bone Surf	1.8E-04	1.8E-05	1.8E-05	1.7E-05	1.9E-05	1.8E-05
Stomach	6.1E-07	5.7E-08	3.4E-08	2.2E-08	1.6E-08	1.4E-08
S.I.	6.3E-07	7.1E-08	4.2E-08	2.6E-08	1.8E-08	1.6E-08
U.L.I.	8.0E-07	1.8E-07	9.7E-08	5.9E-08	3.6E-08	3.0E-08
L.L.I.	1.2E-06	4.4E-07	2.3E-07	1.4E-07	8.0E-08	6.6E-08
Liver	7.1E-05	7.4E-06	5.7E-06	4.5E-06	3.9E-06	4.0E-06
Uterus	6.0E-07	4.9E-08	3.0E-08	1.9E-08	1.4E-08	1.3E-08
C.E.D.E.	1.4E-05	1.4E-06	1.1E-06	1.0E-06	9.8E-07	9.7E-07

Table 5.17: Committed dose equivalent (Sv/Bq) to age 70y for ingested Pu-241. Based on Leggett model for plutonium (ICRP, 1989).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	5.0E-08	5.2E-09	5.4E-09	5.3E-09	5.4E-09	4.8E-09
Testes	6.1E-08	6.1E-09	5.6E-09	5.2E-09	5.3E-09	4.8E-09
Breast	4.5E-09	4.2E-10	3.2E-10	2.5E-10	2.2E-10	2.0E-10
R.B.M.	2.0E-07	2.0E-08	1.8E-08	1.6E-08	1.5E-08	1.5E-08
Lungs	4.5E-09	4.2E-10	3.2E-10	2.5E-10	2.2E-10	2.0E-10
Thyroid	4.5E-09	4.2E-10	3.2E-10	2.5E-10	2.2E-10	2.0E-10
Bone Surf	3.3E-06	3.4E-07	3.5E-07	3.7E-07	3.9E-07	3.7E-07
Stomach	4.6E-09	4.6E-10	3.4E-10	2.6E-10	2.2E-10	2.0E-10
S.I.	4.7E-09	5.3E-10	3.8E-10	2.9E-10	2.3E-10	2.1E-10
U.L.I.	5.6E-09	1.1E-09	6.6E-10	4.5E-10	3.3E-10	2.9E-10
L.L.I.	7.6E-09	2.4E-09	1.3E-09	8.4E-10	5.5E-10	4.7E-10
Liver	1.2E-06	1.3E-07	1.1E-07	9.4E-08	8.3E-08	8.0E-08
Uterus	4.5E-09	4.2E-10	3.2E-10	2.5E-10	2.2E-10	2.0E-10
C.E.D.E.	2.2E-07	2.2E-08	2.1E-08	2.0E-08	2.0E-08	1.9E-08

Table 5.18: Committed dose equivalent (Sv/Bq) to age 70y for ingested Am-241. Based on biokinetic parameters given in ICRP Publication 48 (1986) and the dosimetric model for the skeleton given in ICRP Publication 30 (1979).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	5.8E-06	5.4E-07	4.2E-07	3.4E-07	2.9E-07	2.7E-07
Testes	5.8E-06	5.4E-07	4.2E-07	3.4E-07	2.9E-07	2.7E-07
Breast	1.4E-09	9.6E-11	6.6E-11	4.3E-11	3.1E-11	2.7E-11
R.B.M.	3.3E-05	3.1E-06	2.3E-06	1.8E-06	1.5E-06	1.4E-06
Lungs	1.5E-09	1.0E-10	7.1E-11	4.9E-11	3.8E-11	3.4E-11
Thyroid	1.4E-09	9.7E-11	5.6E-11	2.9E-11	1.6E-11	1.3E-11
Bone Surf	4.1E-04	3.8E-05	2.9E-05	2.2E-05	1.9E-05	1.8E-05
Stomach	2.0E-08	9.4E-09	5.8E-09	3.2E-09	1.7E-09	1.4E-09
S.I.	4.7E-08	2.4E-08	1.4E-08	7.9E-09	4.3E-09	3.4E-09
U.L.I.	2.7E-07	1.4E-07	8.4E-08	4.6E-08	2.5E-08	2.0E-08
L.L.I.	8.0E-07	4.1E-07	2.5E-07	1.4E-07	7.5E-08	5.9E-08
Liver	8.2E-05	7.5E-06	5.3E-06	3.9E-06	3.3E-06	3.2E-06
Uterus	1.2E-09	1.3E-10	8.6E-11	5.4E-11	3.5E-11	3.0E-11
C.E.D.E.	2.3E-05	2.1E-06	1.6E-06	1.2E-06	1.0E-06	9.7E-07

Table 5.19: Committed dose equivalent (Sv/Bq) to age 70y for ingested Pu-238. Based on biokinetic parameters given in ICRP Publication 48 (1986) and the dosimetric model for the skeleton given in ICRP Publication 30 (1979).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	5.1E-06	4.7E-07	3.6E-07	2.9E-07	2.5E-07	2.3E-07
Testes	5.1E-06	4.7E-07	3.6E-07	2.9E-07	2.5E-07	2.3E-07
Breast	1.1E-09	5.6E-11	3.4E-11	1.9E-11	1.0E-11	8.3E-12
R.B.M.	3.0E-05	2.7E-06	2.0E-06	1.5E-06	1.3E-06	1.3E-06
Lungs	1.1E-09	5.6E-11	3.4E-11	1.9E-11	1.1E-11	8.4E-12
Thyroid	1.3E-09	8.7E-11	4.8E-11	2.3E-11	1.1E-11	7.9E-12
Bone Surf	3.7E-04	3.4E-05	2.5E-05	1.9E-05	1.7E-05	1.6E-05
Stomach	1.9E-08	9.0E-09	5.5E-09	3.0E-09	1.6E-09	1.3E-09
S.I.	4.4E-08	2.2E-08	1.4E-08	7.5E-09	4.1E-09	3.2E-09
U.L.I.	2.6E-07	1.3E-07	8.1E-08	4.4E-08	2.4E-08	1.9E-08
L.L.I.	7.7E-07	4.0E-07	2.4E-07	1.3E-07	7.2E-08	5.7E-08
Liver	7.7E-05	6.9E-06	4.9E-06	3.5E-06	3.0E-06	2.9E-06
Uterus	1.1E-09	5.5E-11	3.4E-11	1.8E-11	1.0E-11	7.9E-12
C.E.D.E.	2.1E-05	1.9E-06	1.4E-06	1.1E-06	9.0E-07	8.6E-07

Table 5.20: Committed dose equivalent (Sv/Bq) to age 70y for ingested Pu-239. Based on biokinetic parameters given in ICRP Publication 48 (1986) and the dosimetric model for the skeleton given in ICRP Publication 30 (1979).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	5.7E-06	5.3E-07	4.2E-07	3.3E-07	2.9E-07	2.6E-07
Testes	5.7E-06	5.3E-07	4.2E-07	3.3E-07	2.9E-07	2.6E-07
Breast	1.0E-09	5.2E-11	3.2E-11	1.7E-11	9.6E-12	7.6E-12
R.B.M.	3.2E-05	2.9E-06	2.2E-06	1.7E-06	1.5E-06	1.4E-06
Lungs	1.0E-09	5.2E-11	3.2E-11	1.7E-11	9.6E-12	7.6E-12
Thyroid	1.2E-09	8.2E-11	4.5E-11	2.1E-11	1.0E-11	7.4E-12
Bone Surf	4.0E-04	3.7E-05	2.8E-05	2.2E-05	1.9E-05	1.8E-05
Stomach	1.7E-08	8.4E-09	5.2E-09	2.8E-09	1.5E-09	1.2E-09
S.I.	4.2E-08	2.1E-08	1.3E-08	7.0E-09	3.8E-09	3.0E-09
U.L.I.	2.4E-07	1.2E-07	7.6E-08	4.1E-08	2.2E-08	1.8E-08
L.L.I.	7.2E-07	3.7E-07	2.3E-07	1.2E-07	6.7E-08	5.3E-08
Liver	7.9E-05	7.1E-06	5.1E-06	3.8E-06	3.2E-06	3.1E-06
Uterus	1.0E-09	5.2E-11	3.2E-11	1.7E-11	9.4E-12	7.4E-12
C.E.D.E.	2.2E-05	2.0E-06	1.5E-06	1.2E-06	1.0E-06	9.5E-07

Table 5.21: Committed dose equivalent (Sv/Bq) to age 70y for ingested Pu-241. Based on biokinetic parameters given in ICRP Publication 48 (1986) and the dosimetric model for the skeleton given in ICRP Publication 30 (1979).

	Age					
Organ	3m	1y	5y	10y	15y	20y
Ovaries	1.0E-07	9.7E-09	8.4E-09	7.3E-09	6.4E-09	5.6E-09
Testes	1.0E-07	9.7E-09	8.4E-09	7.3E-09	6.4E-09	5.6E-09
Breast	4.0E-12	3.9E-13	3.5E-13	3.1E-13	2.9E-13	2.6E-13
R.B.M.	4.7E-07	4.5E-08	3.9E-08	3.4E-08	3.1E-08	2.8E-08
Lungs	6.8E-12	6.6E-13	5.9E-13	5.3E-13	4.9E-13	4.6E-13
Thyroid	1.7E-12	1.7E-13	1.4E-13	1.3E-13	1.1E-13	1.0E-13
Bone Surf	5.9E-06	5.7E-07	4.9E-07	4.2E-07	3.8E-07	3.5E-07
Stomach	8.7E-11	4.3E-11	2.6E-11	1.4E-11	7.9E-12	6.3E-12
S.I.	2.1E-10	1.1E-10	6.5E-11	3.6E-11	2.0E-11	1.5E-11
U.L.I.	1.2E-09	6.3E-10	3.9E-10	2.1E-10	1.1E-10	9.0E-11
L.L.I.	3.7E-09	1.9E-09	1.2E-09	6.3E-10	3.4E-10	2.7E-10
Liver	8.9E-07	8.5E-08	7.0E-08	6.1E-08	5.7E-08	5.3E-08
Uterus	1.3E-12	1.3E-13	1.1E-13	1.0E-13	9.2E-14	8.3E-14
C.E.D.E.	3.1E-07	3.0E-08	2.6E-08	2.2E-08	2.0E-08	1.8E-08

5.10 DOSES TO THE FETUS FOR MATERNAL INTAKES OF RADIONUCLIDES

The information given in sections 5.5 to 5.9 detail the biokinetic parameters adopted in this report for calculating doses to the fetus at birth from intakes of isotopes of strontium, ruthenium, iodine, caesium, plutonium and americium. Table 5.22 gives doses to the newborn child at birth following chronic intakes by the mother over the year of the pregnancy. Doses are also given in Table 5.22 for committed doses to age 70 years. For long-lived radionuclides much of this dose arises from the body content of the radionuclide at birth but for short lived radionuclides the contribution to the total dose received from activity in the body at birth is small.

Table 5.22: Dose equivalent to fetal organs, effective dose equivalent to the fetus and activity in the newborn child for chronic uniform intake of radionuclides at 1 Bq y^{-1} by the mother for the year including pregnancy.

Radio-nuclide	f_1	RBM (Sv)	BS (Sv)	OT (Sv)		EDE (Sv)	Amount present at Birth (Bq)	CEDE resulting from activity present at birth (Sv)	Total CEDE to child (Sv)	CEDE to mother (Sv)
^{90}Sr	0.3	$4.2\ 10^{-8}$	$4.2\ 10^{-8}$	$1.1\ 10^{-8}$		$1.6\ 10^{-8}$	$2.4\ 10^{-2}$	$1.2\ 10^{-8}$	$2.8\ 10^{-8}$	$3.3\ 10^{-8}$
		All tissues (Sv)								
^{103}Ru	0.05	$2.0\ 10^{-10}$				$2.0\ 10^{-10}$	‡		$2.0\ 10^{-10}$	$7.4\ 10^{-10}$
^{106}Ru	0.05	$1.2\ 10^{-10}$				$1.2\ 10^{-10}$	$2.8\ 10^{-5}$	$8.6\ 10^{-12}$	$1.3\ 10^{-10}$	$5.8\ 10^{-9}$
		Thyroid (Sv)								
^{129}I	1.0	$2.5\ 10^{-7}$				$7.5\ 10^{-9}$	‡		$7.5\ 10^{-9}$	$6.6\ 10^{-8}$
^{131}I	1.0	$4.8\ 10^{-7}$				$1.4\ 10^{-8}$	‡		$1.4\ 10^{-8}$	$1.3\ 10^{-8}$
^{132}I	1.0	$3.9\ 10^{-9}$				$1.2\ 10^{-10}$	‡		$1.2\ 10^{-10}$	$1.4\ 10^{-10}$
		All tissues (Sv)								
^{134}Cs	1.0	$1.7\ 10^{-8}$				$1.7\ 10^{-8}$	$2.0\ 10^{-2}$	$2.5\ 10^{-9}$	$2.0\ 10^{-8}$	$1.7\ 10^{-8}$
^{137}Cs	1.0	$1.1\ 10^{-8}$				$1.1\ 10^{-8}$	$2.0\ 10^{-2}$	$2.2\ 10^{-9}$	$1.3\ 10^{-8}$	$1.2\ 10^{-8}$
		Kidney (Sv)	Liver (Sv)	Spleen (Sv)						
^{210}Po	0.1	$1.5\ 10^{-6}$	$2.6\ 10^{-7}$	$2.6\ 10^{-6}$		$2.6\ 10^{-7}$	$7.3\ 10^{-4}$			
		RBM (Sv)	BS (Sv)	Liver (Sv)	Gonads (Sv)					
^{238}Pu	10^{-3}	$6.9\ 10^{-10}$	$8.3\ 10^{-9}$	$2.3\ 10^{-9}$	$9.2\ 10^{-11}$	$4.7\ 10^{-10}$	$3.4\ 10^{-6}$	$7.4\ 10^{-9}$	$7.9\ 10^{-9}$	$8.6\ 10^{-7}$
^{239}Pu	10^{-3}	$6.5\ 10^{-10}$	$7.8\ 10^{-9}$	$2.2\ 10^{-9}$	$8.6\ 10^{-11}$	$4.4\ 10^{-10}$	$3.4\ 10^{-6}$	$7.8\ 10^{-9}$	$8.2\ 10^{-9}$	$9.5\ 10^{-7}$
^{241}Pu	10^{-3}	$3.3\ 10^{-13}$	$4.2\ 10^{-12}$	$1.1\ 10^{-12}$	$4.7\ 10^{-11}$	$2.1\ 10^{-13}$	$3.4\ 10^{-6}$	$1.1\ 10^{-10}$	$1.1\ 10^{-10}$	$1.9\ 10^{-8}$
^{241}Am	10^{-3}	$6.9\ 10^{-10}$	$8.3\ 10^{-9}$	$2.3\ 10^{-9}$	$9.2\ 10^{-11}$	$4.7\ 10^{-10}$	$3.4\ 10^{-6}$	$8.1\ 10^{-9}$	$8.6\ 10^{-9}$	$9.8\ 10^{-7}$

RBM = Red bone marrow.
BS = Bone surfaces.
OT = Other tissues.
‡ The trivial amounts present at birth would contribute doses of the order of 1% of the fetal doses quoted.

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6 ESTIMATES OF INDIVIDUAL DOSES IN EC COUNTRIES DUE TO INGESTION OF CONTAMINATED FOODS

6.1 INTRODUCTION

Previous chapters of this report have been concerned with the various types of information necessary to calculate Derived Intervention Levels. In this chapter this information is used to calculate some representative individual doses. These doses will illustrate the possible variation between EC countries and show which foods contribute to the ingestion doses given deposition at various times of the year. Individual doses have been calculated for two cases: firstly for unit deposition separately of strontium-90, caesium-137 and iodine-131; and secondly, for the deposition of a mix of the three radionuclides, summing the doses. The doses calculated are the committed effective dose equivalent from one year's intake for adults and the effective dose equivalent from one year's intake integrated to age 70 years for 5- and 10-year-old children. For convenience, these are simply referred to as doses in this chapter. The illustrative nature of the doses calculated should be emphasised. They do not represent doses that necessarily have been or could be received following an accidental release.

A number of different sets of individual doses have been calculated. For most of these the 'default' foodchain model and agricultural practice, as described in Chapter 2, were used to estimate the concentrations in food. However, the effect of using food concentrations estimated assuming appropriate agricultural practices for each country is also considered. Adult average individual doses were calculated for a number of sets of the dietary intakes that were discussed in Chapter 3. The diets considered are those appropriate for each country individually, then those for groups of countries in the EC, and finally for an 'EC' diet, weighted according to the population in each country. The effects of the distribution of food between regions was not considered in any of these illustrative dose calculations. The variation of individual doses with age is estimated by calculating average individual doses for 5- and 10-year-old children based on the 'EC' weighted dietary intake. For these calculations the dose per unit intake data for children and adults discussed in Chapter 5 were used.

6.2 CALCULATION OF AVERAGE ADULT INDIVIDUAL DOSES USING THE 'DEFAULT' FOODCHAIN MODEL

The default foodchain model described in Chapter 2 was used to calculate concentrations in green vegetables, grain, potatoes, other root vegetables, fruit, milk, beef and sheep meat. The default parameter values and agricultural practices were used in these calculations. Concentrations were calculated assuming the pattern of deposition of iodine-131, caesium-137 and strontium-90 measured in Munich following the Chernobyl reactor accident in 1986. The deposits used are given in Table 6.1. In addition, concentrations in food were calculated for unit deposit of the three radionuclides. Account was taken of losses of activity during culinary preparation in these calculations but no account was taken of delays between production and consumption. For vegetables, fruit, potatoes and root vegetables a multiplying factor of 0.8 was used to represent the amount of activity retained allowing for wastage and processing. The factor used for meat of all types was 0.75. Factors were also used to convert from concentrations in milk to those in various milk products, taking into account the amount of milk used in manufacturing the product and the transfer of the various elements to the milk products considered. For example, for cheese a factor of 1 was used for strontium-90 and caesium-137 while 2 was used for iodine-131. For butter the factors used were 0.3 for strontium-90 and caesium-137, together with 0.9 for iodine-131. For milk powder and condensed milk a factor of 9 was used for all radionuclides. These factors are based on data presented in Chapters 3 and 8 of this report (Tables 3.2, 3.3, 3.4 and 8.3).

Table 6.1: Total deposits of strontium-90, iodine-131 and caesium-137 used to estimate individual doses.

Radionuclide	Total Deposit (Bq m^{-2})
Strontium-90	200
Caesium-137	22000
Iodine-131	99000

Average intake rates for a number of foods were determined as part of the overall study and are discussed in Chapter 3 of this report. Adult average individual doses were determined using the intake rates applicable to each country in the EC (see Table 3.5). In addition, the typical diets for groups of countries within the EC and for the EC as a whole were used (Table 3.11). The doses per unit intake by ingestion used in the dose estimates are those given in Chapter 5 of this report (Tables 5.1, 5.7 and 5.11).

Estimates of concentrations in some additional foods were made for these dose calculations. These were for chickens, pork, eggs and various milk products. Chickens and pigs were assumed to eat contaminated winter grain at concentrations predicted by the model. Equilibrium transfer factors were then used to estimate concentrations in chicken meat and eggs. The intake of fish and various beverages has not been included in the dose estimates.

Table 6.2 gives the average adult dose due to ingestion in the first year, summed over all foods for the total deposition given in Table 6.1 occurring during three times of the year (1st January, 1st May and 1st July). Doses are given for each country using appropriate intake rates and also for the groups of countries are compared in Chapter 3, together with the EC average. From Table 6.2 it can be seen that the variation between countries is not large, with the dose calculated using the EC average diet being roughly in the middle of the range for the individual countries. If the doses for the groups are compared with those from individual countries it can be seen that they represent well the spectrum of doses received. The doses for deposition in the summer are higher in all cases than those for deposition in the winter. This reflects the higher predicted concentrations in some foods following deposition in the summer compared with that in the winter (see Chapter 2).

Table 6.3 shows the percentage contribution of the foods contributing most to the doses received in each country. For deposition on 1 January fruit and green vegetables contribute most to the adult doses for all countries followed by milk and beef. The relative importance of fruit or vegetables depends on the consumption of these by individuals in each country. For deposition in May cereals, milk and beef are the most important foods for most countries. For countries with a higher consumption of sheep and/or goat meat, i.e. Greece, Ireland and the UK, this food contributes between 10 and 15% of the dose. Similarly, for countries with a higher fruit or pork consumption these foods can be relatively more important. For deposition on 1 July, cereals, milk and pork dominate the doses received, between 30 and 50% coming from cereal consumption. It should be noted that it has been assumed that the diet of pigs is 100% contaminated and comprises winter grain. It is felt that, at least for some countries, a large proportion of the diet of pigs would not comprise food that would be contaminated, so the importance of pork may have been overestimated. The differences in the contributions for each food between countries reflect the relative intakes of the food as shown in Table 3.5.

Table 6.2: Average adult dose from one year's intake of food (1).

Country or region	Effective Dose Equivalent (Sv) Following Deposition on 1 Jan	1 May	1 July
Belgium/Lux	6.0 E-4	2.7 E-3	4.7 E-3
Denmark	4.5 E-4	2.5 E-3	4.7 E-3
FRG	6.8 E-4	2.8 E-3	5.1 E-3
France	6.9 E-4	2.9 E-3	4.9 E-3
Greece	(1.3 E-3)	3.0 E-3	5.3 E-3
Ireland	4.5 E-4	(3.3 E-3)	(5.4 E-3)
Italy	1.1 E-3	2.5 E-3	5.2 E-3
The Netherlands	9.4 E-4	(3.3 E-3)	5.0 E-3
Portugal	5.9 E-4	2.0 E-3	4.0 E-3
Spain	9.4 E-4	2.8 E-3	4.7 E-3
UK	4.9 E-4	3.0 E-3	4.8 E-3
Group 1 (2)	4.9 E-4	3.0 E-3	4.8 E-3
Group 2 (2)	1.2 E-3	2.6 E-3	5.2 E-3
Group 3 (2)	7.7 E-4	2.8 E-3	4.9 E-3
EC	7.9 E-4	2.8 E-3	4.9 E-3

Note:

1. For deposition of iodine-131, caesium-137 and strontium-90 as given in Table 6.1.
2. The groups are those defined in Chapter 3. Group 1 contains Ireland and UK, group 2 contains Italy and Greece and group 3 contains Belgium, Luxembourg, FRG, France, the Netherlands and Spain.

( ) indicates the country or group with the highest dose for deposition at a given time of the year.

___ indicates the country or group with the lowest dose for deposition at a given time of the year.

Table 6.3: Percentage contribution of individual foods to adult doses from 1 year's intake following deposition on 1st January.

Country	Green Vegetables	Fruit	Milk	Beef/Veal	Others
Belgium/ Luxembourg	46.0	51.0	0.9	1.0	1.1
Denmark	48.0	48.0	2.4	0.9	0.7
FRG	33.0	64.0	0.8	0.9	0.2
France	44.0	53.0	0.9	1.2	0.9
Greece	44.0	54.0	0.4	0.4	1.2
Ireland	42.0	52.0	3.2	1.3	1.5
Italy	49.0	50.0	0.4	0.6	-
The Netherlands	31.0	66.0	0.9	0.4	1.7
Portugal	62.0	36.0	0.5	0.5	1.0
Spain	42.0	56.0	0.8	0.3	0.9
UK	53.0	42.0	2.0	1.1	1.9

Table 6.3 (cont'd): Percentage contribution of individual foods to dose from 1 year's intake following deposition on 1st May.

Country	Cereals	Potatoes	Fruit	Drinking Milk	Root Veg	Green Veg
Belgium/ Luxembourg	12.0	16.0	6.4	16.0	4.1	5.7
Denmark	12.0	12.0	4.8	34.0	2.9	4.9
FRG	11.0	12.0	8.7	15.0	3.1	4.4
France	12.0	12.0	7.0	16.0	4.4	5.9
Greece	15.0	12.0	13.0	12.0	2.2	10.0
Ireland	12.0	17.0	3.8	34.0	5.0	3.2
Italy	20.0	6.2	12.0	16.0	2.2	12.0
The Netherlands	7.8	12.0	11.0	20.0	3.0	5.0
Portugal	22.0	21.0	6.0	12.0	5.3	10.0
Spain	12.0	17.0	10.0	21.0	4.2	7.8
UK	11.0	16.0	3.7	26.0	4.1	4.8

Country	Milk Powder	Beef/Veal	Pork	Sheep/Goat	Others
Belgium/ Luxembourg	9.7	12.0	6.9	2.3	8.9
Denmark	0.4	9.2	10.0	0.8	9.0
FRG	15.0	11.0	8.6	1.0	10.2
France	6.9	15.0	4.8	5.1	10.9
Greece	0.9	10.0	2.9	14.0	8.0
Ireland	0.5	9.6	4.1	6.9	3.9
Italy	1.1	15.0	4.3	2.0	9.2
The Netherlands	21.0	6.8	5.2	0.5	7.7
Portugal	2.2	8.0	3.8	4.2	5.5
Spain	6.7	5.6	5.3	6.7	3.7
UK	8.7	10.0	3.2	7.5	5.0

Table 6.3 (cont'd): Percentage contribution of individual foods to dose from 1 year's intake following deposition on 1st July.

Country	Cereals	Green Veg	Fruit	Drinking milk	Powder Milk	Potatoes
Belgium/ Luxembourg	35.0	3.2	3.6	9.0	5.6	4.0
Denmark	32.0	2.5	2.5	18.0	0.2	2.6
FRG	32.0	2.4	4.8	8.5	8.2	2.9
France	37.0	3.4	4.1	9.3	4.1	2.9
Greece	45.0	5.9	7.1	6.9	0.5	2.8
Ireland	38.0	1.9	2.4	21.0	0.3	4.4
Italy	50.0	6.0	6.0	7.6	0.5	1.3
The Netherlands	27.0	3.3	7.0	13.0	13.0	3.3
Portugal	57.0	5.1	2.9	6.0	1.1	4.4
Spain	36.0	4.6	6.2	12.0	4.0	4.3
UK	38.0	3.0	2.4	16.0	5.5	4.4

Country	Beef/Veal	Pork	Sheep/Goat	Poultry	Others
Belgium/ Luxembourg	7.4	21.0	1.4	4.2	5.6
Denmark	5.2	29.0	0.4	3.0	4.6
FRG	6.7	26.0	0.6	2.4	5.5
France	9.4	15.0	3.1	4.4	7.3
Greece	6.2	8.9	8.2	3.5	5.0
Ireland	6.4	13.0	4.4	4.1	4.1
Italy	7.7	11.0	1.0	4.1	4.8
The Netherlands	4.8	18.0	0.4	3.5	6.7
Portugal	4.2	9.9	2.1	4.6	2.7
Spain	3.6	17.0	4.1	5.1	3.1
UK	6.8	11.0	4.9	4.4	3.6

Note:

Deposition of strontium-90, iodine-131 and caesium-137 as given in Table 6.1.

The discussion so far has been based on doses calculated for the deposition of a mix of radionuclides, i.e. that at Munich following the Chernobyl accident. It is also interesting to look at the relative doses following deposition of the individual radionuclides and the important foods for each radionuclide. Tables 6.4 to 6.6 give the percentage contribution of the important foods to the doses in the groups of countries considered, as a function of radionuclide and time of deposition.

For deposition on 1 January, fruit and vegetables dominate the doses received for a unit deposit of all the radionuclides. Milk and milk products contribute a few percent for strontium-90, whereas for caesium-137 beef is more important than milk products. For deposition on 1 May, the important foods for the three radionuclides are very different. For strontium-90 potatoes, vegetables, fruit, milk and cheese are important; for caesium-137 cereals, milk and meat, predominantly beef, are important; for iodine-131 potatoes, vegetables, fruit, milk and milk powder tend to be important. These results reflect the behaviour of the radionuclides in terms of their transfer to the various foods. For deposition on 1 July the pattern changes again. For strontium-90 cereals, vegetables, fruit, milk and cheese are important; for caesium-137 cereals, milk, beef, pork and chicken are important; for iodine-131 vegetables, fruit, milk, cheese and milk powder tend to be important. If delays between production and consumption were included the doses from iodine-131 in cheese and milk powder would be lower than indicated here.

Table 6.7 shows the total dose summed over foods that would be received for a unit deposition of each radionuclide at the various times of the year. The doses following deposition of the three radionuclides are quite different and the total ingestion doses received when summed over foods and radionuclides would depend on the relative amount of each radionuclide deposited as well as the time of year.

Table 6.4: Contributions of foods to ingestion doses from one year's intake following unit deposition on 1st January.

a) Strontium-90

Countries	% Contribution						
	Cereals	Green Veg.	Fruit	Milk	Milk Products	Milk Powder	Others
Group 1	0.9	50.0	41.2	4.7	0.1	1.5	1.6
Group 2	0.6	48.7	50.0	1.0	0.1	-	-
Group 3	0.5	38.4	55.7	1.9	0.2	1.2	2.1
Portugal	1.0	61.0	36.0	1.3	-	0.2	0.5
Denmark	0.9	46.0	46.0	5.5	0.5	0.1	1.0
EC	0.6	43.4	50.9	2.1	0.2	0.8	2.0

b) Casesium-137

Countries	% Contribution				
	Green Veg.	Fruit	Milk	Beef & Veal	Others
Group 1	50.0	39.2	3.4	1.9	5.5
Group 2	46.7	50.0	0.7	1.0	1.6
Group 3	40.0	57.9	1.4	1.3	-
Portugal	61.0	36.0	0.9	0.9	1.2
Denmark	47.0	46.0	4.0	1.6	1.4
EC	44.0	50.0	1.4	1.3	3.3

c) Iodine-131

Countries	% Contribution		
	Green Veg.	Fruit	Others
Group 1	52.4	43.3	4.3
Group 2	49.0	51.0	-
Group 3	39.4	57.6	3.0
Portugal	63.0	37.0	-
Denmark	50.0	50.0	-
EC	47.0	52.9	0.1

Note:

The groups of countries are those defined in Chapter 3. Group 1 contains Ireland and UK, Group 2 contains Italy and Greece, and Group 3 contains Belgium, Luxembourg, FRG, France, the Netherlands and Spain.

Table 6.5: Contributions of foods to ingestion doses from one year's intake following unit deposition on 1st May.

a) Strontium-90

Countries	% Contribution Potatoes	Root Veg.	Green Veg.	Fruit	Milk	Cheese	Others
Group 1	25.5	6.6	15.5	12.3	25.5	1.3	13.3
Group 2	9.4	2.4	32.6	32.6	12.4	3.0	7.6
Group 3	19.2	4.9	17.3	24.5	15.3	2.6	16.2
Portugal	29.0	7.3	29.0	17.0	11.0	1.2	5.5
Denmark	19.0	4.7	16.0	16.0	34.0	3.1	7.2
EC	18.7	4.6	20.6	25.0	16.8	2.5	11.8

b) Caesium-137

Countries	% Contribution Cereals	Potatoes	Green Veg.	Fruit	Milk	Beef/Veal	Pork	Sheep/Goat	Others
Group 1	18.6	5.1	3.0	2.4	25.6	15.1	5.2	11.6	13.4
Group 2	28.2	2.2	7.4	7.5	14.1	20.5	6.3	6.0	7.8
Group 3	17.5	4.3	3.9	5.5	16.2	16.2	10.2	5.5	20.7
Portugal	37.0	6.8	6.8	3.9	12.0	12.4	6.3	6.7	8.1
Denmark	18.3	3.6	3.1	3.1	32.4	13.6	15.5	1.2	9.2
EC	20.0	4.0	4.4	5.2	17.5	16.2	8.4	6.7	17.6

c) Iodine-131

Countries	% Contribution Potatoes	Root Veg.	Green Veg.	Fruit	Milk	Cheese	Milk Powder	Others
Group 1	33.3	8.3	7.2	5.6	27.5	2.6	8.3	7.2
Group 2	17.0	4.3	21.6	21.6	18.2	8.7	1.2	7.4
Group 3	28.2	7.0	9.1	13.6	18.2	6.4	11.8	5.7
Portugal	42.8	10.9	15.6	9.1	12.8	2.8	2.3	3.7
Denmark	25.3	6.4	7.9	7.8	37.4	6.8	0.5	7.9
EC	29.0	7.3	12.0	14.0	21.0	6.3	9.2	1.2

Note:

The groups of countries are those defined in Chapter 3. Group 1 contains Ireland and, UK, Group 2 contains Italy and Greece, and Group 3 contains Belgium, Luxembourg, FRG, France, the Netherlands and Spain.

Table 6.6: Contributions of foods to ingestion doses from one year's intake following unit deposition on 1st July.

a) Strontium-90

Countries	% Contribution					
	Cereals	Green Veg.	Fruit	Milk	Cheese	Others
Group 1	34.0	15.5	12.3	25.5	1.3	11.4
Group 2	33.8	24.6	24.6	9.1	2.2	5.7
Group 3	29.4	16.6	23.5	14.5	2.5	13.5
Portugal	47.6	23.8	14.3	8.8	1.0	4.5
Denmark	31.7	14.9	14.9	31.7	2.9	3.9
EC	32.1	18.7	22.6	14.9	2.3	9.4

b) Caesium-137

Countries	% Contribution							
	Cereals	Potatoes	Milk	Beef & Veal	Pork	Sheep/Goat	Poultry	Others
Group 1	43.1	4.4	11.5	7.4	12.6	5.3	5.0	10.7
Group 2	57.1	1.5	5.2	8.1	12.4	2.3	4.6	8.8
Group 3	39.5	3.4	6.8	7.4	23.1	2.4	4.4	13.0
Portugal	62.5	4.4	4.1	4.5	11.2	2.3	5.3	5.7
Denmark	35.8	2.5	12.1	5.8	32.6	0.5	3.4	7.3
EC								

c) Iodine-131

Countries	% Contribution							
	Potatoes	Green Veg.	Fruit	Milk	Milk Products	Cheese	Milk Powder	Others
Group 1	3.8	12.1	9.6	46.5	1.5	4.5	14.1	7.9
Group 2	1.4	26.4	26.4	22.2	3.9	10.7	1.5	7.5
Group 3	2.8	13.3	20.0	26.7	4.5	9.5	17.3	5.9
Portugal	5.7	30.0	17.5	24.7	1.6	5.5	4.5	10.5
Denmark	2.5	11.1	10.9	52.3	6.3	9.5	0.7	6.7
EC	2.8	16.7	19.4	29.2	3.9	8.7	12.8	6.5

Note:

The groups of countries are those defined in Chapter 3. Group 1 contains Ireland and UK, Group 2 contains Italy and Greece and Group 3 contains Belgium, Luxembourg, FRG, France, the Netherlands and Spain.

Table 6.7: Doses from 1 year's intake of food for a unit deposition of each radionuclide.

a) Deposition on 1st January

Countries	Dose (Sv per Bq m^{-2}) strontium-90	 caesium-137	 iodine 131
Group 1	3.4 E-8	1.3 E-8	2.1 E-8
Group 2	7.8 E-8	3.0 E-8	5.1 E-8
Group 3	5.2 E-8	1.9 E-8	3.3 E-8
EC	5.3 E-8	2.0 E-8	3.4 E-8

b) Deposition on 1st May

Countries	Dose (Sv per Bq m^{-2}) strontium-90	 caesium-137	 iodine-131
Group 1	4.7 E-8	8.6 E-8	1.2 E-8
Group 2	4.9 E-8	7.8 E-8	8.8 E-9
Group 3	4.9 E-8	8.0 E-8	1.1 E-8
EC	4.8 E-8	8.0 E-8	1.0 E-8

c) Deposition of 1st July

Countries	Dose (Sv per Bq m^{-2}) strontium-90	 caesium-137	 iodine-131
Group 1	4.7 E-8	1.9 E-7	7.1 E-9
Group 2	6.5 E-8	2.1 E-7	7.2 E-9
Group 3	5.1 E-8	1.9 E-7	7.5 E-9
EC	5.3 E-8	1.9 E-7	7.2 E-9

Note:

The groups are those defined in Chapter 3. Group 1 contains Ireland and UK Group 2 contains Italy and Greece and Group 3 contains Belgium, Luxembourg, FRG, France, the Netherlands and Spain.

6.3 DOSES TO CHILDREN INGESTING CONTAMINATED FOOD

Children generally eat less food than adults but for many radionuclides the dose per unit intake by ingestion is higher for children than for adults. It is therefore of interest to see how the ingestion doses for children eating contaminated food compare with those for adults. As discussed in Chapter 3, detailed dietary intake data are not available for all EC countries. However, it has been possible to estimate the fraction of the adult's diet that would be consumed by children aged 5 and 10-years-old. Based on the information given in Table 3.13 and Chapter 3, the reduction factors in Table 6.8 were applied to the EC weighted intakes and used to calculate average individual doses for 5- and 10-year-old children. The doses per unit intake used for strontium-90, iodine-131 and caesium-137 were those discussed in Chapter 5 of this report (see Tables 5.1, 5.7 and 5.11). Doses were calculated both for foods contaminated following the deposition of the mix of radionuclides as given in Table 6.1, and for unit deposit of the three radionuclides separately. As in the previous calculations the default foodchain model, parameters and agricultural practices were assumed.

Table 6.8: The intake of various foods by 5- and 10-year-old children relative to that of adults.

	Reduction factor	
Foods	5-year-old	10-year-old
Cereals, fruit, potatoes and root vegetables	0.5	0.7
Milk, milk products and eggs	1.0	1.0
Green vegetables	0.6	0.8
All meat	0.4	0.6

Table 6.9: Dose from 1 year's intake of food by 5-year-old and 10-year-old children and adults.

a) Deposition on 1st January

	Dose (Sv)		
Countries	5	10	Adult
Group 1	6.5 E-4	5.3 E-4	4.9 E-4
Group 2	1.6 E-3	1.3 E-3	1.2 E-3
Group 3	1.0 E-3	8.3 E-4	7.7 E-4
EC	1.1 E-3	8.6 E-4	7.9 E-4

b) Deposition on 1st May

	Dose (Sv)		
Countries	5	10	Adult
Group 1	4.8 E-3	3.4 E-3	3.0 E-3
Group 2	3.5 E-3	2.6 E-3	2.6 E-3
Group 3	4.4 E-3	3.2 E-3	2.8 E-3
EC	4.2 E-3	3.1 E-3	2.8 E-3

c) Deposition on 1st July

Countries	5	10	Adult
Group 1	4.4 E-3	3.8 E-3	4.8 E-3
Group 2	4.1 E-3	3.8 E-3	5.2 E-3
Group 3	4.4 E-3	3.8 E-3	4.9 E-3
EC	4.3 E-3	3.8 E-3	4.9 E-3

Notes:

1. The groups are those defined in Chapter 3. Group 1 contains Ireland and UK, Group 2 contains Italy and Greece and Group 3 contains Belgium, Luxembourg, FRG, France, the Netherlands and Spain.

2. For deposition as given in Table 6.1.

Table 6.9 shows the total ingestion dose from 1 year's intake for the 'EC' diet following deposition of the mix of radionuclides for adults, 5-year-old and 10-year-old children. Results are also given for the three groups of countries considered earlier. For deposition at all three times of year the differences in the calculated doses to the three age groups are small with the doses to adults being the highest for deposition in July and the doses to 5-year-olds being highest at the other two times of the year. The same pattern in the doses is seen for the four sets of intakes considered.

Ingestion doses for the three age groups have also been calculated for unit deposition at the three times of year of strontium-90, iodine-131 and caesium-137. Results are given in Table 6.10 for the EC weighted diet only; as the same intake reduction factors are applied those for the groups of countries show very similar patterns. For strontium-90 and caesium-137 individual doses increase with age with the 5-year-old dose being less than a factor of two smaller than the adult for strontium-90 and greater than a factor of two smaller for caesium-137. In contrast, for iodine-131 the individual doses decrease with age with the dose to a 5-year-old being a factor of about three higher than that for the adult.

Table 6.10: Doses from 1 year's intake of food following unit deposition for 5-year-old and 10-year-old children and adults for the EC diet.

a) Deposition on 1st January

Radionuclide	Dose (Sv per Bq m^{-2}) 5 y	10 y	Adult
Strontium-90	3.2 E-8	4.7 E-8	5.3 E-8
Iodine-131	8.8 E-9	6.0 E-9	3.4 E-9
Caesium-137	7.7 E-9	1.1 E-8	2.0 E-8

b) Deposition on 1st May

Radionuclide	Dose (Sv per Bq m^{-2}) 5 y	10 y	Adult
Strontium-90	3.4 E-8	4.5 E-8	4.8 E-8
Iodine-131	3.5 E-8	2.1 E-8	1.0 E-8
Caesium-137	3.4 E-8	4.6 E-8	8.0 E-8

c) Deposition on 1st July

Radionuclide	Dose (Sv per Bq m^{-2}) 5 y	10 y	Adult
Strontium-90	3.7 E-8	4.9 E-8	5.3 E-8
Iodine-131	2.7 E-8	1.5 E-8	7.2 E-9
Caesium-137	7.1 E-8	1.0 E-7	1.9 E-7

Note:

These doses are for the EC diet using reduction factors as given in Table 6.8.

Table 6.11: Dose received from 1 year's intake of food for adults. Individual doses (Sv) calculated using regional and default agricultural practices

Country	Dose (Sv) following deposition in:					
	January		May		July	
	Regional	Default	Regional	Default	Regional	Default
Belgium/ Luxembourg	6.8 E-4	6.0 E-4	2.3 E-3	2.7 E-3	4.2 E-3	4.7 E-3
Denmark	5.3 E-4	4.5 E-4	2.1 E-3	2.5 E-3	4.2 E-3	4.7 E-3
FRG	7.7 E-4	6.8 E-4	2.4 E-3	2.8 E-3	4.5 E-3	5.1 E-3
France	6.8-8.5 E-4	6.9 E-4	2.5-4.5 E-3	2.9 E-3	1.5-4.7 E-3	4.9 E-3
Greece	1.5 E-3	1.3 E-3	4.7 E-3	3.0 E-3	1.6 E-3	5.3 E-3
Ireland	4.4 E-4	4.5 E-4	2.9 E-3	3.3 E-3	5.1 E-3	5.4 E-3
Italy	1.3 E-3	1.1 E-3	4.3 E-3	2.5 E-3	1.3 E-3	5.2 E-3
The Netherlands	1.0 E-3	9.4 E-4	3.0 E-3	3.3 E-3	4.5 E-3	5.0 E-3
Portugal	6.4-6.6 E-4	5.9 E-4	2.3-3.3 E-3	2.0 E-3	0.9-3.2 E-3	4.0 E-3
Spain	1.0-1.1 x E-3	9.4 E-4	3.3-4.3 E-3	2.8 E-3	1.4-3.7 E-3	4.7 E-3
UK	4.9 E-4	4.9 E-4	2.7 E-3	3.0 E-3	4.6 E-3	4.8 E-3
EC	-	7.9 E-4	-	2.8 E-3	-	4.9 E-3

Note:

For deposition as given in Table 6.1.

6.4 THE EFFECT ON INDIVIDUAL DOSES OF ASSUMING REGIONAL AGRICULTURAL PRACTICES

All of the doses given so far were obtained using food concentrations calculated with the default foodchain model and assumptions on agricultural practices. As discussed in Chapter 2 of this report, there are significant variations in agricultural practices across the EC and this leads to differences in predicted food concentrations. To see the effect of this on doses, adult average individual doses were calculated using food concentrations estimated assuming agricultural practices appropriate to the region concerned. The default foodchain model and parameter values were retained.

Table 6.11 shows the average adult ingestion doses calculated using regional agricultural practices for each country. Results obtained using the default practices are included for comparison purposes, as are the EC weighted intake results. In general, the effects of assuming regional agricultural practices are small. Parts of France lie within all four of the regions considered for agricultural practice (see Figure 2.4 in Chapter 2). This leads to a predicted variation in food concentrations between different parts of France of up to a factor of three. The largest differences between the regional results and those calculated using the default are for the Mediterranean countries (south of France, Greece, Italy southern Spain and southern Portugal) for deposition in July. This reflects the lower food concentrations predicted for these areas for milk and meat from grazing animals as discussed in Chapter 2. Even when regional agricultural practices are assumed the EC weighted dose is still representative of the range of doses estimated for the individual countries.

6.5 DISCUSSION

From the estimates of individual doses presented in this chapter it is possible to make a number of general points. The differences in doses following deposition at different times of the year are quite marked. These seasonal differences are seen both for the total ingestion doses and also in which foods contribute most to the total dose.

The foods that contribute most to individual doses for deposition at a particular time of year depend to some extent on the mix of radionuclides considered. For deposition of strontium-90, iodine-131 and caesium-137 in January the intake of fruit and green vegetables dominates the resulting ingestion doses. For deposition in May the important foods are different for the three radionuclides considered. For strontium-90 potatoes, green vegetables, milk and cheese are important, for caesium-137 it is cereals, milk and meat that are important, while for iodine-131 the important foods tend to be potatoes, vegetables, fruit, milk and milk powder. For deposition on 1st July the important foods are again different. Cereals but not potatoes are now important for strontium-90, while potatoes are no longer important for iodine-131. Different foods contribute most to the dose in the different countries in the EC depending on the consumption pattern. For countries with a higher consumption of sheep and/or goat meat (Greece, Ireland and the UK) this food becomes important, contributing 10 to 15% of the dose for a deposition in May. In many cases consumption of pork has been found to be an important contributor to dose, notably for deposition in July. However, this finding should be treated with caution as it has been assumed that the diet of pigs comprises 100% contaminated winter grain. Pigs are often given a variety of different feedstuffs some of which are imported from some distance and so would not necessarily be contaminated following an accident. The doses from ingestion of pork may therefore have been significantly overestimated. The relative importance of intake in fruit should also be treated with caution. The intakes of fruit include a large component due to the consumption of fruit juices and in many countries these may be imported from outside the EC. The intake of offals was not included in the dose assessment but additional calculations have shown that their inclusion would increase the doses by only a few percent.

Calculations were also made of the ingestion doses for 5 and 10-year-old children and the results compared with those for adults. The differences with age were found to be small. For deposition of iodine-131 alone the doses calculated for 5-year-old children were about a factor of three higher than for adults. However, for deposition of strontium-90 or caesium-137 adult doses were calculated to be higher than those for children.

The effect of using an appropriate regional agricultural practice in calculating ingestion doses compared with a 'default' European practice has also been investigated. The effects are generally small and indicate that for many situations assuming a default agricultural practice is adequate.

However, for the Mediterranean countries (southern France, Italy, Greece, southern Spain and southern Portugal) differences up to a factor of four are estimated for deposition in July. In this case regional agricultural practices should be taken into account. The same foodchain model parameters have been used for all regions; using more site specific parameter values could have an effect on the results presented here.

7 CHARACTERIZATION OF CRITICAL POPULATION GROUPS WITH SPECIAL CONSUMPTION HABITS IN BAVARIA

7.1 INTRODUCTION

The Chernobyl accident in 1986 has shown that the absence of uniform international and, in some cases, national intervention levels for radioactive substances in foodstuffs was a cause for concern among the population, and that trade between the countries of the European Community was affected by the differing contamination levels. The Commission of the European Community consequently appointed the Group of Experts established under Article 31 of the Euratom Treaty in May 1986, to advise on suitable intervention levels for the limitation of the radiological risk from ingestion of contaminated foodstuffs which might be imported into the Community or moved between Member states in the period following any future nuclear accident. To fulfill this task, a corresponding Working Party was constituted by the Group of Experts, to work out a scientific concept for the establishment of intervention levels for major food groups by following the radiation protection principles recommended by the International Commission for Radiation Protection (ICRP, 1984).
The concept is described by equation 7.1:

$$A = \frac{E}{D \cdot V \cdot f} \qquad \text{(eq.7.1)}$$

A: Derived intervention level in Bq/kg (Bq/l);
E: Intervention level of dose in Sv/a;
D: Effective dose per unit ingested activity in Sv/Bq;
V: Consumption rate of foodstuffs of concern during a given time - e.g. in a year - in kg/a (l/a);
f: Relative contamination factor (definition according to the Group of Experts: fractional contamination of a foodstuff in relation to the considered intervention level; $0 < f \quad 1$).

For the parameters which characterize the pattern of food supply (distribution, type and amount of consumed foodstuffs), statistical data were chosen that are broadly representative for the whole Community. The objective of this chapter is to analyse the range of values for the parameters describing the consumption habits with regard to critical population groups to determine the extent of differences in special intervention levels are based. Members of a critical population group are subjects who prefer less marketable dose-relevant food items or who provide themselves predominantly with self- or locally produced food that is not subject to official control. Members of critical groups have been studied to determine their consumption habits and measurements made of the resulting body burden of radiocesium in comparison to non-self-supporters chosen as a reference group.

The investigations were performed in a region bordering the Alps in Southeast-Bavaria, where the highest accidental deposition of radiocesium (> 42000 Bq/m^2 Cs 137) within the Federal Republic of Germany occurred. In this region results from duplicate studies of food and whole-body-counting, conducted in 1987 and 1988, showed a significant difference in the body content and intake rate of radiocesium by ingestion between partial self-supporters and non-self-supporters (Burkhardt and Lux 1988). The population-specific differences could primarily be explained by the comparatively high specific activity of radiocesium in milk- and meat-products consumed by self-supporters, which was not detected in greater degree during the 3rd and 4th years following the accident, apart from exceptional situations observed in exposed regions of Europe (Lettner, 1989). During the 3rd and 4th years after the accidental release of radioactivity, only contaminated game and mushrooms contributed significantly to the internal dose by ingestion in individuals which provided an above-average consumption rate of these food items. For this reason not only self-supporters but also game-hunters and mushroom-eaters are defined as critical population groups and were included in the research program for comparison against non-self-supporters as a reference group. The methodology, type and scope of the investigations are described in the following chapter.

7.2 METHODOLOGY

To characterize and differentiate population groups with different consumption habits, the following points are examined in greater detail:

a) Qualitative and quantitative composition of population-specific food baskets depending on the season of the year.

b) Level of self-support; that is the contribution of locally/regionally produced foodstuffs to the amount of dose-relevant food or whole food.

c) Body burden and ingestion of radiocesium depending on consumption habits and season of the year.

The research program includes the following investigations:

a) Analysis of the qualitative composition of collective-specific food baskets daily over a period of one month per season from winter 1988/1989.

b) Inquiry into the origin of consumed foodstuffs to evaluate the amount of regionally produced products from winter 1988/89.

c) Measurements of the consumption rate of dose-relevant food items from spring 1989.

d) Whole-body-counting monitoring in time intervals of 6-7 weeks from autumn 1988.

e) Measurements of the specific activity of radiocesium in critical foodstuffs (game, mushrooms, milk, fish) on a random basis from autumn 1988.

f) Estimation of the dietary intake of radiocesium via a biokinetic approach or an approach based on the consumption rate and contamination of critical food items.

Forty-one volunteers, residing in Southeast-Bavaria, were chosen for collaboration in the reasearch program and assigned to the following population groups:

Non-self-supporters	(N)
Self-supporters	(S)
Game-hunters	(H)
Mushroom-eating individuals	(M)

Twenty-one individuals agreed to measurements of their body content of radio-cesium by whole-body-counting, performed at the Institute for Radiation Hygiene of the Federal Office for Radiation Protection in Munich. A survey in reference to number and sex of members of the different collectives is presented in Table 7.1.

Over a period of one month in each season, the volunteers had to record daily the types of foodstuffs, consumed at main and interim meals and the origin of the foodstuffs. For this purpose a questionnaire was designed which takes all foodstuffs into consideration. An example of the questionnaire and a specification of the types of vegetables and fruits are given in Burkhardt et al. (1990). In addition to the qualitative inquiries, the subjects had to record the amount of dose-relevant foodstuffs consumed over a period of one week per season.

The food items to be considered as dose-relevant depends on the respective food consumption pattern in the region of concern and on the season in which the nuclear accident occurred, as well as on the composition and inventory of the accidently-released radioactive substances. In this study, those components of the regional diet are designated as critical or dose-relevant foodstuffs, that are/were most contaminated by accident-specific radionuclides (radioiodine, radiocesium): milk and milk-products, meat and game, lake-fish, vegetables and mushrooms. Products which are not produced in the investigated region, or are not considered as a potential source of contamination, were not recorded quantitatively (fruits, cereals, eggs, oil and fat, spices).

On the basis of recorded consumption data, the following parameters were estimated by means of expressions 7.2-7.5:

Table 7.1: Type and size of population groups participating in the whole-body-counting measurements and consumption habits inquiry (m = male, f = female)

	Number of Persons Participating in:	
Population Group	Consumption Habit Inquiry	Whole-Body-Measurements
Non-self-supporters	11 (4 m, 7 f)	5 (2 m, 3 f)
Self-supporters	12 (6 m, 6 f)	4 (2 m, 2 f)
Game-hunters	14 (11 m, 3 f)	9 (8 m, 1 f)
Mushroom-eaters	4 (4 m)	3 (3 m)
Total	41	21

CONSUMPTION FREQUENCY F_K

F_K - Number of meals of a foodstuff K of concern during a given time - e.g. month, week - in (time unit)$^{-1}$.

(eq. 7.2)

REGIONAL FRACTION R_K

$$R_K = \left(\frac{F_R}{F}\right)_K \qquad \text{(eq. 7.3)}$$

F_K : Consumption frequency for foodstuff K in (time unit) $^{-1}$;

F_{RK}: Consumption frequency for the fraction of foodstuff K, which is produced in the region of concern.

LEVEL OF SELF-SUPPORT S

$$S = \frac{\sum_{K=1}^{n} (R \times V)_K}{\sum_{K=1}^{n} V_K} \times 100 \qquad \text{(eq. 7.4)}$$

S: Level of self-support in %;

R_K: Regional fraction of consumed foodstuff K;

V_K: Consumption rate of consumed foodstuff K in kg/d;

K: Serial number of foodstuff K;

n: Number of foodstuffs of concern.

CONSUMPTION RATE V_K

Assuming that all collectives consume comparable amounts of a foodstuff of concern per meal, averaged over a period of one month, the consumption rate of foodstuff K, which was not analysed in quantitative terms in this study - e. g. fruits, cereals - can be estimated by means of equation 7.5 underlying data on the collective-specific consumption frequency and statistical consumed amount:

$$V_K^{\,x} = \frac{F_K^{\,x}}{F_K^{Ref}} \times V_K^{DGE} \qquad \text{(eq. 7.5)}$$

$V_K^{\,x}$: Consumption rate of foodstuff K for the population group x in kg/d;

V_K^{DGE}: Statistical consumption rate of foodstuff K according to (DGE 1984) in kg/d;

$F_K^{\,x}$: Consumption frequency of foodstuff K for the population group x in (time unit)$^{-1}$;

F_K^{Ref}: Consumption frequency of foodstuff K for non-self-supporters as reference population group.

The intake of radiocesium by ingestion is estimated according to a biological method underlying reference values for the sex-specific effective half-life for Cs 134 and Cs 137 according to ICRP and data on the body burden of Cs-134 and Cs-137 or via a mathematical approach based on the consumed amount and contamination of critical food items. For the biokinetic approach two different retention phases are to be taken into account, which are expressed by the balance - and equilirium model. The balance model (equation 7.6) implies no equilirium conditions, for which reason the intake rate is estimated by step for the time intervals between whole-body-counting measurements:

$$Z = \frac{\left[A - A' \cdot \exp(-\lambda_{eff} \cdot t)\right] \cdot \lambda_{eff}}{f_1 \cdot (1 - \exp(-\lambda_{eff} \cdot t))} \qquad \text{(eq. 7.6)}$$

Z: Daily intake by ingestion in Bq/d;

A: Body burden at the end of the last stage of constant intake in Bq;

A': Body burden at the end of the preceding stage of constant intake in Bq;

λ_{eff}: Effective elimination constant in day^{-1} for Cs-134 or Cs 137 respectively;

f_1: Fraction reaching the whole body by ingestion.

The equilibrium model provides equilibrium conditions at each point of time throughout the monitoring program as expressed by constant rates of intake and excretion of radiocesium:

$$\lim_{t \to \infty} A_{(t)} = Z / \lambda_{eff} \qquad \text{(eq. 7.7)}$$

The applicability of biokinetic models is further discussed in section 7.6.2.

According to expression 7.8 the intake rate of radioactivity is derived from data on the consumption rate and contamination of dose-relevant food items:

$$Z_t = \sum_{k=1}^{n} (A_{sK} \times V_K \times R_K)t \qquad \text{(eq. 7.8)}$$

Z_t : Intake rate during season t in Bq/d;

A_{sK}: Specific activity of radiocesium in dose-relevant food item K in Bq/kg;

t : Season of consideration;

K : Serial number of food item K.

7.3 CONSUMPTION FREQUENCY OF FOODSTUFFS

7.3.1 General description

On the basis of data on the consumption frequency of foodstuffs, consumed during the course of one month per season, the seasonal consumption habits for a population group can be characterized qualitatively. The values on the consumption frequency are subdivided into classes (Table 7.2). It should be noted that differences in the class frequency among food items will not strictly indicate similar differences in the corresponding consumption rates; for example honey and jam are consumed more frequently than fresh vegetables, the consumption rate of which is comparatively high. However considering only one food item, related variations in the consumed amount might be inferred from differences in the data on the consumption frequency by the different groups, assuming that the amounts of the food item consumed per meal are comparable between the population groups of concern. In the case of food items, recorded in qualitative and quantitative terms, seasonal and group-specific variations in the consumption rate are rather well reflected by the corresponding data on the consumption frequency. On the basis of these observations the consumed amount of food items that are recorded in qualitative terms, can be estimated by means of equation 7.5, as it is done in chapter 7.4.2. The following tabulation shows the composition of the regional food basket in the order of decreasing values for the consumption frequency, averaged over the whole period of analysis and the different population groups:

Table 7.2: Classification of values on consumption frequency F

Time Period	Consumption Frequency	F in Month XX-1	Class
monthly	never/rarely	≦ 0.9	1
monthly	several times	≦ 4.5	2
weekly	1-3 times per week	≦ 13.8	3
weekly	4-6 times per week	≦ 26.1	4
daily	once	≦ 38.4	5
daily	several times; occasionally	≦ 55.8	6
daily	several times; regularly	> 55.8	7

Foodstuff/Foodgroup	Consumption Frequency
Bread	daily, several times; occasionally
Cereals	4-6 times per week - daily
Milk plus milk products	4-6 times per week - daily
Milk products	4-6 times per week - daily
Milk	4-6 times per week
Cheese	4-6 times per week
Honey and jam	4-6 times per week
Pork	4-6 times per week
Leafy vegetables	4-6 times per week
Potatoes	(up to) 3 times per week
Fruits	(up to) 3 times per week
Fruit juice	1-3 times per week
Fresh vegetables without leafy vegetables	1-3 times per week
Beef/veal	1-3 times per week
Poultry	several times per month
Fish (lake- and sea-fish)	several times per month
Mushrooms*	never/rarely per month
Lamb / mutton*	never/rarely per month
Game*	never/rarely per month

* Mean value does not include game-hunters or mushroom-eaters respectively

7.3.2 Seasonal and population-specific variations in the consumption frequency of foodstuffs

Full data on the consumption frequency are compiled in Burkhardt et al. (1990), the results are summerized as follows:

In winter, self-supporters drink milk most days, game-hunters only up to 3-times per week; non-self-supporters have intermediate consumption frequencies. In spring, the consumption frequency for milk and milk-products increases for game-hunters and mushroom-eaters, but is still not equal to the values for the groups of self-supporters and non-self-supporters, confirmed by quantitative results. The distribution pattern of consumption frequency data does not change until autumn.

Pork is consumed most days in each population group, beef is part of the diet up to 3-times per week. The supply of fresh meat (pork and beef/veal) is dependent on the season, so no variations are seen in consumption frequency. On the whole, fresh vegetables are consumed in spring and summer with a higher frequency than in autumn and winter.

7.4. CONSUMPTION RATE OF FOODSTUFFS

7.4.1 Dose-relevant foodstuffs in comparison to German reference values according to the Society For Food Research (DGE)

The population-specific consumption rates of dose-relevant food items are given in Burkhardt et al. (1990) in relation to the corresponding statistical values on consumption amounts according to DGE (1984). The following paragraph gives a summary of the results.

The consumption of milk, averaged over the groups studied and over seasons, exceeds the statistical data by only 30%. In summer, the milk consumption is somewhat lower. The group-specific consumption of milk varies to a greater extent from representative data, by factors of 0.6-2.2 in spring, 0.5-1.7 in summer and by factor 0.5-2.0 in autumn and winter. A maximal consumption rate of 400 ml/d was computed for male self-supporters in spring and a minimal rate for game-hunters and mushroom-consumers.

Consumption of fresh meat averaged over all the population groups is about 50% higher than the reference value. Hunters consume twice the reference amount of meat due to the availability of provided self-hunted game as well as locally raised mutton/lamb and pork in spring. The daily consumption of game (40 - 60 g/d) exceeds the statistical value for beef/veal according to DGE (1984) by a factor 1.5 - 2, for which reason game can be classified as a major foodstuff for the group of game-hunters. In spring the consumption rate for fresh vegetables is generally higher than the statistical value by more than a factor 2. In summer, the values show a tendency to drop but are still 1.4- to 2-times higher than the reference value according to DGE (1984). In winter self-supporters consume smaller amounts of fresh vegetables, exceeding the statistical value only by a factor 1.3.

In autumn and spring mushroom-eaters consume nearly 30g/d mushrooms. In summer, the main growth-season, the consumption rate amounts to about 50 g/d, and mushrooms are therefore classified as major foodstuffs according to the season.

Group-specific consumption of lake-fish exceeds the reference value of DGE (1984) by a factor of about 4.

7.4.2 Consumption rates in comparison to EC-diets and the European reference values of Article 31 Group of Experts

The following section examines the extent to which the regionally recorded consumption data correspond with EC-diets, recorded in Chapter 3, and with the reference values chosen by the Group of Experts established under Article 31 of the Euratom Treaty.

The consumption rates of food items which were analysed in qualitative terms only (cereals without bread, fruits, butter, poultry), were evaluated according to equation 7.5. In addition, the consumption rates for bread and cheese which were recorded in previous years in the field of self-support and non-self-support (Burkhardt and Lux 1988), were used as a basis for the calculation of values for the group of hunters and mushroom-eating persons according to equation 7.5. A tabulation in Burkhardt et al. (1990) shows the seasonal consumption rates for all food items of the different groups covering most of the regional and group-specific food baskets. For comparison with EC-diets, recorded in Chapter 3, and with European values for food classes chosen by the Article 31 Group of Experts, food items of the same category were combined in food classes and listed in Table 7.3.

As indicated below, the regional data on food items like dairy produce, meat/poultry, fruits/vegetables and cereals, are in the same range as the values for the same food classes, consumed in the 3 groups of the EC countries recorded in Chapter 3. The lower consumption of fruits/vegetables for Bavaria may be explained by the fact that fruit juices are not included in the regional calculations:

	Regional diets of all four groups		EC-diets	
	mean	range	mean	range
	kg/a		kg/a	
Dairy produce	119	71 - 166	124	98 - 153
Meat/Poultry	84	71 - 113	80	71 - 87
Fruits/Vegetables	123	110 - 128	149	89 - 210
Cereals	88	70 - 98	84	74 - 113

Differences between group-specific consumption data and reference values according to the Group of Experts are expressed by deviation factors (see Table 7.4). During the one-year-period of analysis the following food classes are underestimated by the reference values of the Expert Group:

Vegetables and fruits	all groups	deviation factor 1.1-1.3
Vegetables, fruits and potatoes	all groups	deviation factor 1.6-2.0
Dairy produce	self-supporters	deviation factor 1.4
Meat incl. poultry	game-hunters	deviation factor 1.4

Table 7.3: Annual consumption rate (kg/a) of major food classes for different population groups according to inquiries during different seasons

Winter 1989/1990

	CEC*	N	S	H	M
Dairy produce	120	122	167	75	54
Meat and poultry (without bone)	80	66	72	110	74
Vegetables and fruits	100	131	106	126	130
Veg., fruits, potatoes	-	178	157	189	182
Cereals	100	89	101	75	99

Spring 1989

	CEC*	N	S	H	M
Dairy produce	120	143	186	96	90
Meat and poultry (without bone)	80	70	71	102	91
Vegetables and fruits	100	134	107	140	114
Veg., fruits, potatoes	-	188	153	212	155
Cereals	100	89	96	63	108

continued Table 7.3:

Summer 1989	CEC*	N	S	H	M
Dairy produce	120	147	149	112	75
Meat and poultry (without bone)	80	69	70	104	86
Vegetables and fruits	100	118	113	125	137
Veg., fruits, potatoes	-	166	157	191	188
Cereals	100	85	97	74	93

Autumn 1989	CEC*	N	S	H	M
Dairy produce	120	150	162	104	67
Meat and poultry (without bone)	80	78	70	137	75
Vegetables and fruits	100	127	113	114	109
Veg., fruits, potatoes	-	171	154	187	167
Cereals	100	84	98	69	85

* CEC: Underlying data of the Article 31 Group of Experts

Table 7.4: Consumption rate of major food groups for different population groups during winter (I), spring (II), summer (III) and autumn (IV) 1989 relative to reference values according to the Article 31 Group of Experts
s: standard-deviation

Food Class	Non-Self-Supporters				
	I	II	III	IV	mean +/- s
Dairy produce	1.0	1.2	1.2	1.3	1.2 +/- 0.12
Meat and poultry (without bone)	0.8	0.9	0.9	1.0	0.9 +/- 0.08
Veg. and fruits	1.3	1.3	1.3	1.3	1.3 +/- 0.05
Veg., fruits,potatoes	1.8	1.9	1.7	1.7	1.8 +/- 0.09
Cereals	0.9	0.9	0.8	0.8	0.8 +/- 0.06

Food Class	Self-Supporters				
	I	II	III	IV	mean +/- s
Dairy produce	1.4	1.6	1.2	1.4	1.4 +/- 0.16
Meat and poultry (without bone)	0.9	0.9	0.9	0.9	0.9 +/- 0.00
Veg. and fruits	1.1	1.1	1.1	1.1	1.1 +/- 0.00
Veg., fruits,potatoes	1.6	1.5	1.5	1.5	1.6 +/- 0.06
Cereals	1.0	1.0	1.0	1.0	1.0 +/- 0.00

Table 7.4 continued

Food Class	Game - Hunters I	II	III	IV	mean +/- s
Dairy produce	0.6	0.8	0.9	0.9	0.8 +/- 0.14
Meat and poultry (without bone)	1.4	1.3	1.3	1.7	1.4 +/- 0.19
Veg. and fruits	1.3	1.4	1.2	1.1	1.3 +/- 0.13
Veg., fruits, potatoes	1.9	2.1	1.9	1.9	2.0 +/- 0.10
Cereals	0.7	0.6	0.7	0.7	0.7 +/- 0.05

Food Class	Mushroom-Eaters I	II	III	IV	mean +/- s
Dairy produce	0.5	0.8	0.6	0.6	0.6 +/- 0.12
Meat and poultry (without bone)	0.9	1.1	1.1	0.9	1.0 +/- 0.11
Veg. and fruits	1.3	1.1	1.1	1.1	1.2 +/- 0.15
Veg.,fruits,potatoes	1.8	1.6	1.9	1.7	1.7 +/- 0.13
Cereals	1.0	1.1	0.9	0.9	1.0 +/- 0.09

The European reference value, however, slightly overestimates the consumption of cereals by about 10%. Excluding the data for vegetables the differences are cancelled out when an average is estimated for all the population groups and the whole period of analysis. The results indicate that the the regional consumption habits are rather well represented by the European reference values recommended by the Group of Experts, considering the total population and a one-year period. Considerable variations in the seasonal and group-specific consumption rates of fresh food items like raw milk, fresh vegetables and fresh meat can be disregarded, if the calculations do not differentiate between consumption habits and seasons.

7.5 ORIGIN OF FOODSTUFFS

7.5.1 Single foodstuffs of regional origin

In Burkhardt et al. (1990) data on the percentage of consumption of foodstuffs, produced in the region of Southeast-Bavaria, are given in detail according to the season and kind of population. Below maximal levels of self-support of various foodstuffs are shown for a period of one year that were recorded in different rural population groups.

The data show that the maximal level of self-support of basic foodstuffs like milk, milkproducts, various species of vegetables and fruits amounts to more than 60% of the annual need:

Milk	:	98%	Veg. (leafy)	:	68%
Milkproducts	:	74%	Veg. (roots, tubers)	:	64%
Cheese	:	15%	Veg. (other)	:	39%
Pork	:	24%	Potatoes	:	41%
Beef, Veal	:	31%	Fruits (domestic)	:	69%
Game	:	89%	Fruit juices	:	54%
Lamb/Mutton	:	45%	Fish	:	42%

Self-supporters are providing up to 100% of their own milk and by 75% of milk products from the region. Hunters and mushroom-eaters likewise living in rural areas, consume about 25-30% of locally produced milk and milk products. Seasonal effects are not observed.

In winter and spring the fraction of pork and beef/veal produced locally amounts to about 15 - 40% in the rural population (self-supporters, game-hunters, mushroom-eating persons). Even in the field of non-self-support, about 15% is produced locally, because the butcher shops in the provincial countryside are more in favor of local meat production than the competing central markets. In summer, the proportion of fresh meat consumed by self-supporters, that is produced locally, increases, whereas the proportion decreases for the other groups.

The local production of vegetables contributes about 25% of total consumption during winter and 50-60% during spring and summer. During winter the population is supplied with vegetables from greenhouses or provided with frozen food. For self-supporters, the regional contribution of fresh vegetables is several times greater than for the urban population. In the rural population the consumption of local fruits during winter accounts for about 50% of total consumption (storage and frozen fruits). During spring, the regional contribution declines to a level of 20 - 30%, because the stock diminishes and the harvest has not begun. Bad weather conditions during the last year studied resulted in a crop shortage, such that the regional fruit supply has not increased significantly again in the group of self-supporters.

The consumed amounts of dose-relevant foodstuffs of regional origin are listed in Table 7.5 and the percentage of the total amounts consumed are shown in Figures 7.1 - 7.4: The highest consumption rates are for raw milk and milk products for self-supporters, followed by game in the group of game-hunters.

7.5.2 Contribution of regional foodstuffs to the amount of dose-relevant food and total food

Table 7.6 shows the regional fraction of the dose-relevant food and Table 7.7 the regional fraction of the total food for the different population groups according to the season. During the annual period of analysis in 1989, the self-supportes obtained 71 - 75% of the dose-relevant food from the region. In the remaining rural population, the regional contribution is about half of that for self-supporters and the contribution is even lower for the urban population by factors of 4 to 11 depending on the season. The regional products also contribute approaching 50% of the total food consumed by self-supporters. The results thus indicate that self-supporters should be classified as the most critical population group.

Since the investigations are conducted in the vicinity of conveniently-situated medium-sized towns with a modern infra-structure, the recorded data may underestimate the degree of self-support in any isolated regions. On the other hand, the results may be representative for larger areas of the European Community.

Table 7.5 Consumption rate of dose-relevant foodstuffs from the region of Southeast-Bavaria in g/d during winter (I), spring (II), summer (III) and autumn (IV) of 1989 (data are not related to sex).

Population	Annual Season	Raw Milk	Milk Prod.	Pork	Beef	Game	Mutton/ Lamb
N	I	0	2.0	6.0	4.0	0.0	0.0
	II	45	5.0	2.0	2.0	0.0	0.0
	III	0	0.0	0.6	0.6	0.2	0.0
	IV	11	1.0	2.0	2.0	0.3	0.3
S	I	324	51	22	2	4.0	4.0
	II	330	47	10	14	3.0	0.0
	III	285	67	15	10	0.6	0.5
	IV	318	43	4	10	6.0	0.1
H	I	38	7	6	8	48	8
	II	89	28	21	9	37	4
	III	55	17	3	6	41	4
	IV	38	9	5	4	52	6
M	I	25	7	16	16	0	1
	II	27	6	24	14	0	0
	III	36	29	0	0	10	0
	IV	29	8	0	0	0.3	0

Table 7.5 continued

Pop.	Annual Season	Fish (Lake)	Vegetables leafy	Vegetables roots/tubers	Vegetables other	Mushrooms
N	I	0.0	6	12	4	0.0
	II	2.0	13	5	4	1.0
	III	0.3	13	5	15	0.1
	IV	0.4	13	4	15	1.0
S	I	0.0	15	14	2	0.0
	II	0.3	37	37	16	0.5
	III	4.0	42	15	30	1.0
	IV	1.0	47	19	29	0.1
H	I	6	1	0	2	4.0
	II	8	10	4	9	0.5
	III	10	10	4	6	8.0
	IV	6	4	1	1	3
M	I	2	42	12	7	25
	II	17	35	27	13	19
	III	0	34	16	28	46
	IV	5	44	20	12	30

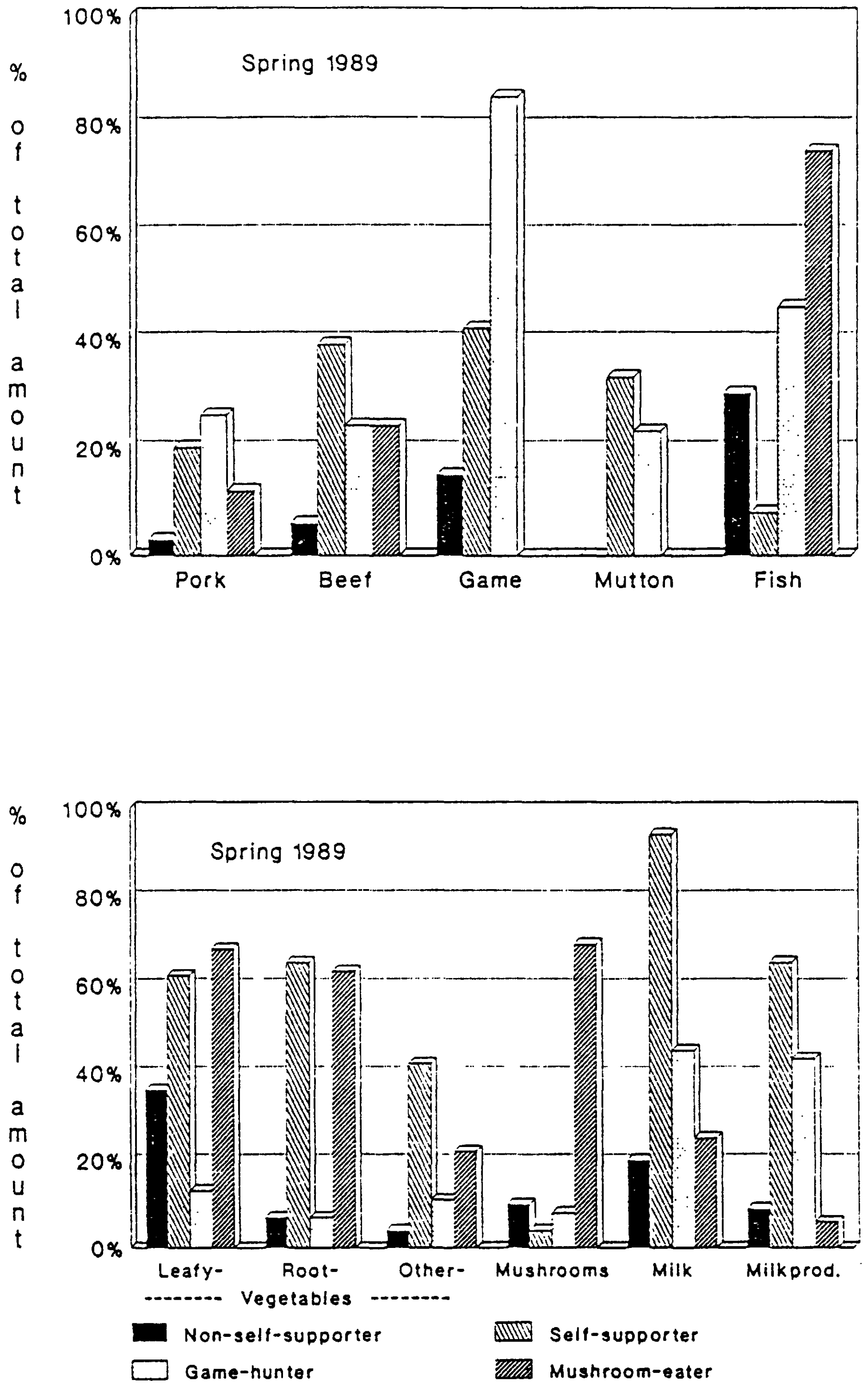


Figure 7.1: Regional fraction of major and critical food items in spring 1989

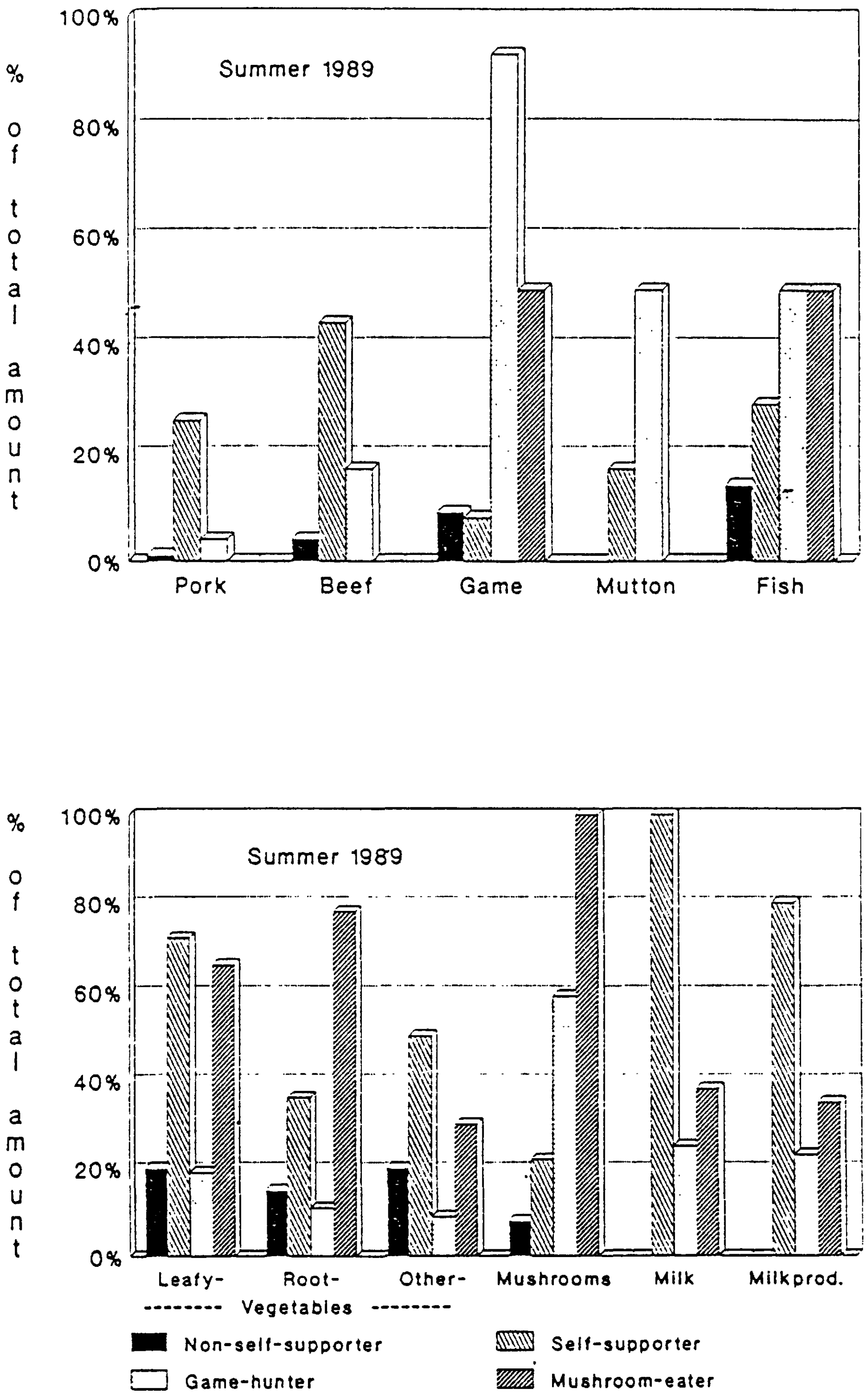
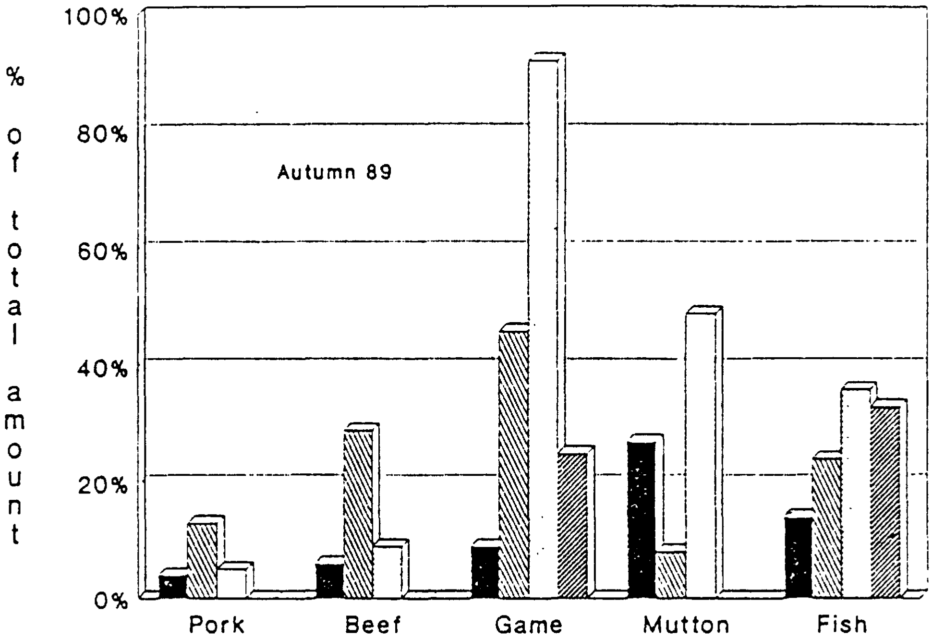


Figure 7.2: Regional fraction of major and critical food items in summer 1989



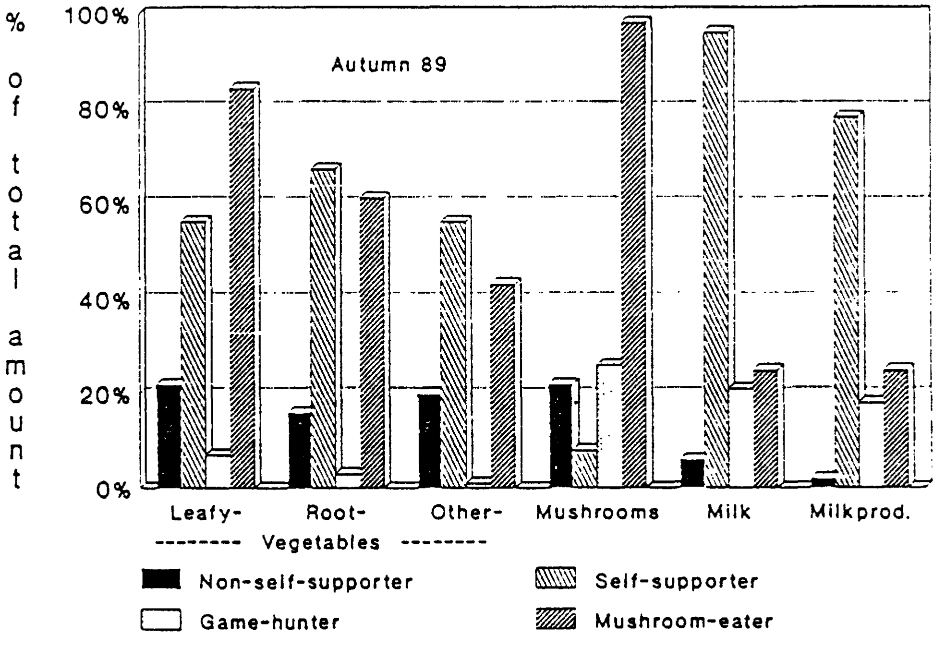


Figure 7.3: Regional fraction of major and critical food items in autumn 1989

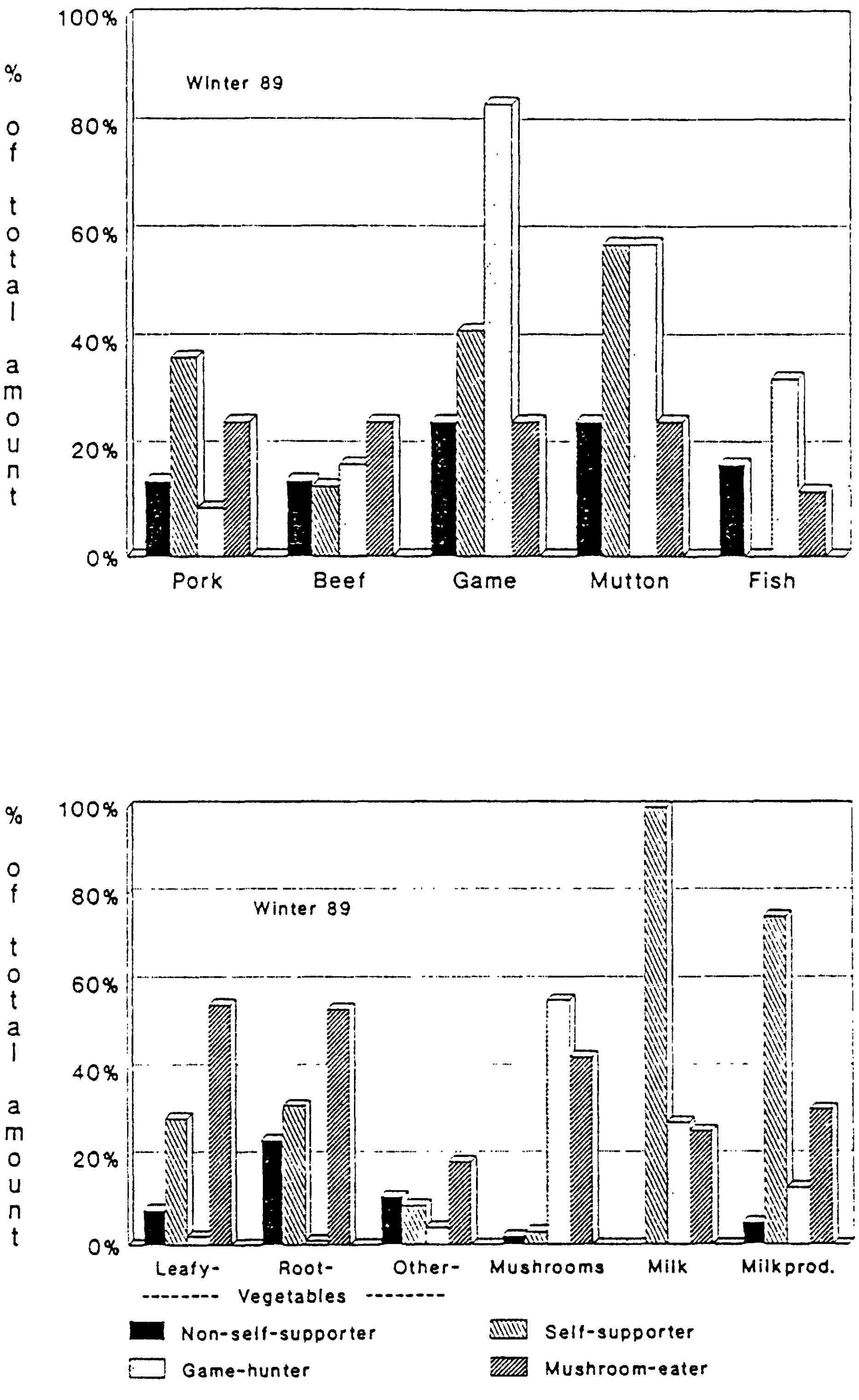


Figure 7.4: Regional fraction of major and critical food items in winter 1989/90

Table 7.6: Regional fraction of the dose-relevant food for the different population groups during spring, summer, autumn and winter 1989.

(Pop./N = ratio between the population group of concern and non-self-supporters; data without consideration of sex)

Population	Fraction in %				Pop./N			
Group	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
N	13	7	10	7	1.0	1.0	1.0	1.0
S	73	74	75	71	4.2	10.6	7.5	10.1
H	32	26	21	23	1.8	3.7	2.6	3.3
M	31	37	35	31	2.0	5.3	3.7	4.4

Table 7.7: Regional fraction of the total food for the different population groups during spring, summer, autumn and winter, 1989.

(Pop./N = ratio between the population group of concern and non-self-supporters; data without consideration of sex)

Pop.	Fraction in %				Pop./N			
Group	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
N	10	6	10	9	1.0	1.0	1.0	1.0
S	48	48	47	45	3.8	8.0	4.7	5.0
H	22	16	13	16	1.7	2.7	1.3	1.8
M	23	35	33	33	2.0	5.8	3.3	3.7

7.6 INGESTION AND INCORPORATION OF RADIOCESIUM

The consumption statistics are adopted by the methodology for fixing intervention levels of radionuclides in food. In this regard, it is of particular interest to analyse whether variations in consumption habits may result in different radiation exposures. For this purpose whole-body-counting measurements of incorporated radiocesium were performed simultaneously with the inquiries in food consumption habits to gain a basis for quantitative assessments of the internal dose from ingestion. The incorporated Cs-content is not exclusively a reflection of the current consumption because the whole-body-content will include some activity ingested during preceding periods of time. In this respect it is necessary to derive the actual intake rate from data on the whole-body burden which can then be related to group-specific consumption data.

7.6.1 Body burden of radiocesium

From 41 participants who collaborated in the research of consumption habits, 21 persons were selected for the control of a temporal change in body burden. As the participants had to take leave for one day to travel to the whole-body-counter 170 km away from their place of residence, the selection of individuals could not be made by random criterion but was also dependent on the flexibility of the persons and their readiness for a continued collaboration. Beginning in September 1988, the measurements were conducted in time intervals of 6-7 weeks with a whole-body-counter at the Institute for Radiation Hygiene in Munich.

Table 7.8 shows the mean value and the range of incorporated activity of radiocesium for the seasons autumn 1988, winter 1988/89, spring, summer and autumn 1989. Cesium, like potassium, concentrates in cells particularly in muscle tissue, for which reason the Cs-content and retention is age- and sex-specific. In order to eliminate sex- and age-specific variations, the incorporated activity was additionally referred to the K-40-content of the body. As the ratio-values indicate the same tendency toward population-specific and temporal differences in body burden, only data that refer to the Cs-content are discussed below:

Table 7.8: Incorporation of radiocesium (Cs-134 + Cs-137) in different population groups (N, S, H, M)

Annual Season	Population Group	(Cs-134 + Cs-137) (Bq) mean	range	(Cs-134 + Cs-137)/K-40 Ratio mean	range
Autumn 1988	N	611	295 - 1110	0.17	0.08 - 0.28
	S	1073	870 - 1180	0.30	0.22 - 0.39
	H	2022	700 - 5120	0.41	0.18 - 0.91
	M	1727	700 - 3540	0.41	0.18 - 0.84
Winter 1988/89	N	530	334 - 860	0.13	0.09 - 0.21
	S	861	590 - 1000	0.24	0.19 - 0.33
	H	2050	1020 - 3816	0.41	0.23 - 0.68
	M	1262	450 - 2500	0.30	0.12 - 0.59
Spring 1989	N	425	238 - 630	0.12	0.06 - 0.17
	S	619	323 - 800	0.17	0.10 - 0.24
	H	1548	660 - 3080	0.31	0.16 - 0.55
	M	972	343 - 1990	0.23	0.09 - 0.47
Summer 1989	N	270	174 - 407	0.08	0.05 - 0.12
	S	531	324 - 640	0.16	0.10 - 0.23
	H	1134	443 - 2170	0.23	0.11 - 0.48
	M	728	306 - 1140	0.17	0.08 - 0.27
Autumn 1989	N	287	199 - 448	0.07	0.05 - 0.11
	S	469	276 - 700	0.14	0.09 - 0.23
	H	1186	548 - 1950	0.25	0.14 - 0.46
	M	948	730 - 1070	0.21	0.16 - 0.25
Winter	H	1123	540 - 1910	0.23	0.13 - 0.41

Table 7.9: Body burden of radiocesium (accident-specific ratio of the isotopes Cs-134 and Cs-137) for critical population groups in relation to the body burden of radiocesium for non-self-supporters

	Critical Pop./Non-self-support Ratio			Maximal Cs-Content (Cs-134 + Cs-137 in Bq)		
Annual Season	Self-Supporter	Hunter	Mushroom-Eater	Self-Supporter	Hunter	Mushroom-Eater
Winter 1986/87	4.3	-	-	17300	-	-
Spring 1988	3.0	-	-	4240	-	-
Autumn 1988	1.8	3.3	2.8	1180	5120	3540
Winter 1988/89	1.6	3.8	2.4	1000	3816	2500
Spring 1989	1.5	3.6	2.3	800	3080	1990
Summer 1989	2.0	4.2	2.7	640	2170	1140
Autumn 1989	1.6	4.1	3.3	469	1186	948

The differences in the group-specific body burden of radiocesium are significant (F-test). The group-specific mean values range from about 300 Bq (non-self-supporters during summer 1989) to more than 2000 Bq (game-hunters during autumn 1988 and winter 1988/89). The greatest internal contamination of game-hunters was more than 5000 Bq. From autumn 1988 to spring 1989, the body burden decreases by 30% for non-self-supporters and by about 50% in the groups of self-supporters and mushroom-eaters.

As the result of their special consumption habits, the temporal change of the body burden of game-hunters departed from the normally observed decreasing tendency: as expected, the whole-body activity remained nearly constant over the hunting season from autumn to winter and then dropped by 45% during the time up to summer 1989. In autumn 1989 clearance of incorporated radiocesium decreased again, most likely due to the rise of the consumption amount of contaminated game by a factor 1.3.

In Table 7.9 the mean group-specific body burden of radiocesium is compared to the Cs-content of non-self-supporters as a reference group and compared with analogue results obtained in 1987 and 1988 from the field of self-support and non-self-support in the same region (Burkhardt and Lux, 1988). During the two-year-period after the accident, the self-supporters differed from non-self-supporters in the incorporated activity by a factor of 3-4. Not before the 3rd year after the accident did the body burden of self-supporters drop to a level close to that of the urban population. During the 3rd and 4th year after the accident, the game-hunters were the group with the greatest maximal body burden, with a deviation factor of 3-4, followed by the mushroom-eaters with body burdens greater than that of the urban population by a factor 2-3. A simultaneously scheduled whole-body-counting program with Bavarian school-classes similarly showed that mushroom-eating children had higher body contents by a factor 2 (Bayer. STLMU, 1989).

During the first year after the nuclear accident, the direct contamination of grass (surface deposition of radioactivity from fall- and rainout) culminated in peaks of incorporated activity up to more than 17000 Bq radiocesium, primarily due to the high contamination of raw milk and beef/veal (Burkhardt and Lux, 1988). The comparatively small peaks of incorporated activity during the 3rd year after the nuclear accident, which amount to values of more than 5000 Bq in the group of hunters, are the result of the indirect contamination of special foodstuffs such as game and mushrooms (uptake of radionuclides from soil by plant roots), which are consumed in small quantities on a one-year-average. Thus, groups of considerably different consumption habits are defined as critical population groups in the following temporal succession: self-supporters, game-hunters and mushroom-eaters. This chronological order is likely to be adaptable to large areas of the Member States. One exception is exposed terrains such as alpine pastures in the high mountain region of the Austrian Alps, where in summer 1989 a mean activity concentration of 600-800 Bq/l radiocesium was still measured in raw milk (Lettner, 1989). Even during the third year after the nuclear accident, self-supporters in these areas may be the most critical population group as a result of indirectly contaminated critial food items like milk and meat.

7.6.2 Intake of radiocesium by ingestion

The intake rate of radiocesium is evaluated via a biokinetic approach according to the balance model (equation 7.6) and equilibrium model (equation 7.7). For both models the dietary intake of radiocesium is assumed to be constant. Considerable variations in the daily intake may actually occur when highly contaminated mushrooms and game are occasionally consumed. However, the records of consumption habits show that hunters and mushroom-eaters consume these foodstuffs in amounts that are in the order of major food items. On the basis of these facts, it can be assumed that variations in the intake may be at least partially balanced out. Accordingly the intake rate for game-hunters and likewise for mushroom-eaters are calculated via the biokinetic models. The group-specific data on intake via the biokinetic approach are compiled in Table 7.10:

Table 7.10: Intake of radiocesium (Cs-134 + Cs-137 by ingestion in different population groups during autumn 1988, winter 1988/89, spring, summer and autumn 1989, calculated by means of kinetic models. (Value in brackets includes the individual who reacted on the first whole-body-counting measurements by restriction of mushroom consumption.)

Season	Population Group	Intake Rate in Bq/d			
		Balance Model		Equilibrium Model	
		mean	range	mean	range
Autumn 1988	N	4.0	1.7 - 5.6	3.9	2.6 - 7.9
	S	5.5	2.2 - 9.8	7.2	6.2 - 10.5
	H	12.7	2.5 - 33.9	12.5	6.2 - 36.5
	M	7.6(5.5)	3.6(1.0) - 11.7	12.3	5.0 - 25.2
Winter 1988/89	N	2.2	1.1 - 3.9	4.1	3.0 - 6.1
	S	3.4	0.0 - 7.3	6.8	5.2 - 8.8
	H	11.2	3.9 - 25.9	14.1	7.3 - 27.2
	M	9.2(5.3)	6.5(1.5) - 11.8	9.0	3.2 - 17.8
Spring 1989	N	3.1	1.4 - 7.8	3.4	2.1 - 4.5
	S	3.0	1.3 - 4.8	4.9	2.8 - 6.3
	H	6.2	1.3 - 16.4	12.5	4.7 - 21.9
	M	2.7(1.2)	2.3(0.0) - 3.1	6.9	2.4 - 11.3
Summer 1989	N	1.3	0.0 - 2.9	2.4	1.5 - 3.6
	S	3.8	2.0 - 5.5	4.0	2.9 - 5.6
	H	5.0	0.4 - 16.5	8.2	3.1 - 15.4
	M	8.4	3.0 - 14.1	5.2	2.2 - 8.1
Autumn 1989	N	2.4	0.8 - 4.8	2.2	1.8 - 3.6
	S	3.8	1.7 - 6.4	3.9	2.4 - 5.8
	H	8.2	1.4 - 15.1	8.0	3.9 - 13.8
	M	7.9	5.8 - 10.7	6.5	5.2 - 7.6
whole period of study (mean value)	N	2.6	-	3.2	-
	S	3.9	-	5.4	-
	H	8.7	-	11.1	-
	M	7.1	-	8.0	-

During the period from autumn 1988 to autumn 1989, the mean intake rate ranges from 1 to 13 Bq/d according to the balance method and from 2 to 14 Bq/d according to the equilibrium method. A maximal dietary intake up to 35 Bq/d radiocesium with a mean value of 12 Bq/d has been calculated for the group of game-hunters during the main hunting season from autumn to winter 1988/89. A minimal intake ranging from 2-4 Bq/d and 3-7 Bq/d, depending on the season, has been calculated for self- and non-self-supporters, revealing no marked difference between those groups in regard to the ingestion of radioactivity. Thus deviations in their body burden may be explained primarily by differences in the level of food contamination that occurred in preceding periods. In the group of mushroom-eaters the intake rate amounts to 8-9 Bq/d during autumn and winter in accordance with the ready supply of fresh and dried mushrooms. In spring, the dietary intake of radiocesium drops to a level of 3 Bq/d and increases again by a factor 3 in summer, the main season for mushroom growth. These results demonstrate that seasonal variations in group-specific consumption habits are more clearly reflected by the temporal change of the intake rate than by variations in the body burden with respect to time.

The data on the dietary intake of radiocesium according to the equilibrium model are less clearly indicative of seasonal variation in consumption habits. On average, these values are higher by less than 50% - in single cases by a factor 2 - than corresponding data from the balance model.

On the whole during the period from 1988/89 to 1989/90, ingestion of radiocesium was higher by a factor 1.5, 2.5 and 3.5 respectively in the group of self-supporters, mushroom-eating persons and hunters compared to the urban population.

For assessing the ingestion of radiocesium according to model function 7.8 (see chapter 7.2), the food contamination must be known. As expected, during the third year after the accident only a few food items were considerably contaminated; a food duplicate study was omitted and only samples of critical food items were taken for analysis of the temporal change of radioactive contamination. Data on the specific activity of radiocesium in critical foodstuffs are listed in Table 7.11. For evaluating the intake rate of radiocesium according to equation 7.8, the group-specific consumption amount of raw milk, game, mushrooms and lake-fish were taken into account. It was furthermore taken into account that less contaminated subspecies of a critical foodgroup were preferred by the individual consumer. For example, the mushroom-eaters preferentially consumed Boletus edulis in autumn, morels in spring and avoided highly contaminated species like Boletus badius at least during the first stage of the study.

Table 7.12 shows the data on the intake rate according to equation 7.8.

Table 7.11: Specific activity of radiocesium (Cs-134 + Cs-137) in selected foodstuffs in 1988 and 1989 (mean values are taken as a basis for the estimation of the intake rate of radiocesium by ingestion)

GAME		MUSHROOMS	
Type	Specific Activity Bq/kg	Type	Specific Activity Bq/kg
	AUTUMN-SPRING 1988-1989		AUTUMN 1988
Red deer	79 +/- 30	Boletus edulis	302 +/- 85
Roe	405 +/- 370	Lactarius deliciosus	1355 +/- 21
Game	240 (mean	Cantharellus	200
		Russula	310
		Mixed Mushrooms	540
		Mixed Mushrooms (80% Boletus edulis)	480(mean)
	SUMMER 1989		SPRING 1989
Red deer	362 +/- 35	Morchella	33 +/- 4 (mean)
Roe	690 +/- 350		
Chamois	259		
Game	440 (mean)		

Table 7.11: continued

AUTUMN 1989		SUMMER-AUTUMN 1989	
Red deer	260	Amanita	80
Roe	480 +/- 200	Cantharellus	280
Chamois	210	Boletus badius	3402 +/- 860
Game	320 (mean)	Russula	900
		Boletus edulis	250 +/- 60
		Lactarius deliciosus	111
		Mixed mushrooms	837
		Mixed mushrooms (80% Boletus edulis)	390 (mean)

LAKE FISH Specific Activity Bq/kg	RAW MILK Specific Activity Bq/l
SPRING 1989	SPRING 1989
14 +/- 2	13 +/- 16
SUMMER 1989	SUMMER 1989
7 +/- 2	2 +/- 3

Table 7.12: Intake of Cs-134 + Cs-137 for the period from autumn 1988 to autumn 1989 calculated on the basis of the mean radiocontamination of critical food items and the collective-specific consumption rate of the foodstuff of concern.
* Estimation according to measurements on random basis.

Season	Population Group	Intake of Radiocesium in Bq/d					
		Game	Mushrooms	Lake Fish	Raw Milk	*Rest of diet	Total
Autumn	N	0.0	0.50	0.00	0.1	1	1.6
Winter		0.0	0.00	0.00	0.0	1	1.0
Spring		0.1	0.02	0.00	1.0	1	2.1
Summer		0.1	0.04	0.00	0.0	1	1.1
Autumn		0.0	0.40	0.00	0.0	1	1.4
Autumn	S	1.4	0.00	0.00	4.1	1	6.5
Winter		1.0	0.00	0.00	4.2	1	6.2
Spring		1.9	0.02	0.05	4.5	1	7.5
Summer		0.3	0.40	0.03	0.6	1	2.3
Autumn		1.9	0.00	0.00	0.6	1	3.5
Autumn	H	12.5	1.40	0.00	0.5	1	15.4
Winter		11.5	0.96	0.08	0.5	1	14.0
Spring		10.3	0.02	0.20	1.0	1	12.5
Summer		18.4	3.10	0.07	0.1	1	21.6
Autumn		16.6	1.20	0.00	0.1	1	18.9
Autumn	M	0.0	14.4	0.00	0.4	1	15.8
Winter		0.0	12.00	0.03	0.3	1	13.3
Spring		0.0	0.90	0.30	0.7	1	2.9
Summer		4.5	17.90	0.00	0.1	1	23.5
Autumn		0.0	11.70	0.00	0.0	1	12.7

The results show these estimated values to be in the range as the data calculated via the biokinetic approach and reveals the same tendency to exist in collective-specific differences. On average the dietary intake rate estimated on the basis of the specific activity of radiocesium in foodstuffs is higher by a factor 1.5 than the intake rate calculated via the biokinetic approach (balance method).

7.6.3 Dose calculations

The effective dose equivalent by ingestion is assessed on the basis of a monthly dose factor of 4.7 µSv per 1000 Bq incorporated Cesium-134 and 3.1 µSv per 1000 Bq incorporated Cesium-137 for adults (according to D. Nosske and H.-D. Roedler: personal communication). As the dose factors used for the calculation refer to equilibrium conditions for a period of about one month, which cannot be guaranteed for the whole period of measurements, the results are to be seen as approximation to the real internal dose.

The serial measurements of the body burden of radiocesium for each second half of the years 1987 and 1989 are incomplete, therefore the internal dose was calculated each time for a period of 6 months and not for one year. Data on the group-specific internal dose are listed in Table 7.13. The mean effective dose equivalent due to incorporated radiocesium ranges from 10 µSv (non-self-supporters: 1989) to about 200 µSv (self-supporters: 1987) per 6 months. The additional internal radiation exposure due to accidentally released radiocesium is evaluated in comparison with the natural internal and total radiation exposure which amounts to 0.25 mSv/a and 1.5 - 4 mSv (mean: 2 mSv) per year. As shown below, due to ingestion of radiocesium resulting from the accident, the internal and total radiation exposure increased from 1986 to 1987 by a factor 1.6 (max. 2.1) and factor 1.1 respectively in the urban population and by a factor 3.3 (max. 4.3) and factor 1.3 for self-supporters. In 1988, the additional internal dose by ingestion for game-hunters amounts to 50-100% of that from natural internal radiation exposure:

		Factor of Increase per Year	
Period	Population Group	Internal Dose	Total Dose
1986-1987	Self-Supporters	3.3 (max. 4.3)	1.3 (max.1.4)
1987	Self-Supporters	2.6	1.2
1986-1987	Non-Self-Supporters	1.6 (max. 2.1)	1.08 (max.1.13)
1987	Non-Self-Supporters	1.4	1.1
1988	Game-Hunters	1.3 (max. 1.9)	1.0 (max.1.1)

Table 7.13: Effective dose equivalent due to ingestion of radiocesium (Cs-134 + Cs-137) for each 6-months-period from 1986 to 1989

*Method of calculation in Burkhardt and Lux (1988a)

Year	Period	Effective Dose Equivalent in μSv Non-Self-Supporters mean	 range	 Self-Supporters mean	 range
1986/87	1st year after Chernobyl*	160	max. 270	570	max. 830
1987	1st half-year	50	40 - 70	200	110 - 370
1988	1st half-year	15	10 - 20	40	20 - 80
1988	2nd half-year	15	5 - 25	20	15 - 25
1988	whole year	30	15 - 45	60	35 - 105
1989	1st half-year	10	5 - 15	15	10 - 20
1989	July/August	2	1 - 3	4	2 - 5

Year	Period	Game-Hunters mean	 range	Mushroom-Eaters mean	 range
1988	2nd half-year	40	15 - 110	35	15 - 75
1989	1st half-year	40	15 - 75	20	10 - 45
1989	July/August	10	5 - 15	5	2 - 10

7.7 SUMMARY AND CONCLUSIONS

The Commission of the European Community appointed the Group of Experts established under Article 31 of the Euratom Treaty to advise on suitable intervention levels to limit the radiological risk from ingestion of contaminated foodstuffs. In support of this work, a corresponding Working Group was assigned to work out a scientific concept for the derivation of intervention levels of radioactivity in major foodstuffs. In the methodology applied by the Group of Experts consumption data are adopted that are based on statistical budget surveys, and/or supply balance sheets.

The model parameters generally used to quantify food supply assume consumption habits which are broadly representative for the whole Community and do not consider special situations, such as individual consumption habits or a regionally bound high level of self-support in an above-average contaminated area. As it is not known to what extent the range of European consumption habits is covered by the model data, a research program for their validation was initiated by the Commission of the European Community in 1988 to investigate the various consumption patterns. In this project which is linked to the EC-research program, consumption patterns of critical population groups are further investigated to determine the extent to which the statistical data of the German (DGE) und European (EC) budget surveys will include individual consumption situations. Individuals whose consumption habits cannot be recorded by statistical surveys because they prefer dietary components that are not subject to market control are regarded as members of a critical population group. The study was conducted in a region bordering the Alpes in Southeast-Bavaria, where the highest accidental deposition of radiocesium (>42000 Bq/m^2 Cs-137) after the Chernobyl accident occured within the Federal Republic of Germany. There, an inquiry onto the origin, type and amount of dose-relevant and season-dependent food items was performed in groups of self-supporters, hunters and mushroom-eaters and compared with non-self-supporters, chosen as reference group. To examine the influence of consumption habits on the internal dose by ingestion, simultaneous whole-body-counting measurements were conducted in time intervals of 1.5 - 2 months and the contamination of critical foodstuffs with radiocesium was measured by random criterion. The following is a brief summary of results.

Depending on annual season and population group, the milk consumption deviates from German consumption statistics (DGE) by a factor 0.5 - 2.2. In harmony with observations during recent years, also in 1989 the highest milk consumption was recorded to have been in the field of self-support. Among the dose-relevant products, raw milk was the most critical food item for self-supporters during the first 1-2 years after the nuclear accident of Chernobyl, because raw milk is consumed regularly in large amounts without an interposing radiological control.

Fresh vegetables were consumed by all the population groups by far more than was expected according to statistical surveys. The daily consumed amount exceeds the representative DGE- and EC-values by a factor 1.8 and 1.2, respectively. The hunters consume double the amount of fresh meat than indicated by German statistical budget surveys, due to a larger supply of locally raised pork and lamb/mutton and self-hunted game. In view of a statistical consumption rate of only 2 g/d (DGE), game is a negligible dietary component, but for hunters it ranks as a major foodstuff because its consumption amounts to 40 - 60 g/d is comparable with the statistical values for the consumption of meat from the current major sources supply. The consumption of mushrooms falls in the range of major foodstuffs, considering mushroom-eaters alone: the consumption rate amounts in autumn and spring to about 30 g/d and in summer to about 50g/d. During the one-year-period of analysis and according to the type of population, the following food classes are underestimated by the European statistical EC data: vegetables and fruits in each examined group, milk products in the group of self-supporters as well as fresh meat in the group of hunters. With the exception of data on vegetables, the population-specific differences are balanced out when the collective-specific consumption rates are averaged over the total population groups and the whole period of investigation. For the derivation of intervention levels it is of importance that the regional data on food items are in the same range as the values for the analogue food classes, consumed in the 3 main groups of the EC countries.

The regional fraction of raw milk and milk products amounts to 100% and 75% respectively for self-supporters. The local production of vegetables contributes, in spring and summer, as much as 60% of the requirements of the rural population groups. In addition, 20-40% of meat (pork, lamb/mutton and beef/veal) is obtained from the region. The maximum amounts of regional foodstuffs consumed were for milk and milk products for self-supporters, followed by game for the group of hunters.

The relatively high body burden of radiocesium, measured in the group of hunters, can be explained primarily by the fact that large amounts of contaminated game are consumed. Thus,an average incorporated activity of 2000 Bq and single values of up to 5000 Bq were found in autumn of 1988. As could be expected, according to measurements of the specific activity of radiocesium in random samples of milk, meat and total diet, the self-supporters were only slightly contaminated during the 3rd year after the accident. With respect to internal contamination, mushroom-eaters rank in an intermediate position, most likely due to the fact that the consumption rate of contaminated mushrooms is only about half the consumed amount of game for hunters outside of the growth season for mushrooms. The mushroom-eaters reacted to the results from the first whole-body-measurements with special caution by selecting less contaminated wild-mushrooms for meals and by avoiding highly contaminated species, such as Boletus badius. Dietary duplicates of mixed mushrooms (Boletus edulis, chanterelle, russula, morel) were thus contaminated up to the same level as game in the range of 200 - 500 Bq/kg.

The group-specific internal dose by ingestion as well as the capacity of replacement of a dose-relevant food class, are suitable criteria for the evaluation of the radiation risk of a population group in any future nuclear accident. Judging by the level of internal contamination, the hunters prove themselves to be the most critical population group during the third year following the accident. But it must be pointed out that contaminated game is a minor and replaceable dietary component at least in the region where our investigations took place. The conditions for self-supporters are quite different. There, a maximal dietary intake and body burden of radiocesium were measured during the first year after the accident, exceeding as much as by several factors the peaks of internal contamination measured on hunters in 1988/89. In the period from 1986 to 1987 the internal dose from natural radiation exposure (250 μSv/a) was increased by a factor 3 for self-supporters by the additional radiation exposure from ingestion of radiocesium.

Additionally, according to the present study, self-supporters obtain about 75% of dose-relevant foodstuffs from the region; meanwhile, the dose-relevant contribution from the region was about half that for self-supporters for the remaining rural population. The dose-relevant fraction of the total food is the total of indispensable basic foodstuffs as milk, milk products, vegetables and fresh meat that can only be replaced occasionally or partially by adequate products in any future nuclear accident.

Besides, the self-supporters were selected in the vicinity of conveniently situated medium-sized towns and often have their working place in the urban environment. In view of this infrastructure it is unlikely that these persons represent a minority. They rather constitute a larger section of the population that should be quantified and taken into account in the introduction of protective measures to avoid supply problems.

Accordingly, the results indicate that in any emergency situation, self-supporters should be classified as the most critical population group.

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8 FACTORS TO BE CONSIDERED IN DERIVING INTERVENTION LEVELS

8.1 INTRODUCTION

In the case of a nuclear accident resulting in a large release of radioactive material to the environment, timely interventions may considerably reduce doses to the public. However, countermeasures always lead to intervention in the normal daily practice with undesirable social or economic consequences.

The Chernobyl accident clearly demonstrated the impact of foodstuffs being contaminated over extremely wide areas. Although the basic concepts of emergency management after nuclear accidents were generally accepted, the intervention levels for food contamination adopted shortly after the accident showed a lack of consensus, even in the recommendations made by different international organisations. Another problem was the lack of experience and knowledge of countermeasures other than destruction of food and the lack of knowledge of the parameters required in order to take adequate countermeasures.

This chapter deals with a basic methodology to derive intervention levels for food. In addition, various types of countermeasures and other factors of importance for taking decisions on interventions will be discussed. The methodology described is based on radiation protection concepts as recommended by, amongst others, ICRP and CEC. A major role is given to an optimisation procedure according to the ALARA (As Low As Reasonably Achievable) principle, in which projected dose reductions have to be balanced with social and economic consequences. This methodology can only be applied if certain information on the countermeasures considered is available. This information is presented in this chapter. In general, for each countermeasure information was collected on its effectiveness in dose reduction, its feasibility and the costs involved. In particular, those countermeasures are considered which may be relevant when food has already been contaminated. Only limited information is presented on countermeasures related to agricultural practice. Effects due to the amount of food involved, food trade disruptions, etc. were generally considered to be beyond the scope of this work. The information presented on the economic consequences or costs has to be considered to serve only indicative or even illustrative purposes, as the work is primarily concerned with the radiological consequences of interventions. Some information is presented on spontaneous reactions of the public after incidents with food contamination, because this was considered to be one of the main causes of disruptions in food trade.

The aim of this chapter is not to calculate specific derived intervention levels for radionuclides in food or to recommend specific countermeasures, which could directly be used by the authorities. The social, economic and public health implications related to intervention levels are too complicated and their impact on society is too large to allow such specific calculations or recommendations. Also, positive as well as negative consequences of countermeasures may be influenced by local, seasonal and other conditions. In this chapter, however, a methodology and a technical review of countermeasures and important parameters will be discussed which may be considered when practical intervention levels have to be derived.

8.2 APPROACHES FOR DERIVING INTERVENTION LEVELS IN FOOD

The impact of an intervention will depend on the actual radiation levels, the type of intervention and other specific conditions of the emergency situation. Therefore, the most important organisations in radiological protection, such as ICRP, CEC and IAEA (IAEA 85a, IAEA 86, ICRP 84), have defined two reference levels of dose between which decisions on intervention should be based on the ALARA principle. The two reference levels, referred to here as H_{low} and H_{up}, are defined as projected effective dose equivalents or dose equivalents, expected to be received in the first year after a release of radionuclides. Their numerical values for food intervention are 5 and 50 mSv, respectively, for the individual effective dose equivalent or 50 and 500 mSv for the dose equivalent to a single organ of an individual. Below the lower reference level, introduction of a countermeasure is generally not justified because economic and social consequences of intervention are not expected to be balanced by the benefit of a slight reduction in dose. Above the upper reference level it is considered that the countermeasure must be introduced due to the high doses involved. Between these two reference levels, introduction of a countermeasure should be considered on the base of an optimisation procedure using for example a cost-benefit analysis.

The methodology presented here is designed to derive optimized radionuclide intervention levels in food complying with the dosimetric constraint, given by the individual dose reference levels, and the economic constraint derived from a more specific cost-benefit analysis.

8.2.1 Dosimetric Approach

In the dosimetric approach, the derived intervention levels of radionuclide concentrations in food are directly related to the projected individual effective dose equivalent reference levels. The methodology for the dosimetric approach is first described for the simple problem of a single food product contaminated by one radionuclide. In several steps, the methodology is extended to the general case of various food products contaminated by a spectrum of radionuclides.

A single product contaminated by a single radionuclide

If only one product is contaminated by a single radionuclide, the relation between its average concentration C over the year following the release of radioactive material and the effective dose equivalent H due to food consumption is given by equation 8.1,

$$C = H / (I * Q) \qquad (8.1)$$

where

C = the mean concentration of the nuclide in the product over one year ($Bq.kg^{-1}$).

I = the per caput annual consumption of the product ($kg.y^{-1}$).

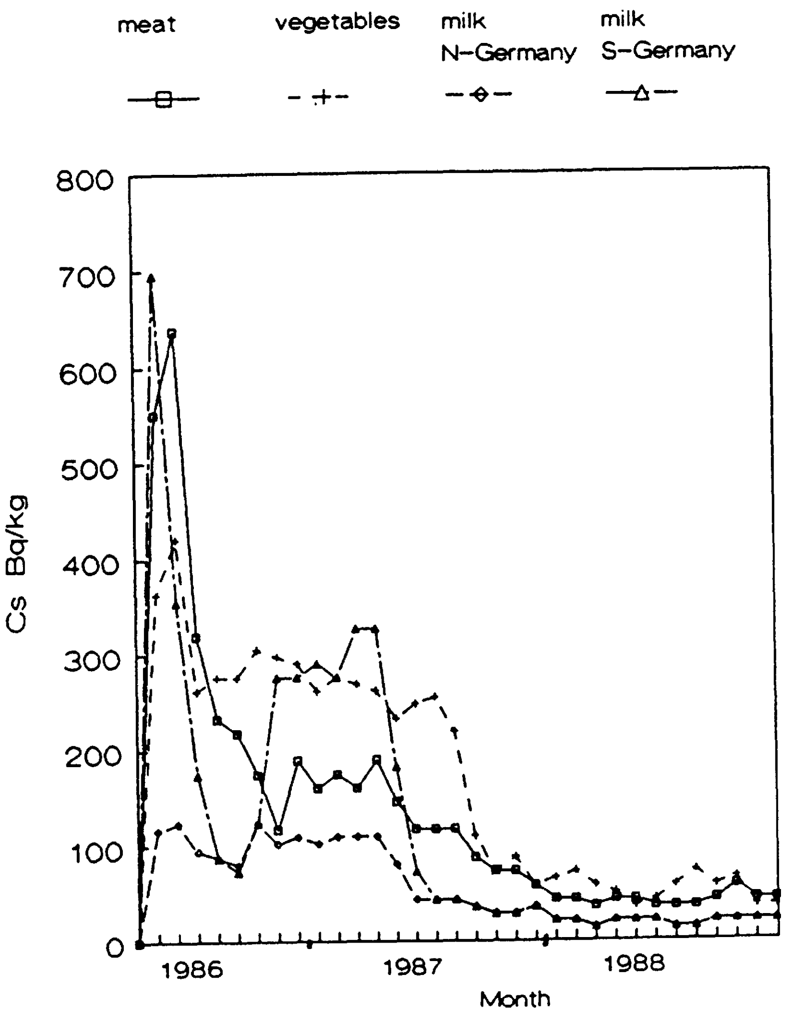
Q = the committed effective dose equivalent by ingestion per unit of intake of the nuclide ($Sv.Bq^{-1}$) (ICRP 79, Noske et al. 85 and Chapter 5 of this report).

H = the projected annual dose ($Sv.y^{-1}$).

The lower and upper reference concentrations C_{low} and C_{up} can be calculated in this way from the projected annual doses H_{low} and H_{up}. As with the dosimetric reference levels H_{low} and H_{up}, between C_{low} and C_{up} the economic approach has to justify implementation of a countermeasure. The concentration in the product may even exceed for some period of time the reference level as C refers to the mean concentration over one year. In order to estimate the difference between the mean concentration and the actual concentration some corrections are necessary, e.g. for radioactive decay, for heterogeneity of the contamination levels, for variation in daily intake and food distribution etc. More quantitative information on these aspects is given in Chapters 3, Food Consumption, and 4, Food Distribution. Such corrections were for example included in the methodology used by the article 31 group of experts, assuming that for the first year after the accident only 10% of one individuals intake would be contaminated up to the intervention level (Commission of the European Communities 89).

In the first year after a release, the radionuclide concentration in the product will be particularly influenced by radioactive decay and other factors which have an effect on the radioecological behaviour of the radiocontaminants. In figure 8.1 an example of the change with time of the concentration of a radionuclide in food is shown.

Figure 8.1: The evolution of the contamination of different food classes in the FRG after the Chernobyl accident (Bundesgesundheitsamt).



As equation 8.1 refers to the mean concentration during the first year, a higher radionuclide concentration may temporarily be allowed provided that the mean concentration over the first year will be low enough to keep doses in this year below H. However, it is often not easy to predict how radionuclide concentrations are likely to vary in the future, and national authorities may assess their intervention measures assuming persistent contamination levels over prolonged time periods.

H and Q may both refer either to the effective dose equivalent or to the dose equivalent to a critical organ, depending on which will give the lowest reference levels. For example, H and Q will refer to the effective dose equivalent in the case of cesium, for iodine they will refer to the thyroid dose equivalent.

Various products contaminated by a single radionuclide

If several food products are simultaneously and uniformly contaminated by a single radionuclide, the projected annual dose, H, is related to the contributions of all products involved. In this case, the projected annual dose associated with consumption of product i, H_i, can be obtained from equation (8.2),

$$H_i = H * I_i / \Sigma_i I_i \qquad (8.2)$$

where

H_i = the projected annual dose associated with consumption of contaminated product i ($Sv.y^{-1}$)

H = the projected annual dose ($Sv.y^{-1}$)

I_i = the per caput annual consumption of product i ($kg.y^{-1}$)

$\Sigma_i I_i$ = the total consumption of all contaminated food products ($kg.y^{-1}$)

Application of this equation, combined with equation (8.1), will give equal limiting radionuclide concentrations, C_i, for all contaminated products (equation (8.3)).

$$C_i = H / (Q * \Sigma_i I_i) \qquad (8.3)$$

Various products contaminated by various radionuclides

In general, accidental releases will consist of mixtures of various radionuclides. Differences in radiotoxicity of those radionuclides will complicate the method described above for the derivation of intervention levels. For one product contaminated by different radionuclides the limiting concentrations can be obtained from equation (8.4),

$$\Sigma_n(C_n * I * Q_n) = H \qquad (8.4)$$

where

C_n = the concentration of nuclide n in the product ($Bq.kg^{-1}$)

Q_n = the committed effective dose equivalent by ingestion per unit of intake of nuclide n ($Sv.Bq^{-1}$)

The radiotoxicity of all compounds may be expressed in terms of the dose received per unit intake of a reference radionuclide, r, by defining a ratio k_n for each radionuclide given by:

$$k_n = Q_n / Q_r \qquad (8.5)$$

Combining equations (8.2) and (8.4) renders

$$C_{r,i} * I_i * Q_r = H_i = H * I_i / \Sigma_i I_i \qquad (8.6)$$

or

$$C_{r,i} = H / (Q_r * \Sigma_i I_i) \qquad (8.7)$$

Equation (8.7) is very similar to equation (8.3), in both cases the reference radionuclide concentration is the same for all products.

8.2.2 The economic approach

When dose estimates lie between the reference levels H_{low} and H_{up} cost-benefit analysis may be used as a decision-aiding technique. The technique can be used to evaluate whether intervention is necessary and, if so, to select appropriate countermeasures (IAEA 86, ICRP 84). It balances, for a certain protective action, advantages corresponding to reduction of detrimental effects (dose) and drawbacks associated with the cost and the disruption to society related to the action. A countermeasure will be justified from the economic point of view when reduction in detrimental costs exceeds the costs related to its implementation.

A cost-benefit analysis needs an estimate of the monetary equivalent of the unit of collective dose (the manSievert). Application of this monetary equivalent has the consequence that, even e.g. for iodine, effective doses have to be considered instead of doses to individual organs. This will not give problems as the economic approach will only be used below the upper dosimetric limit which excludes the appearance of non-stochastic effects.

The limiting concentration for one radionuclide in a food product, C_e, will result in the costs related to execution of a countermeasure being equal to the detrimental costs saved by its implementation. This concentration can be calculated according to:

$$C_e * Q * \alpha = P \qquad (8.8)$$

where

C_e = the limiting radionuclide concentration in the product defined on the basis of a cost-benefit analysis ($Bq.kg^{-1}$).

Q = the commited effective dose equivalent per unit of ingested nuclide ($Sv.Bq^{-1}$) (ICRP 79, Noske et al. 85 and Chapter 5 of this report).

α = the cost of one manSievert ($ECU.Sv^{-1}$)

P = the cost of the countermeasure related to 1 kg of product ($ECU.kg^{-1}$).

The result of a cost-benefit analysis is highly dependent on the values assigned to the different parameters. For example, the choice of the value of a manSievert is very important and has been extensively discussed elsewhere (IAEA 85b, Lombard 86). In the case of exposures resulting from a transboundary contamination, IAEA has recommended that cost estimates of a manSievert should not be less than 3 000 ECU. This value originally was given in US dollars but in this chapter all financial figures are expressed in ECU on the basis of an equivalent economic value of US dollar and ECU. According to IAEA, countries with a high gross domestic product per caput may use a higher value; the range of values commonly adopted for α is 3,000 - 100,000 ECU (Lombard 86). The large range in the value of α will not necessarily cause a corresponding range in the value of C_e. Both α and P are related to the standard of living and, consequently, effects of

standard of living on C_e will be smaller than the effects on α and P. The value of P also depends on the type of countermeasure; more information on this subject is provided in section 8.3.
The result of this cost-benefit analysis is a limiting radionuclide concentration, C_e, which is not based on dosimetric limits. The value of C_e may be different for each type of product.

8.2.3 Selection of intervention levels

The dosimetric and the economic approach are based on different hypotheses; they therefore provide complementary results. According to the dosimetric approach, C_{low} and C_{up} are inversely related to the annual consumption of a product if only one product is contaminated. The economic approach, however, will lead to levels which will increase with the costs of the countermeasure. For example, C_{low} and C_{up} will be lower for beef than for pulses because beef consumption is higher. On the contrary, when considering destruction as a countermeasure, the economic approach will lead to higher limits for beef because it is more expensive than pulses.

The intervention levels will depend on several assumptions made in the methodology and on choices of parameter values like the cost of a manSievert and the dose level H. Other important parameters are the costs of the countermeasure, the population exposed, the amount of food involved and the nature of the release. It will be clear that the costs of countermeasures will also depend on the severity of the accident. Critical groups like children and pregnant women may be more vulnerable to the consequences of an accidental release depending on the nature of the food contamination. The isotopic composition of the contamination as well as the relative contamination of the different food products may also have important consequences. The feasibility and costs of countermeasures may depend on the season, stored amounts of food, actual storage capacities etc. Due to the many uncertainties described here it is not possible to assess _a priori_ derived intervention levels which are generally applicable.

8.3 DIFFERENT TYPES OF COUNTERMEASURES

A major problem in planning an intervention is the choice of those countermeasures which will lead to an optimal balance of radiation risk reduction, economic and social consequences.

During the last decades much technical, practical and scientific information on effects of intervention on radionuclide contamination of food has been obtained. In this section a review of this information is presented in order to compare the effectiveness of the most relevant countermeasures in terms of dose reduction.

The economic consequences of radioactive contamination in food and of countermeasures may be very large. It is estimated that the Chernobyl accident may have caused a total economic damage of about $12 * 10^9$ ECU for the Soviet Union, including costs of interventions in the near field, such as evacuation (Smets 88). Damage caused by this accident in OECD countries would exceed $3.5 * 10^8$ ECU (Smets 88). Even for a small country such as Austria the damage was calculated to exceed $5 * 10^7$ ECU (Schönhofer 89).

The social consequences should also not be underestimated. People may react more severely to the consequences of accidental situations than is justified on the basis of the actual risk. The risks related to radioactivity in general are often perceived to be more threatening to people than, for example, analogous chemical risks. Ethical problems may also arise, for example if in a socio-economic context destruction is envisaged whereas strictly on radiation protection grounds the concerned food product may be consumed. Such considerations become even more complex if the contaminated food could be exported to countries where the standard of living does not justify destruction.

In order to take decisions on countermeasures, a detailed insight has to be available on related costs, effectiveness and feasibility aspects. The experience after the Chernobyl accident was that such knowledge was lacking. After the Chernobyl accident additional information was obtained that should be added to the present knowledge.

The countermeasures may be classified as preventive and corrective measures. Preventive countermeasures aim at decreasing or limiting the contamination level during production in agriculture. Examples are fertilisation, deep ploughing and liming of the soil, addition of bentonite to feeding stuff, etc. Corrective countermeasures aim at decreasing the contamination level after the agricultural stage of food production. These countermeasures may, for example, be implemented during food processing or storage.

Until recently it was often thought that preventive countermeasures on radioactive contamination of food should have preference because they cause less disturbance. Only destruction or, in certain cases, storage would be realistic corrective alternatives. However, preventive countermeasures are often not effective or reliable (Lembrechts 89) and the experience after the Chernobyl accident revealed a need for corrective countermeasures other than destruction alone.

As preventive countermeasures are dealt with in a separate EC post Chernobyl action and in the regular EC programme, this section will concentrate on corrective countermeasures. However, some information on preventive countermeasures will be given as well due to the overlap with corrective countermeasures and the need to present a complete review of countermeasures.

Corrective countermeasures can further be divided into two subclasses: (A) countermeasures such as storage or changes in food preparation, which will decrease food contamination without changing the ultimate destination of the product as food, and (B) countermeasures that are more drastic and change the destination of the food product, such as destruction, use as animal feeding stuff and use as raw material for industrial non-food products. Countermeasures of type (A) will in general be cheaper and less restrictive than those of type (B).

Redistribution and mixing of food, actions which also may have a corrective character, do not affect the collective dose to the population. Therefore, in the context of radiation protection, they are not regarded as countermeasures. On the contrary, if not all food is to be consumed within a short time, the dose to the total population might even be lower when the contaminated food is not mixed but separately stored. However, other considerations may favour eventual mixing of food. Doses may be more evenly spread over the population, thus reducing the number of people who are subjected to higher doses. Food trade and consumption may be disrupted when it is known that part of the food is not "safe". As the chapter mainly concentrates on radiological consequences, mixing of contaminated food will not be discussed further.

In this chapter the effectiveness of a countermeasure is expressed in terms of the reduction in contamination of specific food products. In fact, this should be related to ingested quantities in order to estimate the effectiveness in reducing the dose. Due to variability in food consumption, this would lead to an increased uncertainty and decrease the applicability of the data presented for cases other than those considered here.

The costs of countermeasures are assessed assuming that the accident does not affect prices of food, storage, processing, etc. Thus, the data are only relevant when a relatively small amount of food is subject to countermeasures. The effects of season, region and many other specific conditions which may also influence the economic consequences of an intervention are not considered. Consequently, the costs presented here are merely an indication of the real costs of an intervention. Costs will be given in ECU.

The work presented in this chapter covers a wide area of disciplines like agriculture, radioecology, nutrition science, economy, trade and food technology. The chapter primarily will present a general survey of important factors which have to be considered in making a decision on countermeasures in case of radioactively contaminated food. The information was mainly collected from reports or review articles. If necessary, literature reviews were made on specific subjects where surveys appeared to be lacking. Part of the data were collected by personal communications, by expert consultation or from organisations of producers.

8.3.1 Costs, effectiveness and feasibility of the countermeasures

Preventive countermeasures during food production

Preventive countermeasures that could be adopted in arable farming and livestock farming would in general aim to decrease the uptake of radionuclides by plants or animals. In the case of livestock farming, countermeasures may also aim to enhance the excretion of incorporated radionuclides. For completeness and because of the overlap present between preventive and corrective countermeasures, this section presents a short survey of preventive countermeasures. For countermeasures in arable farming more information is presented in the report on the EC Post-Chernobyl action "Practical Countermeasures against Nuclear Contamination in the Agricultural Environment".

Arable farming

The most effective countermeasure leading to a decrease in contamination of crops would be harvesting before deposition occurs. However, the lack of time between the accident and deposition and the growth stage of the crop will in general limit the applicability of this countermeasure. In some cases it may be better for deposition to be on crops, leading to a lower soil contamination and hence to lower contamination levels of future crops (Winteringham 89).

Removal of the contaminated soil layer is another effective countermeasure. It will, however, be impractical for large contaminated areas as the amounts of waste will impose a new problem and the costs of soil removal are high, 2 to 40 $ECU.m^{-2}$ (Marti 88, Sandalls 89). Stabilisation or removal of deposited radionuclides by addition of a polyurethane foam may be less expensive, 2 $ECU.m^{-2}$, but the efficiency depends on the type of soil surface. Removal rates are low, of the order of 1 ha per day (Sandalls 89).

Conventional ploughing of a surface deposit over a 30 cm soil layer decreases the transfer to plants by up to a factor of about 2 (Winteringham 89). A somewhat higher efficiency will be obtained by deep ploughing, or "deep placement", to 1 m depth. The costs for deep ploughing will amount to approximately 0.06 $ECU.m^{-2}$, not including the eventual losses in crop yield due to soil disturbance (Dorp 81, Marti 88). Deep ploughing is also time consuming.

Addition of fertiliser and liming may decrease the transfer to plants of Cs and Sr respectively (Coughtrey 83, Schechtner 89), but in most cases the effectiveness is limited to a decrease in crop contamination of up to a factor 2 (Lembrechts 89, Martin 89), even when unusual large amounts are applied (Ilyin 87, Lönsjö 89). Effects of irrigation will be small (Winteringham 89)

In conclusion, removal of contaminated soil will be very expensive and will lead to considerable waste problems, whereas normal or modified agricultural practices such as fertilisation or irrigation have hardly any effect on the contamination of crops (Lembrechts 89, Romanenko 89). In certain cases it may be beneficial to change to crops with a lower uptake of radionuclides, such as grains (IUR 87), to products with a high removal of radionuclides due to processing (oils or sugar) or to products which are not ingested by humans (cotton, flax).

Livestock farming

A very effective and simple countermeasure to reduce the contamination of animals is the feeding of uncontaminated feeding stuff (tables 8.8-8.11). Today, a change towards qualitatively better feeding stuff just before slaughtering is common practice in intensive livestock farming. Uncontaminated feeding stuff was supplied in some cases after the Chernobyl accident (Henrich 88), but even such a simple intervention can severely disturb farming planning and economy, especially in seasons in which supply of additional feeding stuff is low (Dorp 81, Kerr 88). Furthermore, availability of uncontaminated feeding stuff could be limited.

Quite a number of additives have been examined for their capacity to reduce uptake or to increase excretion of radionuclides. For cesium, different clay types or related substances, such as bentonite, zeolites or vermiculite, and complexing agents (hexacyanoferrates) or chemical analogues (potassium) are often investigated. For strontium, addition of calcium or alginates is investigated. Administration of stable iodine is known to reduce uptake of radioactive iodine isotopes. In applying additives one should, however, consider the problems of production, distribution and waste management which may follow a sudden demand for large quantities of additives shortly after, for example, a nuclear accident.

The effects of administration of clay to cows are rather confusing. Some authors observe a small effectiveness in the reduction of cesium uptake, together with undesirable side-effects on the mineral balance of the animals (Andersson 89, Forberg 89, Giese 88, Giese 89a). Others report effects of up to a factor 10 without any adversive health effects (Dorp 81, Hoek 76, Hoek 87). The reduction in contamination seems to be very limited for poultry, and health effects may be most pronounced for cows. The effectiveness of zeolites is in general smaller than that of bentonite (Forberg 89, Giese 88, Giese 89a).

Administration of ammoniumhexacyanoferrates (Prussian Blue) is often reported as being very effective in reducing cesium uptake (Andersson 89, Giese 88, Giese 89a, Thompson 71, Wagner 87). A reduction in contamination of a factor 10 or more is normal, with only slight constipation as a possible side-effect. Only the inherent toxic capacity of cyanoferrate complexes is a point of concern, although the complexes are often reported to remain extremely stable in the gastro-intestinal tract of animals and are excreted entirely.

Administration of potassium only slightly reduces the uptake of cesium by animals (Wagner 87).

Administration of calcium to animals decreases the uptake of strontium by about a factor of 3 (Dorp 81, Thompson 71); about the same effectiveness was observed for administration of ion exchange resins (Michon 58).

Alginates may reduce strontium uptake by animals by about a factor 3 to 5 (Harrison 66b, Hesp 65, Skoryna 64, Wagner 87). No adverse effects on calcium metabolism were observed, but cows appear to refuse feeding stuff with added alginate (Dorp 81, Thompson 71).

Other countermeasures aim at reducing the contamination of feeding stuffs. Cutting the grass with a higher stubble height has been reported to decrease the contamination of the feeding stuff by about a factor 10 (Andersson 89). Sprinkler irrigation may increase the wheathering half-times for contaminated plants shortly after an accident by a factor of 3 (Dorp 81).

8.3.2 Corrective countermeasures to reduce existing food contamination

Storage

In the case of food contamination with short-lived radionuclides such as I-131, storage may be a simple, cheap and effective means to reduce radionuclide concentrations (fig. 8.2). Social consequences will be negligible, only the lack of capacity for storage or food preparation may cause problems. Problems related to storage capacity or preparation capacity will depend on the type of product. In France, available stocks of vegetables are about 20% of the annual production. About 12 % of the fruit production is transformed into other products, mainly for preservation. In the U.K., cereals are generally stored over a period of about a year before transformation into food products (Haywood 83). In France, the long term storage capacity for cereals is about 2.5 million tons (ONIC) which is 30 % of the total annual production in France.

Storage is not effective in the case of contamination with long-lived radionuclides, such as Cs-134 or Cs-137. For a number of food products, the costs and contamination reductions involved have been assessed for the maximum storage period which will not lead to significant loss of quality (table 8.1). The cost of storage include the costs of storage itself, costs of handling and, if relevant, costs of packaging. The reduction in contamination is calculated by taking into account only physical decay during the storage time. The contamination level may also be changed by food processing steps necessary prior to storage but these effects are dealt with in the section on food processing. In addition, storage periods which are usual in undisrupted situations are presented.

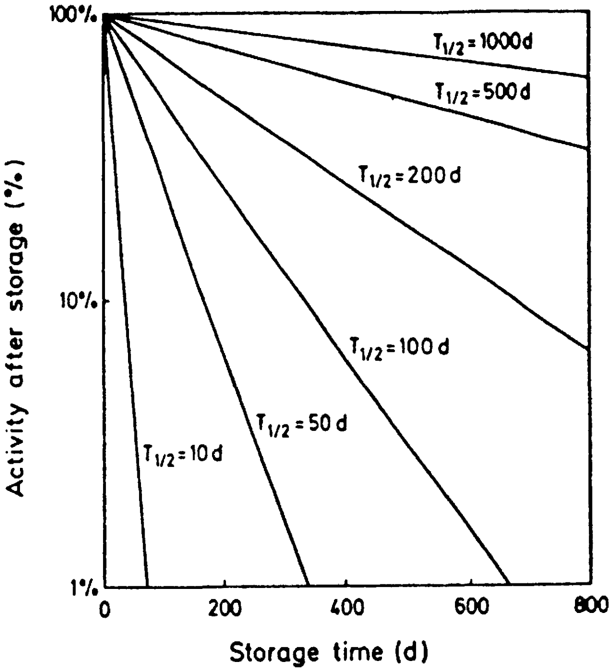


Figure 8.2: The activity remaining in food after storage as a function of storage time and half-life of the radionuclide.

Table 8.1: Normal and maximum storage periods of different food products, the fraction of the radionuclides remaining in the food after maximum storage periods and the costs related to maximum storage periods.

FOOD CLASS	MEAN STORAGE PERIOD days	MAXIMUM STORAGE PERIOD days	Cs-137	Cs-134	I-131	Ru-103	Sr-90	COSTS ECU/kg
MILK PRODUCTS								
fresh milk	3	7	1.00	0.99	0.55	0.89	1.00	
milk powder	25	1000	0.94	0.39	N.S.	N.S.	0.94	
butter	15	1500	0.91	0.24	N.S.	N.S.	0.91	
cheese	70	500	0.97	0.62	N.S.	N.S.	0.97	
MEAT								
fresh	6	20	1.00	0.98	0.18	0.71	1.00	
frozen/canned	20	700	0.96	0.51	N.S.	N.S.	0.96	0.7
GREEN VEGETABLES								
fresh	5	10	1.00	0.99	0.42	0.84	1.00	
frozen/canned	40	500	0.97	0.62	N.S.	N.S.	0.97	0.7
ROOT CROPS								
fresh	100	300	0.98	0.75	N.S.	0.01	0.98	0.17
frozen/canned	100	500	0.97	0.62	N.S.	N.S.	0.97	0.7
FRUIT								
fresh soft	3	14	1.00	0.99	0.30	0.78	1.00	
fresh hard	20	200	0.99	0.83	N.S.	0.03	0.99	0.1
canned	30	500	0.97	0.62	N.S.	N.S.	0.97	0.7
GRAIN PRODUCTS	100	1000	0.94	0.39	N.S.	N.S.	0.94	0.07

N.S. : not significant i.e. less than 0.001

(Haywood 83, Jong 90, ROSSI)

Decontamination of food

Food processing will often change the concentrations of radionuclides in food. Effects of normal industrial and household food preparation may be considered when estimating doses to the population. Advice on changes in household food preparation should only be considered in very extreme situations because of possible public reactions, social consequences and the lack of possibility to control the implications of such advice. However, in emergency situations, doses due to ingestion of radionuclides may be reduced by changes in industrial food processing. In some cases optimised decontamination procedures may decrease food contamination considerably, such as decontamination by the application of ion exchange resins. In general some decrease in the transfer of radionuclides to the population may be obtained by selective processing to certain types of products.

The quantity of radionuclides in food can be decreased by extraction, e.g. as a result of cooking, and thus be partially removed from the diet if the extraction liquid is not used for other culinary purposes, such as gravy, dressing or sauce. Also, the removal of certain parts of the plant may lead to considerable radionuclide losses. Furthermore, radionuclide concentrations will change when the moisture content of the food is altered.

Data on radionuclide behaviour during food processing are scarce. Most measurements date back to the sixties. Another problem is the use of different definitions in the literature to quantify changes in radionuclide content due to food processing. As a result, the intercomparison of data from different investigations is often difficult. A literature review, extensive and thorough enough to be able to generate data which may be applicable for general purposes, was not available. In the framework of this contract, an extensive literature review was made on this subject (Noordijk 89).

Although only a few data are available and accurate estimates cannot be made, effects of food processing on radionuclide contamination are in several cases substantial enough to consider possible countermeasures. Only those data which concern internal contamination of the plants or contamination of animals in vivo have been considered. For external contamination of plants, which may be important in the early and intermediate phase after an accidental release of radionuclides, data are too scarce to allow reliable estimates of radionuclide removal. However, it can be anticipated that this type of removal will in general be larger than in the case of internal contamination.

In table 8.2 a global survey is presented of the fractions of radionuclides which remain in the food after normal food processing procedures, provided that cooking liquids, drippings from meat, bran from grains etc. are not consumed. Additional data on preparation losses or yields are also presented. For example, the boiling of meat results in a retention of 40% of the cesium in boiled meat, the remaining 60% will be present in the cooking liquid (table 8.2). In order to convert the fractions given in table 8.2 into changes in concentration levels in food, reported fractions have to be divided by the yields of the corresponding processes as presented in the same table. For example, only 7% of the strontium present

Table 8.2: The fraction of the radionuclides which remain in the food after normal food processing procedures.

FOOD CLASS / PROCESSING	Cs	Sr	I	Ru/Rh	Yield
MILK PRODUCTS					
cream	0.05	0.07	0.18		0.07
skimmilk	0.95	0.93	0.82		0.93
butter	0.01	0.006	0.035		0.04
buttermilk	0.05	0.06	0.13		
cheese 1) rennet	0.05	- 2)	0.2		0.10
acid	0.12	0.06	0.25		0.10
whey 1) rennet	0.8	- 2)	0.6		0.8
acid	0.8	0.8	0.7		0.8
casein 1) rennet	0.05	- 2)	0.07		0.03
acid	0.01	0.07	0.04		0.02
MEAT					
boiling meat	0.4	0.5	0.6	0.3	0.7
boiling bone	0.3	0.995	0.98	0.7	1.0
frying meat	0.8	0.8			0.7
wet pickling	0.1-0.6				
dry pickling	0.8				
marinating	0.1-0.6				
FISH					
boiling	0.9	0.9			
LEAFY VEGETABLES					
washing	0.8	0.8			1.0
washing + cooking	- 2)	0.8			0.8
canning	0.2	0.5			0.7
freezing	0.7	0.9			0.7
BEANS					
washing + cooking	0.8	0.5			0.9
canning	0.8	0.6			0.9

(continued)

Table 8.2 (continued)

FOOD CLASS / PROCESSING	Cs	Sr	I	Actinides	Yield
FRUITS					
peeling		0.7			
canning		0.5			
CARROTS					
scraping + boiling		0.8			
POTATOES					
peeling	0.7	0.8		0.04	0.8
cooking only		1.0			
peeling + cooking		0.8			
frying		0.6			0.6
canning	1.0	0.7			
CEREALS					
wheat white flour	0.4	0.2		0.2	0.7
dark flour [3]	0.1	0.2			0.1
rye flour	0.6	0.6		0.2	0.8
barley flour	0.5	0.5		0.2	0.8
oats flour	0.4	0.3		0.4	0.4

[1]) For cheese production the type of coagulation process is distinguished.

[2]) Observed measurements range from about 0.1 to 1.0; no mean value can be estimated.

[3]) Dark flour is a less purified fraction than white flour, some components of the bran are still present.

in whole milk will after skimming be present in cream, but, as the yield of cream is also about 7%, the concentration of strontium in cream is about the same as in raw milk (table 8.3). One has also to consider that the consumption of cream or cheese differs from the consumption of milk.

The possibilities for intervention in the dairy industry will now be discussed in more detail, as processes in the dairy industry are rather complicated but very important for radionuclide transfer to the population. For milk products, the data in table 8.2 suggests that production of butter or cheese would be an efficient procedure for removing large quantities of radionuclides from the food chain. In reality, the yield of produced cheese or butter is also small. On the basis of radionuclide concentrations the effects of milk processing are less pronounced (table 8.3). Also, all of the milk is nearly completely converted in the dairy industry to products which are almost entirely destined for human consumption. When considering butter production as a countermeasure, the contamination will still be present in the large volume of by-products (skimmed milk and buttermilk). If these by-products are to be consumed, the countermeasure would have no effect. As the economic value of these by-products of butter production is roughly the same as the value of raw milk, destruction of them could lead to comparable costs and consequences as destruction of the raw milk.

Table 8.3: Concentrations of radionuclides in dairy products as fractions of their concentrations in raw milk. Concentrations are based on fresh weight.

FOOD CLASS / PROCESSING			Cs	Sr	I
MILK PRODUCTS					
	cream		0.7	1.0	- (3)
	skimmilk		1.0	1.0	0.9
	butter		0.3	0.2	0.9
	cheese (1)	rennet	0.5	- (2)	2
		acid	1	0.6	2
	casein (1)	rennet	2	- (2)	2
		acid	0.5	4	2

(1) for cheese production the type of coagulation process is distinguished.

(2) observed measurements range from about 0.3 to 3; no mean value can be estimated.

(3) a value of 2.6 can be calculated from the data in table 8.2, but measurements indicate a value of 1.0. This contradiction is caused by the difference between yields in the experiments on I and the mean yield of all experiments presented in table 8.2.

By-products of cheese production are of minor economic and nutritional importance, so from this point of view concentration of radionuclides in whey would be more advantageous than butter production. Whereas the rennet coagulation procedure tends to concentrate Sr in the cheese and radionuclide transfer appears to be difficult to predict, transfer of radionuclides during the acid coagulation procedure appears to be more predictable and Sr concentration in produced cheese is often slightly lower than in raw milk. In fact, most radionuclides and minerals will be present in the whey (table 8.2) and most components of nutritional value are concentrated in the cheese. The better storage properties and lower consumption of cheese in comparison to milk also favours a conversion of contaminated milk to cheese. In another, more detailed Post-Chernobyl study of the EC executed by NEB (Ireland) it was concluded that, in order to reduce the level of radionuclides in dairy products, production of whole milk powder should be reduced and production of cream, butter, buttermilk and cottage cheese or, when contamination with radiostrontium is not significant, production of hard cheese should be increased (McEnri 89).

In table 8.4 information is presented on the fraction of the radioactivity which remains in the food after special decontamination procedures. Only those decontamination procedures have been considered which provide a considerable decrease in radioactivity of the product combined with only small decreases in taste and nutritional value. In general, the data presented are rather conservative due to difficulties in extrapolating laboratory results to plant-scale decontamination, the radionuclides may be removed more effectively than suggested in table 8.4.

Milk decontamination by ion exchange is the only decontamination method which has been applied on a commercial scale in the past. The fractions remaining in the milk after ion exchange given in table 8.4, refer to commercial scale decontamination applied in the sixties. The costs of the procedure were, corrected for inflation, of the order of 0.1 ECU per liter. For cesium more efficient decontamination may be obtained on the basis of later research using complexing agents. Recently, a pilot plant came into use for decontaminating 5000 tons of radiocesium-contaminated whey powder by use of a hexacyanoferrate complex (Giese 89b). Up to about 97% of the cesium contamination can be removed from the whey, which is destined as feeding stuff for cattle. The complexing agent has to be stored as radioactive waste. The method is, however, very expensive, partially due to the costs of research and building of the pilot plant. Other decontamination procedures for milk, such as coprecipitation with calcium salts or electrodialysis, appeared to be less effective than decontamination by use of ion exchange resins or they lead to an intolerable decrease in taste, nutritional value and appearance of the milk.

Table 8.4: The fraction of the radionuclides which remain in the food after decontamination.

FOOD CLASS / PROCESSING		Cs	Sr	I
MILK	ion exchange	0.3	0.1	0.1
	hexacyanoferrate	0.03		
MEAT	extraction		0.4	
MEAT	pickling/marinating	0.1		
POTATO	extraction	0.2	0.5	
VEGETABLES	extraction	0.5		

Several decontamination procedures have been applied on meat, often resulting in poor decontamination combined with quite unfavourable consequences for the taste and appearance of the meat. Certain ways of pickling or marinating may, however, result in contamination levels of Cs which are about an order of magnitude lower, while the taste remains good. For more technical information on the subject one is referred to the literature review (Noordijk 89).

In general, the costs of changes in food preparation will be much lower than the price of the food itself. Thus, when compared to alternatives like destruction, changes in food processing are generally "cheap" types of countermeasures as the economic value of the food will not be severely affected.

The feasibility of changes in food processing will depend strongly on the product and food technology. Changes in industrial food preparation can be more easily applied and controlled than changes in home food preparation, while the psychological burden to society may also be much heavier in the latter case. Further study on the feasibility of changes in food preparation is thought to be useful, in order to be better prepared in the case of an emergency.

Withdrawal from food trade

The countermeasures discussed in this section all have, as a result, that the product itself will not be consumed as food for humans. In general, the contaminated product will be regarded as waste or as a product with lower value than human food. The decrease in value will be large, often in the order of the price of human food, and consequently costs involved will be near to the value of the product as human food. Costs will be highest for destruction, as alternative use of the food will save destruction costs and part of the economic value of the product. However, feeding stuff for pet animals may have a higher economic value than food for humans. In such cases the costs of the intervention may be negligible although one should also consider possible reactions of the owners of pet animals and the amounts of food which can be absorbed by pet feeding stuff industries.

Although destruction is an efficient countermeasure, a lack of destruction capacity, ecological consequences and other factors may not favour this option. For example, large quantities of vegetables and fruit are destroyed in order to maintain market prices. In 1988, 572000 tons of vegetables and fruit were withdrawn from the market in France alone. Once withdrawn from the normal food trade, one needs to take care of the final destination of the food. In France, food withdrawn from normal trade is sometimes distributed to institutes like prisons and hospitals and it is more often used for animal feeding or as a raw material for the distillation industry (table 8.5). Only if the capacity of these destinations is not sufficient, is the remaining amount of the food destroyed.

Use as feeding stuff for livestock

Use of contaminated food as feeding stuff for animals may be an alternative for destruction. For example, in France, 55% of wheat, 70% of barley and 25% of maize production (including stalks and leaves) are used as animal feeding stuffs. This is also the case for an important amount of vegetable and fruit overproduction (table 8.5). An advantage is that economic losses will be smaller as destruction costs are saved and the price of feeding stuff will be received. Also, centralised destruction may lead to concentration of the contamination whereas use of contaminated field products in farms will maintain a more even distribution of the contamination over the country. However, the use of contaminated feeding stuff in livestock farming will result in contaminated animal products like meat and milk which may cause a considerable distrust amongst farmers and population and may even affect the food trade. Therefore, use as a feeding stuff for livestock will only be relevant if the ultimate contamination of animal products is less than a fraction of the contamination level of the feeding stuff.

Table 8.5: The destination of overproduction of vegetables and fruit in France in 1982/1983. Data given as a percentage of total overproduction (572 000 ton in 1988).

	social institutes	distillation	animal feeding	destruction
apple	4	48	30	18
pear	6	46	35	13
peach	11	48	1	40
orange	2		1	97
mandarine	6		11	83
lemon	2		23	75
cabbage	2		49	49
tomatoes	6		61	33

The difference between contamination levels of feeding stuff and food products of animal origin is calculated in a straightforward way. It is not necessary within this context to use complicated or very accurate calculations or input data, as the calculation has only to demonstrate whether the countermeasure may be relevant in accidental situations which means that the order of magnitude of reduction of food contamination has to be assessed.

Most input data used were taken from the default values used in Chapter 2, only for Ru-103 and for poultry were additional data used (tables 8.6, 8.7). Fm and Ff are transfer factors from feeding stuff to milk and from feeding stuff to flesh, respectively. The animals are assumed to eat over their entire life feeding stuff which was contaminated with 1 Bq .kg^{-1} at the moment of birth of the animal. From this moment the contamination of the feeding stuff decreases by physical decay. After a certain period of time an equilibrium is assumed between contamination levels of animal products and feeding stuff. To take into account the large uncertainty in knowledge on transfer phenomena in young growing animals they are supposed to accumulate twice as much as adult animals, which is a rather conservative approximation. Before slaughtering, the animal may be fed with feeding stuff with a lower contamination level for some period of time in order to reduce radioactivity levels. Such a change to qualitatively better feeding stuff is already common practice in livestock farming. In this case, the contamination level of the animal at the moment of supply of the last contaminated feeding stuff is calculated, followed by a decrease in contamination in the period on to slaughtering, calculated according to the effective half life of the radionuclide in the animal.

Table 8.6: Life span and intake of feeding stuff of livestock.

ANIMAL		FOOD kg- dry\day	MAXIMAL AGE day
COW	calf	2	170
	heifer	6	550
	cow	9	1500
	lactating cow	12	
	young bull	7	550
	bull	9	1000
PIG		3	180
SHEEP/GOAT	lamb	1	300
	ewe	1.5	600
POULTRY	chicken	0.1	45
	laying-hen	0.12	420
	poult	0.3	120

Table 8.7: Transfer factors and effective half lives of several radionuclides.

ANIMAL			Cs-137	Cs-134	I-131	Ru-103	Sr-90
COW	Fm	day/liter	5.0E-03	5.0E-03	5.0E-03	5.0E-06	2.0E-03
	Ff	day/kg	3.0E-02	3.0E-02	2.0E-03	2.0E-03	3.0E-04
	T half	day	4.0E+01	4.0E+01	8.0E+00	4.0E+01	*
PIG	Ff	day/kg	4.0E-01	4.0E-01	5.0E-03	1.0E-02	2.0E-03
	T half	day	3.5E+01	3.5E+01	8.0E+00	4.0E+01	*
SHEEP/GOAT	Fm	day/liter	6.0E-02	6.0E-02	5.0E-01	1.0E-02	1.0E-02
	Ff	day/kg	5.0E-01	5.0E-01	5.0E-02	1.0E-02	3.0E-03
	T half	day	4.0E+01	4.0E+01	8.0E+00	4.0E+01	*
POULTRY	F egg	day/kg	4.0E-01	4.0E-01	3.0E+00	1.0E-02	4.0E-01
	Ff	day/kg	4.4E+00	4.4E+00	1.0E-02	1.0E-01	1.0E-02
	T half	day	1.5E+01	1.5E+01	8.0E+00	4.0E+01	*

* retention function soft tissue Coughtrey vol 1 p 176 for Sr 90

(Andersson 89, Bouville 87, Coughtrey 83, Ennis 88, Hoek 87, Howard 85, Howard 87, IAEA 82, Jackson 87, Martin 89, Ng 78, Ng 82, Voigt 88a, Voigt 88b, Voigt 89, Wirth 86)

Meat contamination appears to be much lower than the contamination of feeding stuff for most animals and radionuclides (table 8.8). For cesium, however, contamination levels remain quite considerable, unless the animal is fed with uncontaminated feeding stuff during the period before slaughtering (table 8.9). Contamination of milk with cesium will also be considerable (tables 8.10, 8.11).

Contamination levels of food products of animal origin may be further reduced by application of feeding stuff additives such as alginates and prussian blue (see section 8.2; preventive countermeasures during food production).

Table 8.8: The contamination of meat when supplying contaminated feeding stuff (Bq/kg meat)/(Bq/kg feeding stuff).

ANIMAL		Cs-137	Cs-134	I-131	Ru-103	Sr-90
COW	calf	0.119	0.103	N.S.	N.S.	0.001
	heifer	0.174	0.108	N.S.	N.S.	0.002
	cow	0.246	0.068	N.S.	N.S.	0.002
	young bull	0.203	0.126	N.S.	N.S.	0.002
	bull	0.254	0.107	N.S.	N.S.	0.003
PIG		1.186	1.017	N.S.	0.001	0.006
SHEEP/GOAT	lamb	0.981	0.758	N.S.	N.S.	0.006
	ewe	0.722	0.431	N.S.	N.S.	0.004
POULTRY	chicken	0.878	0.844	N.S.	0.009	0.002
	laying-hen	0.514	0.359	N.S.	N.S.	0.001
	poult	2.620	2.364	N.S.	0.007	0.006

N.S. : not significant i.e. less than 0.001

Table 8.9: The contamination of meat when supplying contaminated feeding stuff combined with supply of not contaminated feeding stuff in the last quarter of the animals life (Bq/kg meat)/(Bq/kg feeding stuff).

ANIMAL		Cs-137	Cs-134	Sr-90
COW	calf	0.045	0.040	N.S.
	heifer	0.007	0.005	N.S.
	cow	N.S.	N.S.	N.S.
	young bull	0.009	0.006	N.S.
	bull	0.001	N.S.	N.S.
PIG		0.250	0.223	N.S.
SHEEP/GOAT	lamb	0.073	0.060	N.S.
	ewe	0.004	0.003	N.S.
POULTRY	chicken	0.723	0.702	N.S.
	laying-hen	0.084	0.064	N.S.
	poult	1.561	1.445	N.S.

N.S. : not significant i.e. less than 0.001

Table 8.10: The contamination of milk and eggs when supplying contaminated feeding stuff, maximum contamination of the products (Bq/kg product)/(Bq/kg feeding stuff).

ANIMAL	Cs-137	Cs-134	I-131	Ru-103	Sr-89
MILK COW	0.060	0.060	0.060	N.S.	0.024
MILK SHEEP/GOAT	0.090	0.090	0.750	0.015	0.015
EGGS CHICKEN	0.048	0.048	0.360	0.001	0.048

N.S. : not significant i.e. less than 0.001

Table 8.11: The contamination of milk and eggs when supplying contaminated feeding stuff, mean contamination of the products over the first year (Bq/kg product)/(Bq/kg feeding stuff).

ANIMAL	Cs-137	Cs-134	I-131	Ru-103	Sr-89
MILK COW	0.059	0.051	0.002	N.S.	0.024
MILK SHEEP/GOAT	0.089	0.076	0.024	0.002	0.015
EGGS CHICKEN	0.047	0.041	0.011	N.S.	0.047

A nearly complete dose reduction for humans may be achieved when contaminated food is used as feeding stuff for animals which are not destined for human consumption, such as pet animals, breeding animals, animals in a zoo, etc.

The costs of the use of food as animal feeding stuff can be assessed as the difference in price between the product as food for human consumption and as feeding stuff for animals. The costs of the intervention depend highly on the type of food which is given to the animals. Prices of animal feeding stuff, such as hay or lucern, are about 0.1 ECU per kg whereas prices of food for humans range from about 0.1 ECU per kg for products such as wheat or potatoes up to about 3.5 ECU per kg for butter. Most products of animal origin cost about 2 ECU per kg with relatively small differences in price between the different products and between the countries of the EC. Products of vegetable origin, however, range in price from 0.1 to 1 ECU per kg excluding some exceptionally expensive products. One has also to consider the deviations in price levels of certain vegetable products within the countries of the EC. These deviations are in general about a factor 2, but for specific products, such as lettuce, much higher deviations may be observed.

Use as raw material for industrial non-food products

Contaminated food may be used as raw material for industrial processes. In the case of production of distilled beverages, large amounts of vegetables and fruit, removed from normal trade, are used (table 8.5). Also considerable amounts of regular food production are used nowadays for industrial processes. For example, in France 1.8% of wheat, 12% of maize and 15% of barley production are used as non-food products. Wheat and maize are mainly used for starch, gluten or glucose production. Starch is used as a raw material in many processes in the chemical, paper, textile and pharmaceutic industry. Potatoes are also used for cardboard production.

If the final product is not food, often a nearly complete dose reduction for humans will be accomplished. Possibilities to use contaminated food for non-food products are, however, limited. The agricultural products which are used nowadays for industrial products are often well specified. Introduction of a new raw material will often need research to implement it in a production process. Only for very large amounts of contaminated food may such research be economically feasible. Even when the technology is already available the price of the raw material needs to be very low. For example, alcohol production for non-beverages from cereals needs a cereal price which is only about one fifth of the normal cereal price in order to balance production costs.

Destruction and disposal

In general, dose reductions due to destruction of food will be nearly complete, doses due to handling and destruction operations are considered to be too low to be relevant. The costs and feasibility will determine in which way food can be destroyed.

Food may be destroyed in two different ways. The food may be stored as radioactive waste in a special disposal site. In this case concentration of the contamination by volume reduction is favourable as smaller waste volumes will decrease storage costs. Food may also be destroyed on the farms by spreading it over the land. In this case the aim is to dilute the contamination and each action which would lead to concentration of the radioactivity should be avoided.

Disposal as radioactive waste is very expensive. The cheapest way to dispose of radioactive waste is in metal barrels of 225 liter which costs about 106 ECU per barrel (ANDRA 89). Also, the destruction capacity for radioactive waste is limited. Storage as radioactive waste often requires a reduction of the volume, incinerators available at CEA (France) allow treatment of no more than 30 to 40 kg waste per hour at the cost of 17.10 $ECU.kg^{-1}$. By comparison, normal refuse destruction costs about 0.026 $ECU.kg^{-1}$. Destruction as normal waste would, however, lead to some extra costs for decontamination of the installation, filters etc. Nevertheless, if a small area is extremely contaminated, destruction of its production as radioactive waste might be an effective countermeasure.

The costs of other types of food destruction will be small compared with the economic value of the product. For example, the costs of destruction of crops by ploughing under the soil will in general be less than about 1% of the value of the harvest. Such small costs will not be considered in this chapter as the feasibility of the different destruction modes in a specific emergency situation will determine how food will be destroyed. In general, destruction on the field might be easier to implement than destruction of large amounts of stored food. However, ecological effects and the consequences for future crops have to be taken into account before a decision on food destruction on the field is taken.

Milk may be destroyed in several ways. It is theoretically possible to spread milk over the land. Due to the high biological oxygen demand of milk, ecological consequences will only be limited if the area is not sloping or fallow, if milk spreading is restricted to certain periods of the year and if the amounts spread are small per square meter. As a result, possibilities for destroying milk on the farm are limited. Another way to destroy milk is evaporation and, after this volume decrease, storage of the powder as radioactive waste. Total costs of evaporation and storage will be about 0.1 ECU per liter milk.

Destruction of vegetables may take place on the farms where the crop is grown by ploughing it under the soil. Contamination of this crop and future crops will differ as future crops will be contaminated by uptake from the soil, which is less important than contamination by interception of deposition from the air for most radionuclides. For example, in the case of leafy vegetables and a deposition of Cs of 1 $kBq.m^{-2}$, and deposition 30, 10 or 0 days before harvest, the contamination level of the plants will be respectively about 6, 100 and 400 $Bq.kg^{-1}$. The differences are caused by dilution effects of growing and weathering phenomena. For the next crop uptake from the soil after ploughing will lead to a vegetable contamination of only about 0.05 $Bq.kg^{-1}$, which is a factor 100 to 10000 lower (Delmas 88, IUR 87). However, in the case of a high deposition level and nearly total interception by a mature crop, it is interesting to take into account the increase in soil contamination when the crop is to be destroyed on the land.

Destruction, storage etc. outside the farm will include food transport. Costs of transport for vegetables and fruit by road or by rail were in 1985 in the order of 0.07 and 0.04 $ECU.ton^{-1}.km^{-1}$, respectively (INSEE 86). Costs of transport of cereals by waterway are in the order of 0.03 $ECU.ton^{-1}.km^{-1}$. Transport costs vary according to the distance and the quantities transported.

8.3.3 Selection of countermeasures

In the previous section, information was presented on costs, effectiveness and feasibility of countermeasures, which can be considered in the case of radioactive contamination of food. This information is given per countermeasure in order to present all the information in a concise way.

For most countermeasures, costs, effectiveness and feasibility will change with the type of food and the emergency situation. A selection of relevant countermeasures has thus to be made for each type of food separately and it has to be repeated for each emergency situation. However, several factors are valid for a variety of accident situations and food products and may facilitate selection of countermeasures in the future. For example, storage of food is only effective if the radionuclides involved have a short physical half life. In this case, the accident situation or the type of food product are less important for the selection of a countermeasure.

In this section a survey of relevant countermeasures is presented which is applicable to important generalised emergency situations and which involve four general food classes. The survey may be an aid in recognizing the general considerations which facilitate the choice of a countermeasure. Only in some cases may additional new information on a countermeasure be presented.

General survey of relevant countermeasures

Countermeasures have to be selected for each specific combination of food products and each emergency situation. In this section, four food classes are considered; (1) milk and milk products, (2) vegetables and fruit, (3) cereals and (4) meat. Eight emergency cases are considered, depending on the half life of the radionuclides, the contamination level of the food product and the fraction of available food involved. No preventive countermeasures have been taken into account as the survey is focussed on possible countermeasures on contaminated food products.

The half life of the radionuclides is taken into account by considering two groups of radionuclides; short lived and long-lived radionuclides. Short lived radionuclides have a half life of days, long-lived radionuclides have a half-life in the order of years.

The emergency situation is also defined by the level of radioactivity, relative to the intervention level for food banning. In the case of a relatively low contamination of about 1 to 5 times the intervention level, other countermeasures may be relevant than in the case of a much higher contamination level.

Another important factor is the fraction of the food in which the contamination exceeds intervention levels. A small amount of contaminated food may be easily replaced by products from elsewhere, and food trade will hardly be disrupted. Intervention for large amounts of contaminated food will disrupt food trade and might cause a shortage of certain food products.

The first criterion for a countermeasure to be selected is its capacity to reduce food contamination below the intervention level. In the survey, for each accident situation and food product, selected countermeasures are roughly ordered according to increasing costs and consequences following their implementation (tables 8.12, 8.13). A rough subdivision is made by dividing the countermeasures into relatively "cheap" ones of type A, corrective countermeasures to reduce food contamination (see 4.2.2), and more expensive ones of type B, directed at a withdrawal from food trade (see 4.2.3). Countermeasures of type A will not alter food availability or, if food is temporarily withdrawn from the market, it can generally be available again within about a month. Countermeasures of type B will decrease food availability and stored foods or imports may be necessary for replacement.

Sometimes it is impossible to conclude whether a countermeasure will be relevant in a specific accident situation included in the survey. For example, in the case of vegetables, storage may be relevant for beans or carrots, whereas for products such as lettuce storage is not feasible. In such cases where it is not possible to draw general conclusions on the applicability of a countermeasure, the measure is placed in brackets in the survey.

In general, destruction of overproduction may be a generally applicable "cheap" countermeasure. For short lived radionuclides storage is a good alternative to destruction. In the case of contamination with long-lived radionuclides food processing or decontamination may be important to save food when the contamination level is less than about 2 to 5 times the intervention level, otherwise withdrawal from food trade is practically the only way of intervention. In this case, destruction and use as animal feeding stuff are the most relevant intervention modes.

If food is contaminated with a mixture of long-lived and short-lived radionuclides, the strategy could include a sequence of countermeasures aimed at a sufficient reduction of the concentration of both groups of radionuclides in the food.

Table 8.12: Selection of countermeasures when food is contaminated with short-lived radionuclides. A and B refer to "cheap" and "expensive" countermeasures as defined in the text.

<table>
<tr><th rowspan="2">FOOD CLASS</th><th>HIGH CONTAMINATION</th><th colspan="2">LOW CONTAMINATION</th></tr>
<tr><th>small or large food fraction</th><th>small food fraction</th><th>large food fraction</th></tr>
<tr><td>MILK &
MILK PRODUCTS</td><td colspan="3" rowspan="2">A1 destruction of overproduction
A2 storage</td></tr>
<tr><td>CEREALS</td></tr>
<tr><td rowspan="2">VEGETABLES & FRUIT</td><td colspan="2">A1 destruction of overproduction
(A2 storage)</td><td>A1 destruction of overproduction
(A2 storage)
(A3 decontamination)</td></tr>
<tr><td colspan="3">B1 fodder for animals
B2 destruction</td></tr>
<tr><td>MEAT</td><td colspan="3">A1 storage</td></tr>
<tr><td>LIVING ANIMALS</td><td colspan="3">A1 delay of slaughtering + change of fodder + eventually additives</td></tr>
</table>

Table 8.13: Selection of countermeasures when food is contaminated with long-lived radionuclides. A and B refer to "cheap" and "expensive" countermeasures as defined in the text.

<table>
<tr><th rowspan="2">FOOD CLASS</th><th>HIGH CONTAMINATION</th><th colspan="2">LOW CONTAMINATION</th></tr>
<tr><th>small or large food fraction</th><th>small food fraction</th><th>large food fraction</th></tr>
<tr><td rowspan="2">MILK &
MILK PRODUCTS</td><td colspan="2">A1 destruction of overproduction</td><td>A1 destruction of overproduction
A2 decontamination</td></tr>
<tr><td colspan="3">B1 fodder for animals
(B2 industrial use for non-foods)
B3 destruction</td></tr>
<tr><td rowspan="2">CEREALS</td><td>A1 destruction of overproduction</td><td colspan="2">A1 destruction of overproduction
A2 processing</td></tr>
<tr><td colspan="3">B1 fodder for animals
B2 industrial use for non-foods
B3 destruction</td></tr>
<tr><td rowspan="2">VEGETABLES &
FRUIT</td><td>A1 destruction of overproduction</td><td colspan="2">A1 destruction of overproduction
A2 processing</td></tr>
<tr><td colspan="3">B1 fodder for animals
B2 destruction</td></tr>
<tr><td rowspan="2">MEAT</td><td>-</td><td colspan="2">A1 processing</td></tr>
<tr><td colspan="3">B1 fodder for animals
B2 destruction</td></tr>
<tr><td>LIVING ANIMALS</td><td colspan="3">A1 delay of slaughtering + change of fodder + eventually additives</td></tr>
</table>

Often it will be impossible to select just one countermeasure for a large amount of contaminated food. The contamination level will not be constant for all food products and capacities for storage, destruction, processing, etc. have to be taken into account. An intervention, aiming at a minimum of disruption and costs involved, may be obtained taking into account a number of countermeasures, specific for the typical situation in the affected areas.

The next sections will present a more detailed discussion of the selection of countermeasures for the types of food and emergency situations considered here.

Milk and milk products

In the case of contamination of milk with short-lived radionuclides, storage may be an effective countermeasure because, when compared to other alternatives, it allows large reductions in contamination levels with little costs or disruptions involved. In order to obtain a sufficient decrease in contamination level, raw milk has to be transformed in a product which allows storage over a period of months.

Contaminated milk may be collected separately in selected dairies where transformation and storage can take place. Stored quantities of transformed milk in the EC have changed considerably over the last years, from 1.4 million tons of butter and 473 thousand tons of skimmed milk powder in '87 to 212 thousand tons and 7 thousand tons respectively in '89 (ONILAIT 88). The efficiency of this type of intervention depends not only on physical decay and storage times, but also on the transformation processes which influence the contamination level (tables 8.2, 8.3).

In the case of a contamination of the entire milk production with long-lived radionuclides, decontamination procedures may be applied. Also a shift in production towards production of butter and cheese could reduce contamination sufficiently when radioactivity levels do not exceed approximately 5 times the intervention level.

If milk is severely contaminated with long-lived radionuclides, storage or normal processing will not be able to reduce the contamination level below the intervention level. Decontamination techniques, based on e.g. ion exchange resins, are in general not feasible as considerable costs and time will be involved for the construction of a decontamination plant. The milk has to be withdrawn from food trade.

Withdrawal from food trade includes destruction and use as feeding stuff for animals. The use as feeding stuffs for animals is, however, restricted by international regulations (CEC 89). The use of contaminated milk products in the industry on a large scale for non-foods is not yet a realistic alternative. However, contaminated milk powder or whey powder may be added to feeding stuff without a serious transfer to humans (tables 8.8, 8.9). A decontamination procedure before use as feeding stuff could be included (Giese 89). Costs of use as feeding stuff will be lower than costs of destruction and will avoid the problems related to large scale destruction of milk. Whether it is acceptable for farmers and population is difficult to predict.

In all cases described above, contaminated milk may have negative consequences for milk trade and milk consumption. To avoid this, destruction of overproduction or of small quantities of contaminated milk could in many cases be favourable, although in the case of contamination with only short lived radionuclides destruction will lead to, from a pure technical point of view, an unnecessary economic loss.

Meat

Meat contamination with short lived radionuclides can be solved by storage. It may be canned, but deep freezing will in general maintain the best quality.

In the case of meat contamination with long-lived radionuclides storage will not reduce the contamination level effectively. Processing of meat may, in general, decrease meat contamination by not more than a factor of 2. Special procedures, such as wet pickling or marinating with repeated removal of the pickling or marinating liquid, may lead to a decrease in contamination of Cs of about a factor of 10 (table 8.2). Other countermeasures are destruction and the use of contaminated meat as feeding stuff for animals, which will both lead to a large economic loss.

The possibility of a meat contamination exceeding intervention levels may, however, in general be predicted. In many cases, a better countermeasure is to delay slaughtering for some time, eventually coupled with provision of uncontaminated feeding stuff or the use of additives to reduce uptake of radionuclides. Costs of additional feeding are of the order of 0.5 ECU per day per animal, which depends on the availability of feeding stuff and thus on factors such as season, climate and overproduction (Tveten 87). Delay of slaughtering might lead to less problems with trade or public reactions than storage or food processing because the meat is "clean" at the time of slaughtering. However, even for such an obviously simple countermeasure, the disruptions in farming practices may be considerable (Kerr 88). In contrast, if a contamination of meat is foreseen, it might be advantageous to anticipate and slaughter a part of the live stock before it is contaminated.

Vegetables and fruit

In all cases destruction of overproduction is a cheap and effective countermeasure which has to be considered first. If the amount of contaminated food exceeds overproduction, other countermeasures have to be considered.

When the food is contaminated with short-lived radionuclides, storage will not always be an effective countermeasure. The maximum storage time of a product and the physical half-life of the radionuclide determine to what extent contamination with short-lived radionuclides can be decreased by storage. Some products, especially leafy vegetables, cannot be preserved. For other types of vegetables, such as beans, storage over long periods is normal.

When food is contaminated with long-lived radionuclides, certain processing or decontamination procedures may be applied to decrease contamination below the intervention level. The effectiveness of this countermeasure is limited and varies with product and procedure. The decrease in contamination level will in general be not more than a factor of 3.

As with removal of overproduction in normal circumstances, food which is withdrawn from trade may still be used in several ways. It can be used as feeding stuff for animals or in the distillation industry. Transfer of radionuclides to humans can be limited in the case of animal feeding (tables 8.8, 8.9), but an eventual use of contaminated food in the distillation industry has to be preceded by investigating the radionuclide transfer to distilled products if those products are to be used for human consumption. Use of contaminated food as feeding stuff or for distilled products may, however, cause distrust among the population and may disturb trade. The only alternative may then be destruction, which, in general, is better done on the farm.

Cereals

Normal storage times for cereals are of the order of one year. Thus, in the case of food contamination by short-lived radionuclides, intervention may be limited to keeping cereals stored over a certain period.

If cereals are contaminated with long-lived radionuclides, other methods have to be used, e.g. destruction of overproduction. The effects of processing may be taken into account as they may be considerable. For wheat, for example, flour contamination is in general a factor of 2 to 5 lower than grain contamination (table 8.2).

If cereals cannot be used for normal food trade, it can still be used for animal feeding or as raw material for industrial non-food products or for the distillation industry. In the last case, the transfer of radionuclides to distilled products has to be studied first if these products are destined for human consumption. Again, public opinion or trade may favour destruction instead of countermeasures such as the use as animal feeding, use for industrial products or even storage.

8.4 EXAMPLES OF APPLICATION OF THE METHODOLOGY ON SELECTED COUNTERMEASURES

The objective of the methodology is to define a contamination level in food products above which implementation of a countermeasure is justified. The justification is based on economic and dosimetric criteria. The following examples will illustrate the economic approach which balances costs of countermeasures with the detriment saved. Costs presented here are only given as indicative values as the real costs of interventions in specific cases might be different. A more elaborate assessment of these costs is necessary in actual emergency situations. Further in this section a value of 30,000 ECU per manSv is used as a generic value for saving detriment by implementation of countermeasures. This is in the range of 3,000 to 100,000 ECU per manSv commonly adopted (Lombard 86). The value of 30,000 ECU is only used to illustrate the methodology and the intervention levels calculated here have only illustrative purposes, they are not intended to interfere with intervention levels derived by national or international authorities. This section is not exhaustive, as only few examples are discussed to show the implications of the methods.

8.4.1 Beef contaminated by Cs-137

A possible countermeasure is feeding the animals for some time with uncontaminated feeding stuff. The effectiveness of this countermeasure will increase with time. If the countermeasure is applied to cows just before slaughtering and slaughtering can be postponed for 40 days without a change in quality and quantity of the beef, the meat contamination, and thus the dose to humans, can be reduced by a factor of 3 (tables 8.8, 8.9).

If X is the original meat contamination ($Bq.kg^{-1}$) and effects of food preparation are not taken into account, the ingestion dose caused by 1 kg is $1.3*10^{-8}X$ Sv (Chapter 5). If the dose is reduced by a factor 3, the value assigned to saved detriment is $0.66*30000*1.3*10^{-8}X$ ECU per kg beef.

The costs of animal feeding is about 0.5 ECU per day per animal. After an extra feeding period of 40 days and assuming a beef production of 200 kg per cow, the costs of the countermeasure is 0.1 ECU per kg beef.

According to the cost-benefit analysis, application of the countermeasure will be justified when the benefit exceeds costs involved. In this case $2.6*10^{-4}X$ should exceed 0.1, which means that application of the countermeasure is justified when the contamination of beef, X, is higher than 400 $Bq.kg^{-1}$.

8.4.2 Milk contaminated by Cs-137

Contamination of milk can be concentrated by evaporating the water and storage of the powder in a disposal site as low level radioactive waste. Whole milk may be transformed to powder, but it is also possible to make cheese, followed by transformation of the whey to powder. Approximately 80% of the contamination will be concentrated in the whey powder (table 8.2). These different options will be considered in this section.

The costs of the countermeasure will not be directly proportional to the quantity of product involved as it is necessary to include costs of decontamination of the production plant. Washing the plant is a usual operation after production of whey powder or milk powder. Extra costs will be caused by processing of about 10 m^3 of contaminated water and washing solutions. Together with costs of transport and control operations the extra costs are approximately $2*10^4$ ECU. It is assumed that $5*10^6$ l. milk is involved, and therefore extra costs of cleaning will be about $4*10^{-3}$ ECU per kg milk.

Disposal of whole milk powder

The economic value of whole milk powder is 2.6 ECU per kg powder. The costs of storage as radioactive waste is 0.5 ECU per kg powder. One kg of whole milk powder is equivalent to 8.3 kg of raw milk, so the costs of the countermeasure are 0.37 ECU per kg raw milk.

Assuming a contamination of milk of X $Bq.kg^{-1}$ the ingestion dose caused by 1 kg of milk will be $1.3*10^{-8}X$ Sv (Chapter 5). Conversion of whole milk to powder and subsequent storage of it will be justified when $30000*1.3*10^{-8}$ X exceeds 0.37, which results if the concentration of cesium in whole milk exceeds 950 $Bq.l^{-1}$.

Disposal of whey powder

The value of whey powder is 0.33 ECU per kg powder. One kg of whey powder is equivalent to 16 kg of raw milk. Together with costs of storage and decontamination of the plant the total costs of the countermeasure are 0.056 ECU per kg raw milk. The detriment saved will, however, depend on whether the whey is to be used for human consumption or as animal feeding stuff.

If the whey is used for human consumption only, 80% of the cesium present in whole milk would be withdrawn from the human diet by disposal of whey powder (table 8.2). The countermeasure would be justified when $0.8*3.9*10^{-4}$ X exceeds 0.056, which happens when the concentration of cesium is more than 180 Bq per liter milk.

If the whey is used as feeding stuff for beef cattle only, 80*0.17% of the cesium in whole milk would be withdrawn from the human diet by disposal of whey powder (tables 8.2, 8.8). In this case disposal of whey powder as radioactive waste would be justified when the concentration of cesium in raw milk exceeds 1060 $Bq.l^{-1}$.

Application of the countermeasure at lower contamination levels is only justified when dosimetric limits would be exceeded. If it is assumed that only one product, such as meat or milk, is contaminated by Cs-137, a lower dose limit of 5 mSv combined with an intake of 100 kg per year will, according to equation (8.1), lead to a concentration level of 3600 $Bq.kg^{-1}$. In that case, in all examples discussed in this section, the lower dosimetric level would exceed limits derived by the economic approach and thus all interventions would be justified if the lower dosimetric level of 3600 $Bq.kg^{-1}$ is exceeded.

If the upper and lower reference levels derived by the dosimetric approach are 300 and 3000 $Bq.kg^{-1}$ respectively for milk, the economic approach could be an aid in the choice of countermeasures to be considered. If milk contamination is between 300 and 1000 $Bq.kg^{-1}$, only that part of the whey powder production which should otherwise be used for human consumption has to be disposed of. Above a contamination level of 1000 $Bq.kg^{-1}$ disposal of whey powder and whole milk are both justified. At contamination levels between 300 and 1000 $Bq.kg^{-1}$ one could consider the possibility of increasing the production of cheese combined with use of whey powder as feeding stuff for animals.

Again it should be stressed that the examples presented in this section only serve as illustrations and are not intended to interfere with existing regulations by the authorities. Other factors which are not considered in this chapter may influence decisions on interventions.

8.5 PUBLIC OPINION AND SPONTANEOUS REACTIONS IN AN EMERGENCY SITUATION

Public reactions are often able to overrule interventions of the government and may have serious consequences even in situations which have no important harmful consequences.

This section will present some cases of public reactions on food contamination. As cases of public reactions on food contamination with radionuclides are seldom, public reactions on other food contaminants are also included.

In April 1989 Dutch newspapers reported that toxic levels of crop protection agents had been measured in grapes from Chile by the Dutch Food Inspection Department. These toxic levels were only once observed, careful examination of imported fruits from Chile hereafter did not reveal any limit-exceeding levels of toxic agents. Nevertheless, this message in the press had a negative influence on Dutch consumption and trade (import and transit) of Chilean grapes in April. The economic loss from the decrease in trade in that period was estimated to be approximately 1.3 million ECU. Thus, just a single message in the press may have serious negative economic consequences.

Interpretation of public reactions by the use of trade data is often difficult. In 1987, the export of Dutch herring to the FRG severely decreased as a result of reports in the press and on television that herrings were infested with parasites. The Dutch herring exports to the FRG were clearly affected in the months August till October 1987. After October, interpretation of available data is difficult but in 1989 the trade still does not seem to be completely recovered (DAEI 89). The economic loss may be about 2 million ECU over the months August through October.

After the Chernobyl accident, a ban on trade of spinach was announced in the Netherlands from 7 to 10 May 1986. Only a relatively small economic effect of the ban was observed (CBVF 86). Auction prices of other vegetables decreased by a factor of 2 on 6 and 7 May, possibly caused by the embargo on spinach. After 7 May, other effects on the price, especially seasonal ones, may have been of major importance. Dutch exports were not really influenced by the Chernobyl accident despite the interventions and reportings in the media all over Europe.

Analyses of the effects of Chernobyl on food consumption patterns would be valuable. However, only a German study is available on food consumption consequences of the Chernobyl accident (Jürgen-Anders 88). In the FRG, the Strahlenschutzkommission advised against consumption of "Ab-Hof" milk whereas no advices were given against dairy milk. Directly after the accident 35% of the population consumed no or hardly any milk. In South-Germany effects on consumption were most pronounced. Consumption of UHT milk was in the period of May till July 1986 nearly two times higher than previously, whereas consumption of fresh milk was decreased; this decrease was 25% for young women. Consumption of fresh vegetables showed a decrease of 20 to 50 %, and consumption of canned and frozen products was increased. Changes in food consumption habits were observed until winter and at the start of 1987 consumption was nearly normal again.

It may be concluded that spontaneous reactions of the population can have important economic consequences and may interfere with the planning of an intervention. However, the magnitude of this kind of reaction is unpredictable, nearly no detailed data or psychological studies on the subject appear to be available.

8.6 CONCLUDING REMARKS

After a large accidental release of radionuclides to the environment intervention by national public health authorities may be necessary. A major exposure pathway could be ingestion of contaminated food. Although basic concepts of intervention, as e.g. formulated by ICRP, are widely accepted, the early phase of the Chernobyl accident showed a severe lack of consensus in adopted intervention levels for food.

In this report technical and scientific information is given which is useful when, in case of contaminated food products, intervention is considered. Besides these technical factors, other factors such as ethical, political and social factors play a part in the implementation of an intervention, but these factors are not considered in this report. A methodology is developed to derive intervention levels for food products. The methodology is based on general radiation protection concepts and on the ALARA (As Low As Reasonably Achievable) principle. Primarily, limits are set which will restrict doses to a level where only stochastic effects are to be expected. Below these limits, an ALARA approach is elaborated which balances economic consequences with aimed dose reductions. The methodology requires information on costs and effectiveness of an intervention. The methodology, however, is not used to derive generally applicable intervention limits as the complexity of problems related to setting intervention levels for food urges a careful evaluation in each specific emergency situation. The intervention levels calculated in this report serve only illustrative purposes although these levels do not differ much from the intervention levels proposed by the article 31 group of experts.

In the second place, information is provided on the effectiveness, costs and feasibility of a wide variety of countermeasures which may be considered when the contamination of food may exceed intervention levels. In the case of a contamination with long-lived radionuclides which is more than a factor 10 higher than intervention levels, only destruction or use as feeding stuff for animals will be effective. However, restrictions have been posed for the safety of animals which limit the use as feeding stuff for animals. Meat contamination may be decreased effectively by a delay of slaughtering combined with supply of uncontaminated feeding stuff. In the case of a contamination with short lived radionuclides, storage is very effective. If food contamination does not exceed intervention levels more than about two to four times, adequate changes in food processing may decrease the contamination level sufficiently. In certain cases, use as raw material for industrial processes may also lead to sufficient dose reductions.

Costs of the countermeasures depend on the amount of food involved, removal of food from trade will change prices. If relevant and possible, costs are assessed for the countermeasures without taking into account changes in costs and prices due to the accident, the intervention or to public reactions. Assessed costs present therefore only a rough indication as economic consequences may deviate considerably.

Besides technical or economic considerations, the feasibility of an intervention also depends on other aspects. Reactions of the public may have an important impact on food economy. Important trade disruptions may already occur in situations where intervention is still far from being considered. Ethical questions may also arise. These aspects are not discussed in further detail in this report.

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9 EFFECTIVENESS OF COUNTERMEASURES

9.1 INTRODUCTION

In the previous chapter possible countermeasures to mitigate the radio-biological consequences of the contamination of foodstuff has been described and evaluated according to their feasibility and cost-effectiveness. In this chapter the dynamic model ECOSYS (Pröhl, 1990) is used in order to calculate the doses saved due to the application of some of the more important interventions. The effect of countermeasures is quantified in terms of potential collective dose saved or, if possible, as individual dose saved. The effectiveness of the storage of foodstuff and decontamination during preparation and processing was described already in Chapter 8 and is not considered further here.

In this chapter, considerations focus on the effectiveness of food bans, the application of derived intervention levels (DILs) and on countermeasures concerning the feeding management of domestic animals. These calculations should be considered as examples of the use of dynamic food chain models in emergency situations and for the effectiveness of countermeasures in specific situations. It should be borne in mind that the effectiveness of the countermeasures considered here may be different for other scenarios due to a different spatial distribution of the fallout, seasonal effects, and due to the distribution of food. Nevertheless, it is thought that the examples considered give helpful support to any discussions about the application of countermeasures.

9.2 FOOD BANS

The highest activity concentrations in foodstuff occurs in the first harvest following the accident. Beginning with the second harvest and onward, most foodstuff is contaminated due to uptake of radionuclides from the soil which is generally relatively small compared with foliar uptake following the deposition. Fig. 9.1 shows the activity concentration integrated over 50 years of Cs-137 and Sr-90 in winter wheat, fruit

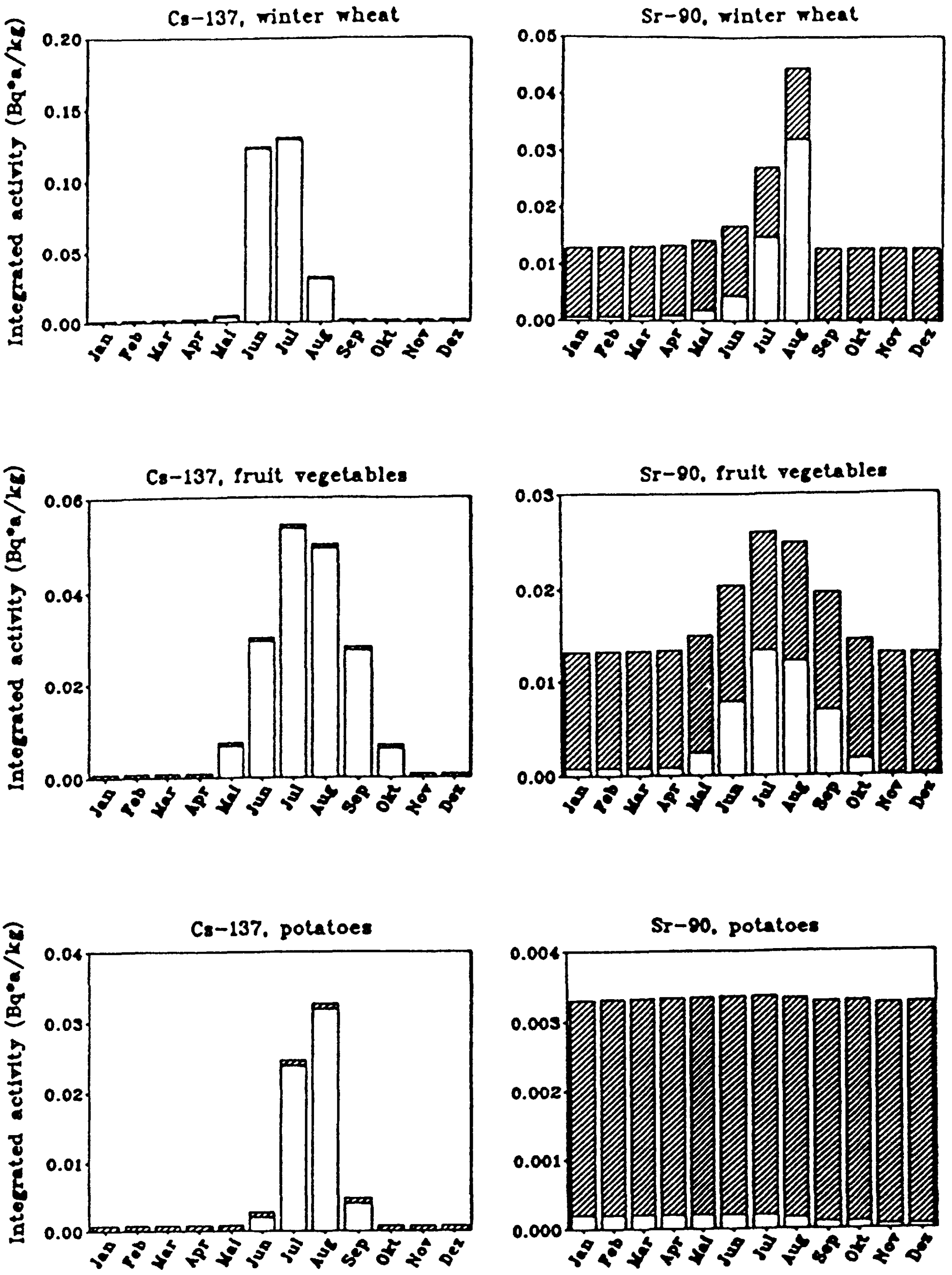

Fig. 9.1: 50-year integral activity concentration of Cs-137 and Sr-90 in winter wheat, fruit vegetables and potatoes as function of the month of deposition (Deposition: 1 Bq/m^2 during a precipitation of 1 mm; white part of columns: foliar uptake dashed part: root uptake).

vegetables and potatoes for different months of deposition. The figure differentiates between the contribution of the first 2 years, represented by the blank part of the columns and the following 48 years, represented by the dashed part of the column. The contribution of the first 2 years is dominated clearly by the contamination of the first harvest following the deposition. It is obvious that a ban in the first year can be a very effective countermeasure, particularly if the deposition takes place during the summer when the plant canopies are fully developed. Bans would be much more effective for Cs-137 than for Sr-90 due to the effective translocation of cesium within the plant and the strong sorption of cesium in the soil. For cesium, up to more than 90% of the collective dose can be avoided by banning the first harvest.

When compared to cesium, the root uptake of strontium is higher by about a factor of 10, whereas the contamination due to direct deposition on the foliage and subsequent translocation is relatively small. Consequently, the reduction of the potential total strontium intake due to a ban in the first year would not be greater than 50% for wheat, fruit, and vegetables. For potato tubers the contamination via the foliage is not relevant, and therefore a ban of potatoes in the first year would have no significant effect on the potential integral intake of Sr-90.

However, the total or partial renunciation of the use of certain foodstuff is a very drastic measure, the realization of which depends on two factors:

- The contaminated foodstuff can be substituted by food which is less contaminated or uncontaminated. Therefore the total renunciation of food for longer periods is only possible in relatively small areas.

- The loss of food due to a ban can be replaced by other stocks. Nevertheless, in larger regions food bans can be only of limited duration and have to focus on the most important foodstuff and radionuclides.

The example illustrated in Fig. 9.1 gives a general overview of the potential effectivness of food bans, whereas in Fig. 9.2 a specific situation is considered. For I-131, due to its short half-life, food bans have a strong influence on the potential activity intake which results almost exclusively from the consumption of milk and leafy vegetables. In Fig. 9.2 the potential reduction of the dose due to I-131 in milk is shown as a function of the duration of the ban. Different curves are given for varying delays between the deposition and the beginning of the ban. It is obvious that a fast reaction after the deposition is very important for the effectivness of the ban. A ban for 20 days starting after 7 days is as effective as a ban for 3 days starting after one day. Furthermore, it should be noted that the amount of milk involved due to the ban is a factor of 7 higher in the first case than the second. This implies that the cost-effectiveness for the second case is about a factor of 7 more cost effective than the first.

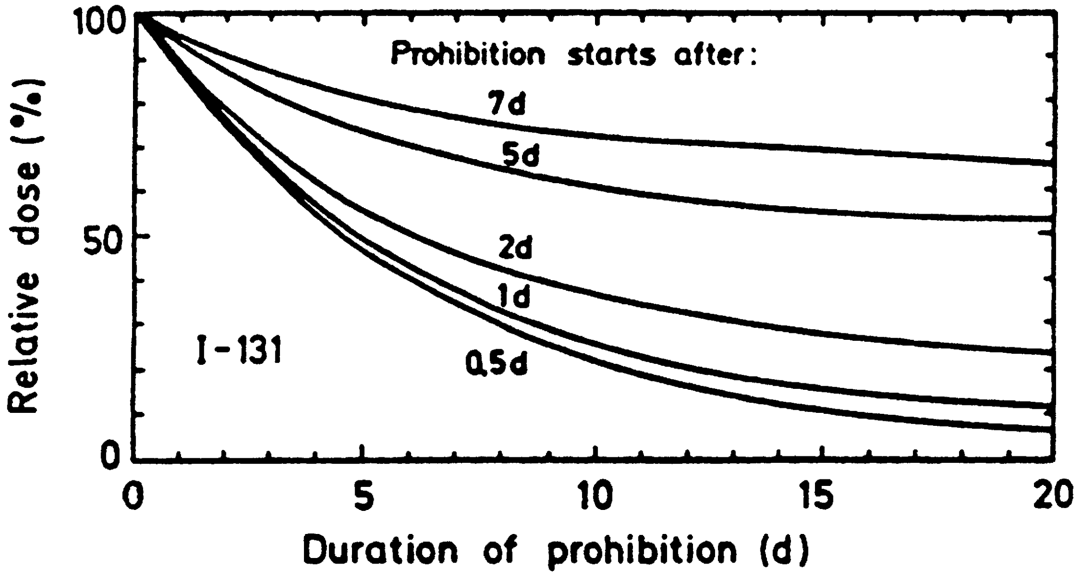

Fig. 9.2: Reduction of the potential intake of I-131 in milk as function of the duration of a ban and the start of the ban after the deposition of I-131 (Jacob et al., 1988).

A fast reaction which is the only guarantee for the effectiveness of the ban in this case, requires an efficient, on-line monitoring system in order to predict or to detect activity in air and rain as early as possible. Another presumption for a quick and effective response is the availability of stored uncontaminated feeding stuff.

A similar effectiveness can be expected for a ban on leafy vegetables. In this case a fast reaction is even more effective because the maximum activity concentration is reached immediately after the deposition. In milk the maximum is observed after 1 to 2 days due to the delay of the iodine transfer feed-milk due to the cow's metabolism.

In Fig. 9.3 the relative reduction in the total ingestion dose from Cs-134, Cs-137, and I-131 due to banning the consumption of green vegetables and fresh milk is shown as a function of the time the intervention is started after a deposition and as a function of its duration, assuming a deposition on 1st May. The deposition pattern is roughly that measured by Hötzl et al. (1987) at Neuherberg in May 1986 (Table 9.1). Again, the food chain model ECOSYS has been used for this calculation.

Table 9.1: Deposition pattern measured by Hötzl et al. (1987) at Neuherberg in May 1986.

Activity in air:	Wet deposition:
Cs-137: 300 Bq*h/m^3	Cs-137: 20000 Bq/m^2
Cs-134: 150 Bq*h/m^3	Cs-134: 10000 Bq/m^2
Sr-90: 3 Bq*h/m^3	Sr-90: 200 Bq/m^2
I-131: 1700 Bq*h/m^3	I-131: 90000 Bq/m^2
(25% aerosol, 25% elemental, 50% organic)	Rainfall: 5 mm

Again, it is obvious that the dose reduction due to banning is the most effective the earlier the bans start. Bans starting very early cut off the peak concentrations in milk and leafy vegetables which contribute a relatively high fraction to the total intake. On the other hand, the overall effect of such bans would be surprisingly small in this case because a significant part of the ingestion dose would be due to the consumption of grain, pork, beef, fruits, and milk during the next winter. In this example it is assumed that the feeding of contaminated silage and hay during the next winter is not affected by countermeasures.

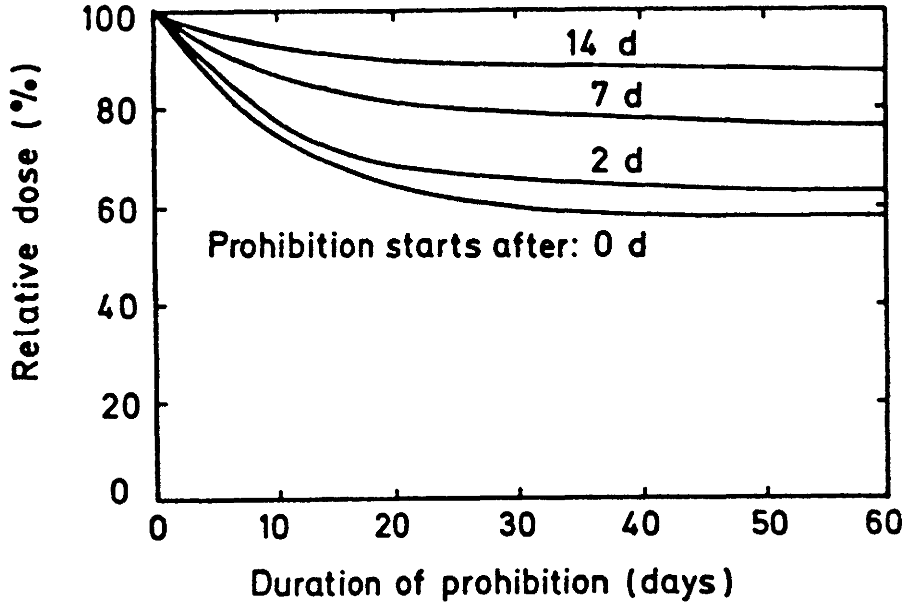

Fig. 9.3: Reduction of total ingestion dose due to the banning of consumption of leafy vegetables and milk as a function of the duration of the ban and the delay between the deposition and the start of the ban.

9.3 REDUCTION OF DOSE DUE TO THE APPLICATION OF DERIVED INTERVENTION LEVELS

The ingestion dose of the population would also be reduced due to the application of derived intervention levels (DILs). This means that foodstuff above a certain activity limit may not enter the market. In order to quantify the dose reduction, ingestion doses are calculated with and without the application of DILs for different deposition scenarios. For these calculations, DILs recommended by the CEC (Luykx, 1989) (Table 9.2) have been applied.

Table 9.2: DILs recommended by the CEC for application after nuclear accidents.

Nuclide	Derived intervention level Milk (Bq/l)	All other Foods (Bq/kg)
Cs-134/137	1 000	1 250
I-131	500	2 000
Sr-90	125	750

The ingestion dose is estimated using the food chain model ECOSYS, which exclusively assumes the consumption of locally produced food and average German consumption habits for adults. The results are summarized in Tables 9.3 to 9.6.

In the calculations given in Table 9.3, a deposition pattern is assumed similar to that measured at Neuherberg in May 1986 by Hötzl et al. (1987) (Table 9.1), but occurring at different times of the year. The ingestion dose without the application of DILs increases from May to July and then gets smaller until September. The absolute dose saved has its maximum after deposition on 1st June. For all other months the doses saved are similar. The relative dose saved is highest after a deposition in May. Although the absolute dose saved in June is greater than in May, the relative dose saved is less. In May, the total ingestion dose is least, and the application of DILs affects only the intake with milk and leafy vegetables. In June and July the activity concentrations in more foodstuff (except milk and leafy vegetables) is increased compared to May, but they are mostly still below the derived intervention level.

However, it should be noted that the ingestion doses calculated for May are higher by about a factor 5 than those derived from whole-body measurements (Schmier et al. 1988), although the predictions of the activity concentrations in foodstuff agrees well with measured activities in foodstuff (Müller and Pröhl 1988). This discrepancy is due to the assumption that only locally produced food is consumed, whereas in reality a considerable part of the food consumed was less contaminated, and no interventions such as bans (e.g. lettuce, spinach) are considered. Furthermore, people tended to avoid the consumption of relatively high contaminated foodstuff such as milk and leafy vegetables in the time after the Chernobyl accident.

The situation is quite different if a deposition is assumed which is a factor of 10 higher (Table 9.4). Again, the maximum of the ingestion dose is around June and July and the absolute dose saved is correlated to the total ingestion dose, but now also the relative dose saved has its maximum in June and July. In this scenario, the activity concentrations of most foodstuff is above the intervention level after deposition in May. Again, the activity concentrations of nearly all foodstuff increases during summer. This enhances the absolute as well as the relative dose saved.

For the calculations shown in Table 9.5, a deposition is assumed which is higher by a factor 100 compared to the example in Table 9.3. The application of DILs reduces the ingestion dose by more than 90%. In this scenario, the activity concentrations in almost all foodstuff is above the intervention level at all times of deposition considered here.

The results presented in Table 9.6 illustrate the influence of the deposition pattern on the dose: Whereas in the example shown in Tables 9.3 to 9.5, wet deposition is dominating, in the calculations of Table 9.6, only dry deposition is assumed. The total deposited activity of the mixed deposition pattern in Table 9.1 is about a factor of 1.5 to 2 higher than in this dry deposition scenario. Nevertheless, the total ingestion dose is higher for all months because in the first case the interception is about 20%, whereas in the latter case it is about 80%. The absolute dose saved has its peak after deposition in June, but the relative dose saved is similar for all months. It is interesting to note that in the examples given in Tables 9.4 and 9.5, the ingestion doses after the application of DILs are, in some cases in one of the two first years, well above 5 mSv which was the reference level for the derivation of the derived intervention level (Luykx 1989). This is because in the cases considered here only locally produced food is consumed. In the estimating of DILs it is assumed by the CEC that the annual average contamination of food over the year following the accident would not exceed 10% of the concentration levels in foodstuff on which controls would be based.

Therefore, the application of DILs can ensure a reduction of the ingestion dose below 5 mSv per year only in those cases in which a) the food is not totally locally produced, and b) the deposition is inhomogeneous so that food distribution has a diluting effect.

In these calculations there is either no or only a very little effect (in the scenario of Table 9.5) of the application of DILs on the ingestion dose after the first two years. In the scenarios considered, the consumption of venison, mushrooms, goat's and sheep milk and lamb is not taken into account. For this foodstuff it might be possible that over a long period after the accident, cesium levels are well above the DILs. Therefore, for population groups which consume such foodstuff the application of DILs will probably also reduce the ingestion dose also in the time following the first two years after the accident.

For all these model simulations, it is assumed that foodstuff with activities above the DILs are consumed with activities equal to those levels. This assumption is conservative. In reality foodstuff above the derived intervention level would not come onto the market, and for the food consumed the DIL would be the upper limit of the activity. Therefore the reductions of doses given in Tables 9.3 to 9.6 can be regarded as lower limits.

From these examples it is obvious that the effectiveness of the application of DILs is a non-linear problem. This effectiveness is dependent on the deposition in relation to the DILs applied, the deposition pattern (wet/dry, rainfall), and the month of deposition. This implies that at different locations with varying growing conditions the effect of the application of DILs might be different because different stages of plant development will influence the activity concentration in foodstuff.

Table 9.3: Ingestion doses saved due to the application of DILs in 2 years and in 50 years following the deposition.

Month of deposit	time period	dose without DILs (mSv)	dose saved with DILs (mSv)	dose saved %
May	2y	0.87	0.2	23
	50y	1.0	0.2	20
June	2y	3.9	0.64	16
	50y	4.1	0.64	16
July	2y	4.2	0.29	7
	50y	4.3	0.29	7
Aug.	2y	2.4	0.24	10
	50y	2.5	0.24	9
Sept.	2y	1.5	0.24	17
	50y	1.6	0.24	15

Activity in air:	Cs-137	300	Bq*h/m^3	
	Cs-134	150	Bq*h/m^3	
	I-131	1 700	Bq*h/m^3	(.25 e,.25 a, .5 o)
	Sr-90	3	Bq*h/m^3	
Wet deposition:	Cs-137	20 000	Bq/m^2	Rainfall: 5mm
	Cs-134	10 000	Bq/m^2	
	I-131	90 000	Bq/m^2	
	Sr-90	200	Bq/m^2	

Table 9.4: Ingestion doses saved due to the application of DILs in 2 years and in 50 years following the deposition, same as Table 9.3, but a factor of 10 higher deposition.

Month of deposit	time period	dose without DILs (mSv)	dose saved with DILs (mSv)	dose saved %
May	2y	8.7	4.4	50
	50y	10	4.4	44
June	2y	39	30	76
	50y	41	30	73
July	2y	42	30	72
	50y	43	30	69
Aug.	2y	24	15	63
	50y	25	15	60
Sept.	2y	15	11	72
	50y	16	11	66

Activity in air:	Cs-137	3 000	Bq*h/m^3	
	Cs-134	1 500	Bq*h/m^3	
	I-131	17 000	Bq*h/m^3	(.25 e,.25 a, .5 o)
	Sr-90	30	Bq*h/m^3	
Wet deposition:	Cs-137	200 000	Bq/m^2	Rainfall: 5mm
	Cs-134	100 000	Bq/m^2	
	I-131	900 000	Bq/m^2	
	Sr-90	2 000	Bq/m^2	

Table 9.5: Ingestion doses saved due to the application of DILs in 2 years and in 50 years following the deposition same as Table 9.3, but a factor of 100 higher deposition.

Month of deposit	time period	dose without DILs (mSv)	dose saved with DILs (mSv)	dose saved %
May	2y	87	80	92
	50y	100	82	82
June	2y	390	380	97
	50y	410	382	93
July	2y	420	404	96
	50y	430	406	94
Aug.	2y	240	224	93
	50y	250	226	90
Sept.	2y	150	141	94
	50y	160	143	89

Activity in air:	Cs-137	30 000	Bq*h/m^3	
	Cs-134	15 000	Bq*h/m^3	
	I-131	170 000	Bq*h/m^3	(.25 e,.25 a, .5 o)
	Sr-90	300	Bq*h/m^3	
Wet deposition:	Cs-137	2000 000	Bq/m^2	Rainfall: 5mm
	Cs-134	1000 000	Bq/m^2	
	I-131	9000 000	Bq/m^2	
	Sr-90	20 000	Bq/m^2	

Table 9.6: Ingestion doses saved due to the application of DILs in 2 years and in 50 years following the deposition same as table 9.3, but only dry deposition which is a factor of 10 higher.

Month of deposit	time period	dose without DILs (mSv)	dose saved with DILs (mSv)	dose saved %
May	2y	3.5	1.8	51
	50y	3.6	1.8	50
June	2y	13.2	7.1	54
	50y	13.4	7.1	53
July	2y	14.6	6.3	43
	50y	14.7	6.3	43
Aug.	2y	9.0	3.6	40
	50y	9.1	3.6	40
Sept.	2y	6.1	3.4	55
	50y	6.3	3.4	54

Activity in air:			
	Cs-137	3 000	Bq*h/m^3
	Cs-134	1 500	Bq*h/m^3
	I-131	17 000	Bq*h/m^3 (.25 e,.25 a, .5 o)
	Sr-90	30	Bq*h/m^3

No wet deposition
No rainfall

9.4 USE OF HIGHLY CONTAMINATED FOOD FOR ANIMALS

In order to use the valuable contents of food, it is possible in some cases to give highly contaminated feed stuff to animals, especially if the application is restricted to the beginning of the fattening period or combined with additives which reduce the gut uptake of the radionuclides.

In Fig. 9.4, the Cs-137-activity in beef is plotted as a function of the length of the period of activity intake. After this period the animals are fed on uncontaminated feed stuff until the time of slaughtering (550 days after the first application of contaminated feeding stuff). By stopping the activity intake about 100 days before slaughtering, the remaining activity concentration in beef would be by a factor of 4 lower than if feeding with contaminated food stuff continued.

In Fig. 9.5 the same function has been plotted for pork. The activity concentrations in pork would be much higher than in beef due to the higher transfer factor and the shorter fattening period. During this fattening period, the time for the excretion of cesium after intake is stopped is too short to reduce the activity in meat as effectively as in beef.

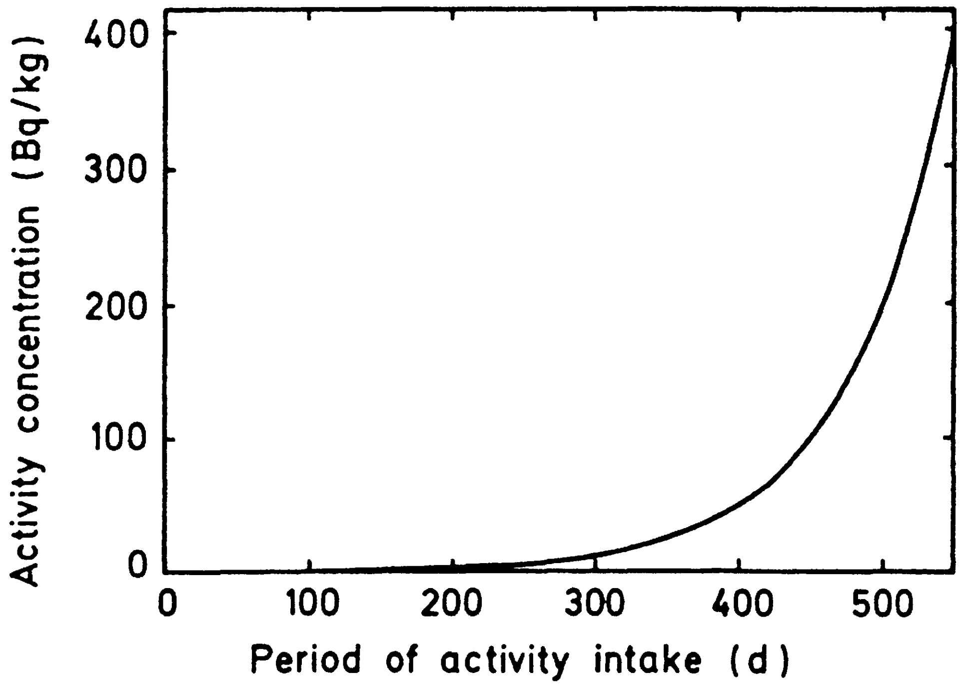

Fig. 9.4: Cs-137-concentration in beef as function of the period of activity application (transfer factor feed-beef: 0.04 d/kg; biological half-life: 50 d; activity intake: 10000 Bq/d, age at slaughtering: 550 d).

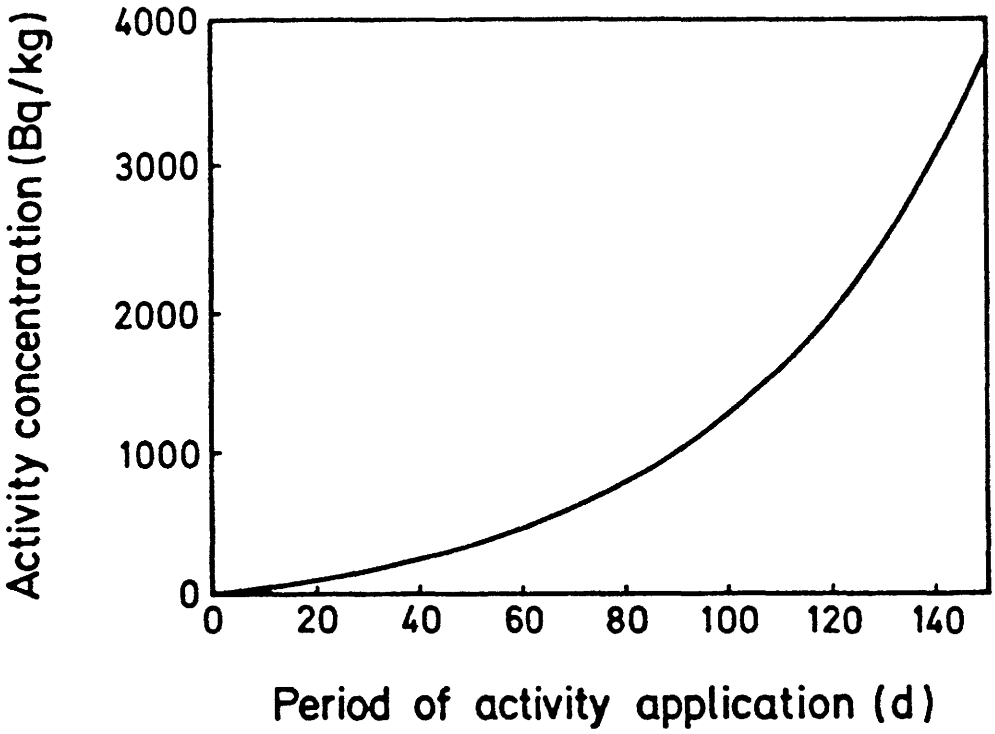

Fig. 9.5: Cs-137-contamination of pork as function of the period of activity application (transfer factor feed-pork: 0.4 d/kg biological half-life: 35 d, activity intake: 10000 Bq/d, age at slaughtering: 150 d).

Fig. 9.6 shows the ratio of the total Cs-137-activity in pork and beef to the total Cs-137-activity ingested by the animal during the period of activity intake. The figure indicates what part of the potential dose can be saved if contaminated products are not directly ingested by man but fed to animals. After feeding pigs during the whole fattening period with contaminated feed, the total Cs-137-inventory in meat is about 20% of the whole activity applied; for beef only 2% of the activity is recovered in the meat. The recovered fractions are much smaller if the intake of contaminated feed is restricted to an early part of the fattening period.

The reduction of the cesium activity in meat and milk due to application of bentonite and ammonium-ferric-cyano-ferrate (II) (AHCF) to domestic animals is shown in Table 9.7. These reduction factors have been determined by Voigt et al. (1989).

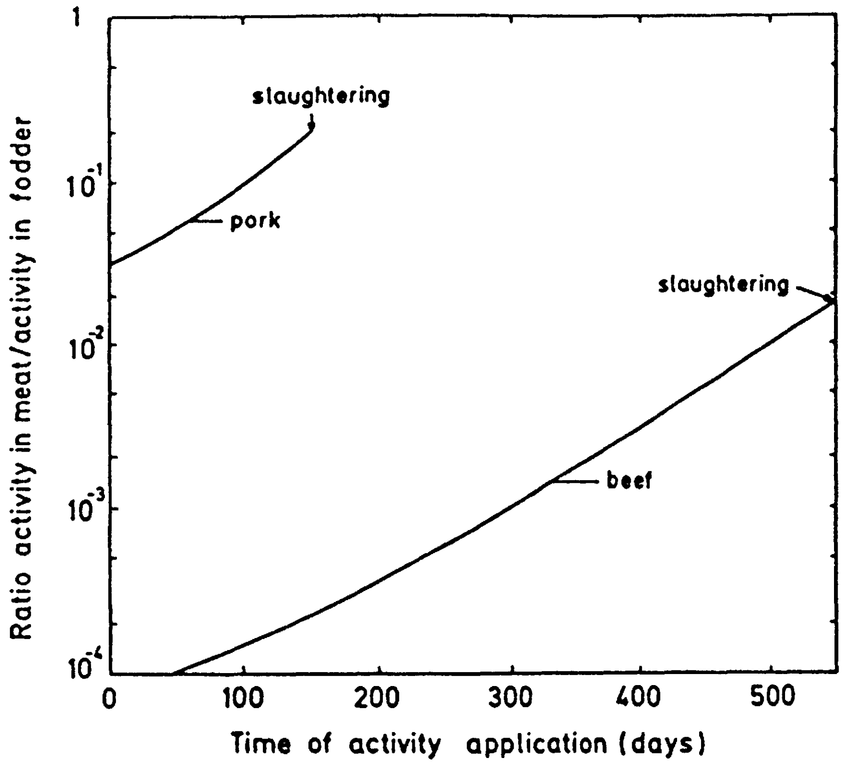

Fig. 9.6: Ratio of the activity recovered in total meat of pigs and beef cattle to the activity in food stuff as function of the period of activity intake.

Table 9.7: Reduction of cesium activity in animal food products due to the application of bentonite and AHCF (according to Voigt et al. 1989).

Animal product	Reduction factor due to bentonite	Reduction factor due to AHCF
Cow's milk	3.7	5.5
Beef (cow)	4.3	4.0
Veal	-	12.0
Pork	1.9	9.1

The highest effectiveness of AHCF occurs for pork and veal. For all other applications of bentonite or AHCF (except pork), the activity in foodstuff could be reduced by a factor of 4 to 5.

The restriction of feeding with highly contaminated foodstuff in the first part of the fattening period, together with the application of ion-exchangers, would be the most effective countermeasure for reducing the activity of cesium in animal food products without a total banning of contaminated foodstuff.

A further countermeasure to avoid unacceptable activity levels in animal foodstuff is a change in the feeding regimes of the animals. An example of the effect of this type of countermeasure is shown in Fig. 9.7. This graph shows the time-dependent activity concentrations of Cs-137 in cow's milk after a deposition at the beginning of May, assuming different feeding regimes for dairy cattle during winter. In all cases, cows are fed on fresh pasture during the spring and summer months. During winter in all diets, except diet 'a', grass is partly (diet 'b' and 'c') or entirely (diet 'd' and 'e') substituted by other foodstuff. The activity concentrations of these substitutes are much lower. That is because the initial deposition onto the foliage of the plants used is lower than for grass due to their minute vegetative development at the beginning of May, and also because they are harvested more than three months after the deposition; by which time most of the activity has already weathered off.

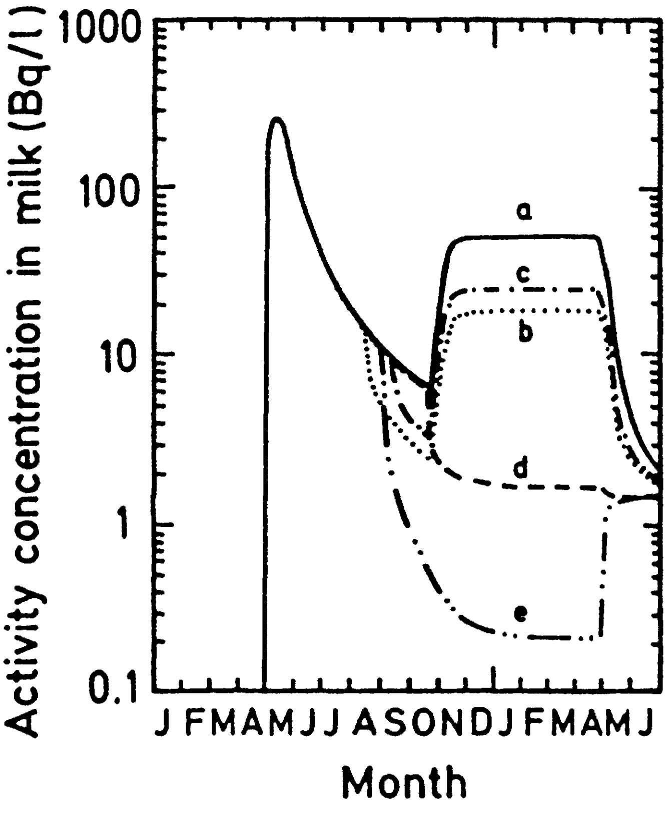

Fig. 9.7: Time-dependence of Cs-137-concentration in cow's milk for different winter feeding diets a–hay, b–hay and maize, c–hay and beet, d–brewing residues and maize e–distillery residues and maize; time of deposition: 1st May; deposition pattern: see Table 9.1.

The influence of countermeasures relating to the feeding management on the individual ingestion dose is summarized in Table 9.8. For these calculations, depositions on the 1st May and 1st July are assumed. The deposition pattern is again nearly that measured at Neuherberg after the Chernobyl accident (Table 9.1). The ingestion dose is integrated over the first 20 months following the deposition. Again, it should be borne in mind that the doses due to ingestion of Cs-134 and Cs-137 calculated here are about a factor of 5 higher than those determined from whole-body counting due to food distribution, change of consumption habits and countermeasures. In case 2, the application of AHCF to milk cows, bulls, pigs, and calves is simulated which reduces the total ingestion dose by 33% after deposition on 1st May and by 17% after deposition on 1st July. In case 3 of Table 9.8 the intake of contaminated foodstuff is stopped during the last 50 days of the fattening period of pigs and calves, and during the last 150 days for bulls leading to 7% and 5% lower ingestion doses for 1st May and 1st July respectively. The change of feeding diets for milking cows and pigs (case 4) leads to 14% and 10% lower doses. In this case, milking cows are fed during the winter with maize and brewing residues instead of hay and silage, and pigs are fed on corn cobs instead of grain.

All of the countermeasures concerning feed management are appropriate for reducing the activity concentrations in foodstuff considerably, or to reduce the potential collective dose due to highly contaminated foodstuff. On the other hand, all these countermeasures presume that the farmers will collaborate and that the farmers and consumers will accept the countermeasure (e.g. application of AHCF).

Another important presumption is the existence of a well-organized feed management system on the farms which is able to follow the recommendations of the authorities.

Table 9.8: Individual ingestion dose integrated over the first 20 months following the deposition due to introduction of countermeasures concerning the feeding management after different times of deposition; for deposition pattern: see Table 9.1.

Time of deposition	Nuclide	Ingestion dose (mSv) Case 1	Case 2	Case 3	Case 4
1st May	Cs-134	0.24	0.15	0.21	0.19
	Cs-137	0.39	0.24	0.34	0.29
	all nuclides	0.88	0.59	0.82	0.76
1st July	Cs-134	1.4	1.2	1.3	1.2
	Cs-137	2.4	2.0	2.2	2.1
	all nuclides	4.1	3.4	3.9	3.7

Case 1: Dose without countermeasures

Case 2: Dose after application of AHCF

Case 3: Dose after stop of activity intake during the last period

Case 4: Dose after change of feeding diet for milking cows and pigs

9.5 SUMMARY

The results of these calculations can be summarized as follows:

- After deposition during the vegetation period, the destruction of the first harvest is a very effective countermeasure due to the effective uptake of radionuclides (especially those of caesium and iodine) via the foliage.

- The banning of milk and leafy vegetables is more effective the earlier the bans are started.

- The reduction of ingestion dose due to the application of derived intervention levels is dependent on the deposition pattern and the month of deposition.

- Countermeasures concerning the feeding management of domestic animals can reduce the ingestion dose after nuclear accidents considerably. In particular, a situation-specific combination of countermeasures after an accident should minimize the activity concentrations in animal food products.

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10 DISCUSSION AND CONCLUSIONS

10.1 INTRODUCTION

The Commission of the European Communities, through the Article 31 Group of Experts, instituted a two-year programme of work centred on the underlying data for Derived Intervention Levels (DILs) of contaminated foodstuffs. The objective of the programme was to compile data that would allow more detailed calculations of the DILs. In the previous chapters results were given concerning consumption and distribution of food, radioecological and biokinetics modelling, representative dose calculations, critical group characterisation, and finally countermeasures and their effectiveness. In this last chapter discussion and conclusions are presented for each of these subjects.

10.2 FOOD CONSUMPTION AND DIETARY HABITS

One of the parameters that must be determined when estimating doses due to ingestion of radionuclides is the diet. In Chapter 3 data are presented on average food consumption for the total population of each EC country. These data are also generalized to consumption of groups of countries and to the average diet of a citizen of the EC.

When the 'average EC diet' is compared with the values on food consumption adopted by the Article 31 Group of Experts for the derivation of intervention levels, consumption of dairy products and meat is about the same. The value of the Article 31 Group adopted for fruit and surface vegetables is about one-third lower than the value of the 'average EC citizen'; whereas the value for cereals is about 25% higher. However, when the consequences of differences in diet are studied in more detail, food consumption of separate countries must be taken into account. Data on national diets were clustered by defining three groups of countries with a rather similar diet. The first group consists of the United Kingdom and Ireland, with a diet characterized by a high consumption of potatoes and fresh dairy products, and a low consumption of fruit. Italy and Greece make up the second group; consumption of cereals, vegetables and fruit is high, whereas consumption of dairy products is low. The rest of the continent belongs to the third and largest group, which has a larger spread in consumption than the other two groups. For most foodstuffs, consumption is moderate and does not show extremes. Portugal and Denmark could not be grouped with any of the other countries.

Several factors influencing food consumption have been considered. Differences in age, in level of urbanisation and regional differences seem to have the largest effect. Effects of the other factors, sex, social class and season are rather small.

Total consumption increases regularly with age from one-year-old infants to 18-year olds, with few changes in later years. One-year-old infants consume about 50% of an adult diet; for five- and ten-year-old children this figure is 60 and 80%, respectively. The values for the total diet also apply to separate classes of foods, except for consumption of milk and milk products which remains quite constant during growth.

Within one country, regional consumption of a certain class of food may vary about 30% from the average national consumption. Consumption of potatoes and fruit may even be twice as high in a given region. Consumption in rural and urban areas, when compared with that of the entire country, varies from 70% to 150% and is higher in rural areas for most products.

Self-support influences the origin of the foodstuffs, as well as the amounts consumed. In general, consumed amounts are increased for self-supporting population groups. Self-support seems to be more important in the southern areas of the European Community.

Population groups with extreme diets cannot be described by separate factors but by combinations of factors. The uncertainty involved in quantifying effects of combinations of factors is great because the different factors are often correlated. Therefore only the most important factors, region and level of urbanisation, are considered. The factor 'age' is not taken into account because it is supposed not to be correlated to any other factor. The amount of food consumed by the average individual of a specific group may vary between 50% and 200% of the average total consumption in the population.

Conclusions on influences of age, sex, and of the factor self-support are supported by data from almost all EC member states. For the other factors such as level of urbanisation and season, data on only a few countries are usually available. More information is needed, especially for countries in southern Europe where, for instance, the influence of social class and of the distinction between urban and rural locations may be greater. The factor of self-support may play a very important role in case of a local contamination. In general, only statistical data on products that are marketed are available, and consumption of products which are hunted or gathered in the wild is not known. Data on self-support concern averages over the entire population, and the specific population groups involved are not known. In summary, there is a lack of information on self-supporting groups and their diets.

10.3 DISTRIBUTION OF FOODSTUFFS

The distribution of foodstuffs is recognized as of major importance for two reasons. Firstly, distribution can lead to a dilution of contamination in two ways: export of contaminated food and a decrease of local contamination by import of uncontaminated food from other regions or countries. Secondly, authorities need to know the importance of exchanges within the Community and with other countries when they have to decide on countermeasures which might temporarily limit or ban the trade of foodstuffs. In Chapter 4, for each major foodstuff, the proportion imported and its origin was determined at the regional and/or national level and dilution factors were estimated.

However, importance of exchanges should not be overestimated. In general, each EC country has achieved a high level of self-sufficiency for the main foodstuffs with most countries overproducing.

For animal products, self-sufficiency is higher than 80% in almost all countries. Consequently, imports are low relative to production, which in general are less than 25%. More than 80% of imports come from within the EC. A few countries show large deficits in specific product areas: Italy in all dairy products, the United Kingdom in butter and cheese, Greece and Italy in meat, and the Federal Republic of Germany in eggs.

For the different vegetable products, national self-sufficiency varies much more. It amounts up to 90% for potatoes in all countries with the one exception, Ireland (80% only). On first analysis for the EC as a whole, importations of vegetables represent less than 10% of the production and they come from within the EC for more than 90%. There are, however, large discrepancies at the national level: overproduction in the southern countries and the Netherlands, large deficiencies in Denmark, Ireland, the UK, and in the FRG (more than 50% of the usable amount of fresh vegetables is imported in FRG). There is a general fruit deficit in the EC: imports represent one-third of the production and are equally supplied by non-EC countries and EC countries which overproduce (Greece, Italy, and Spain respectively). With regard to wheat, importation amounts to a maximum of 20% of production. BLEU, Ireland, Italy, the Netherlands, and Portugal show severe deficiencies that are provided for largely by wheat from EC countries (80%, principally from France and the UK).

A general deficit of foodstuffs exists in all regions that are highly urbanized and industrialized. They represent areas without agricultural production but with well developed trade and distribution networks; their imports generally show less preference than is commonly given to EC products.

In summary, for all EC countries and for all foodstuffs, imports for a given foodstuff represent in general 20% of the corresponding national production, and imports come 80% from within the EC countries. This means that, on average, 84% of the resources are provided for by national production, 13% by the production of other EC countries, and only 3% comes from outside the EC. On the basis of these average figures, in a country, the imports of uncontaminated food from foreign countries are unlikely to decrease the contamination level of food by more than 20% in the case of contamination of the national production. However, contamination will probably not be homogeneous for large countries. Usual inter-regional exchanges will, therefore, have considerable importance. Thus, high dilution factors can be reasonably expected at the regional level; they will depend on regional self-sufficiency and they can be estimated by national authorities on a case by case basis. Such considerations for large regions do not hold for small areas that can be severely affected as could occur in the near-field of an installation after a large accident.

10.4 MODELLING THE TRANSFER OF RADIONUCLIDES THROUGH TERRESTRIAL FOODCHAINS

Models to predict the transfer of radionuclides through terrestrial foodchains have a number of uses in the context of Derived Intervention Levels. These uses are both in deriving the levels and in applying them in the event of an actual accident. For example, results of foodchain models can be used to investigate the extent to which food countermeasures would be required in particular circumstances. They can also be used in the period following an accident before measurements are available and to determine how long any countermeasure might be retained. In Chapter 2, a 'default' terrestrial foodchain model was described. It was derived following a comparison of the predictions of the two models, FARMLAND and ECOSYS, with environmental measurements and an inter-comparison of the model predictions. The default model and its results are intended for use where more site specific information is not available. Such a relatively simple model is particularly appropriate for estimating representative doses from the ingestion of terrestrial food over large areas. It is appropriate for use with probabilistic accident consequence codes which deal with a range of meteorological conditions and the consequences of postulated accidental releases over large areas. The default foodchain model is also useful for preliminary emergency planning to look at the likely extent of food countermeasures following accidental releases. It can also be used to pre-calculate food concentrations for use in the early phase after an actual accident before detailed meteorological data or measurements in food are available.

However, in any applications of the default model the variability in the results should be borne in mind. As shown in Chapter 2, the variation in the predicted concentrations in food in different meteorological conditions is particularly important. The variation due to releases at different times of year and due to different agricultural practices can also be significant. In addition, the uncertainty in the foodchain model results, due to lack of knowledge of the parameter values, should be recognised.

For post accident analysis, when full details of the meteorological conditions and other site-specific data are available, a more detailed foodchain model such as ECOSYS is more appropriate. A more detailed model is also better if a knowledge of the likely range of possible food concentrations following a given accidental release is required, for example for detailed emergency planning.

10.5 AGE DEPENDENT BIOKINETIC AND DOSIMETRIC MODELLING

In estimating doses from the ingestion of radionuclides by the general population, it is important to take account of their absorption from food and water by different age-groups and of age-dependent metabolism and dosimetry. Values of dose per unit intake have accordingly been calculated in Chapter 5 of this report for three-month-old infants, for 1, 5, 10, and 15 year-old children, and for adults. The radionuclides considered were isotopes of strontium, ruthenium, iodine, caesium, plutonium and americium and, for each element, the biokinetic data used in the calculations have been explained. The approach taken was consistent with that of an ICRP Task Group on age-dependent dosimetry; further details of methodology and more extensive dosimetric data will be available in the Task Group report.

The intake of radionuclides by pregnant women and irradiation of the fetus have also been considered. Fetal dosimetry is in an early developmental stage and is a subject of current research funded by CEC. Estimates of doses to the fetus are complicated by its rapid growth and differentiation. Little is known about the ability of the human placenta to discriminate against many radionuclides and information must therefore be obtained from experimental animals. However, different animal species have different types of placentae so care is needed in extrapolating to humans. Nevertheless, preliminary estimates of doses to the fetus have been made.

Although single values have been given for dose per unit intake for a particular radionuclide and age-group, consistent with the approach adopted by ICRP and others, there has been an increasing recognition of the need to consider the variation between individuals and uncertainties in estimates. These parameters have been quantified in this report for the examples of caesium isotopes, iodine-131 and plutonium-239.

10.6 CALCULATION OF REPRESENTATIVE INDIVIDUAL DOSES

In Chapter 6 illustrative calculations of individual doses from ingestion are presented. They were intended to illustrate the possible variation of individual doses between EC countries and to show which foods contribute to the doses following an accidental release at different times of the year.

From the estimates of individual doses, several conclusions can be drawn. The most significant difference in doses seen is that due to accidental releases occurring at different times of the year. These seasonal differences are observed both for the total dose and also in which foods contribute most to the total dose. The foods that contribute most to individual doses following deposition at a particular time of the year depend to some extent on the mix of radionuclides considered. For deposition of strontium-90, iodine-131 and caesium-137 in January the intake of fruit and green vegetables dominates the resulting ingestion doses. For deposition in May, the foods which make a major contribution to the dose depend on radionuclides considered. For strontium-90 potatoes, green vegetables, milk and cheese are important, for caesium-137 it is cereals, milk and meat that are important, while for iodine-131 the important foods tend to be potatoes, vegetables, fruit, milk and milk powder. For deposition on 1st July the important foods are again different. Cereals and not potatoes are now important for strontium-90, while potatoes are no longer important for iodine-131. Different foods contribute most to the dose in the different EC countries depending on the consumption pattern. For countries with a higher consumption of sheep and/or goat meat (Greece, Ireland and the UK) this food becomes important, contributing 10 to 15% of the dose for a deposition in May. In many cases consumption of pork has been found to be an important contributor to the dose, notably for deposition in July. However, the dose from ingestion of pork may have been significantly overestimated as it has been assumed that the diet of pigs comprises 100% contaminated winter grain. The relative importance of intake in fruit should also be treated with caution. The intake of fruit includes a large component due to the consumption of fruit juices, and in many countries a large component are imported from outside the EC.

Calculations were also made of the ingestion doses for 5 and 10 year-old children and the results compared to those of adults. The differences with age were found to be small. For deposition of iodine-131 alone, the doses calculated for 5-year-old children were about a factor of three higher than for adults. However, for deposition of strontium-90 or caesium-137, adult doses were calculated to be higher than those for children.

The effect of using an appropriate regional agricultural practice in calculating ingestion doses compared with a 'default' European practice has also been investigated. The effects are generally small and indicate that in many situations the assumption of a default agricultural practice is adequate. However, for the Mediterranean countries (South France, Italy, Greece, South Spain and South Portugal) differences up to a factor of four are estimated for deposition in July. In this case regional agricultural practices should be taken into account. The same foodchain model parameters have been used for all regions; using more site specific parameter values could have an effect on the results presented here.

To summarize, these illustrative calculations show that in most circumstances it is adequate to use dietary intakes that are representative of the EC as a whole in estimating doses. Also, in general, it is not necessary to take into account regional agricultural practices in estimating doses. An important exception appears to be the Mediterranean countries and additional work is required to better characterise the food intakes, agricultural practice and foodchain transfers in this region.

10.7 CHARACTERISATION OF CRITICAL POPULATION GROUPS

For the derivation of intervention levels, the parameters which characterize the food supply (for example consumption rate and origin of foodstuffs) are based on statistical data that are broadly representative for the Community. Chapter 7 presents a study that was initiated after the Chernobyl accident and which concerns critical groups like self-supporters, game-hunters and mushroom-eaters. These groups live in a highly contaminated region bordering the Bavarian Alps. The self-supporters were selected in the vicinity of conveniently situated medium-sized towns and they often work in town. These three groups were examined as to their consumption habits and to the resulting body burden of radiocaesium and were compared with non-self-supporters. According to the study, 75% of the dose relevant foodstuffs consumed by the self-supporters comes from within the region.

During the first year following the nuclear accident, the maximal body-burden of radiocaesium was measured in the group of self-supporters (17000 Bq Cs-134 plus Cs-137). During the same period, the internal dose from natural radiation exposure (250 micro-Sv/year) was increased by about a factor of three for the group of self-supporters. In the third year following the accident, the hunters seem to be the most critical group on the basis of their level of internal contamination (maximal incorporated caesium content: 5000 Bq Cs-134 plus Cs-137). Mushroom-eaters are in an intermediate position, but it must be pointed out that contaminated game and mushrooms are minor and replaceable dietary components, at least in the region where the investigations took place. The caesium body content of the self-supporters does not now differ significantly from that of the non-self-supporters.

Concerning the self-supporters, in some countries it is unlikely that these persons represent a negligible minority. They constitute a rather large group of the population, the size of which has to be estimated. They should probably be taken into account, as the most critical group, when introducing protective measures and principally to avoid food supply problems.

10.8 COUNTERMEASURES

In the event of food contamination, national public health authorities may intervene. But, although the basic concepts of intervention, as e.g. formulated by ICRP, are widely accepted, the early phase of the Chernobyl accident demonstrated firstly a lack of consensus in adopted intervention levels for contaminated food, and secondly a lack of knowledge about all possible countermeasures. Chapters 8 and 9 present technical and scientific information which is useful when intervention is considered. Besides these technical factors, other factors such as ethical, political and social factors could play a part in the implementation of an intervention, but these factors are not explicitely considered here.

Firstly, a possible methodology for the derivation of intervention levels for foodstuffs was developed. The methodology is based on general radiation protection concepts and on the ALARA (As Low As Reasonably Achievable) principle. Primarily, limits are set which will restrict doses to a level where non-stochastic effects of radiations are avoided.

Below these limits, the ALARA approach balances economic consequences with aimed dose reductions for the possible countermeasures. The methodology requires information on costs and effectiveness of an intervention. The methodology, however, is not used to derive generally applicable intervention limits as the complexity of problems related to setting intervention levels for food urges a careful evaluation in each specific emergency situation.

Secondly, information was provided on the effectiveness, costs and feasibility of a wide variety of countermeasures which may be considered when the contamination of food exceeds intervention levels. The dosimetric effectiveness of a food ban, which is the most common decision, has been estimated by using the dynamic radioecological model ECOSYS. From the calculations the following conclusions can be drawn:

- Following an accidental release during the vegetation period, food bans can reduce ingestion doses significantly. However, the total or partial withdrawal depends on the possibility to substitute it with less contaminated or uncontaminated food. Therefore, the total withdrawal of food for longer periods is only possible in relatively small areas. In larger areas food bans are only possible during a limited period.
- Food bans are more effective for short-lived than for long-lived radionuclides.
- The shorter the time between the deposition and the start of the ban, the more effective is the ban. There is, therefore, a requirement for well equipped facilities for the detection of increased levels of artificial radionuclides in air and rain, and an alert reaction of the authorities.

The ECOSYS model was also used to determine the reduction of dose following the application of the DILs. The reduction factor is dependent on the total activity deposited as well as on the deposition pattern (contribution of dry and wet deposition) and on the season. Given that the spatial distribution of the deposition is not likely to be homogeneous, and people do not exclusively eat food that is produced locally, the application of DILs can probably ensure that an ingestion dose of 5 mSv in the first year is not exceeded.

An important problem is the procedures to be adopted with contaminated food. In the case of a contamination with long-lived radionuclides higher than 10 times the intervention levels, destruction of food is the most effective intervention. In certain cases (for example milk), decontamination procedures may be used. At lower contamination levels, a reasonable alternative may be to use contaminated food as feeding stuff for animals. Indeed countermeasures concerning the feed management, such as application of additives and change of diets, are appropriate for the reduction of the activity concentrations in foodstuffs or of the potential dose due to highly contaminated foodstuffs. However, the use of contaminated foodstuffs for animal feeding is restricted by regulations. Such restrictions might be reconsidered when the advantages of using contaminated food as feeding stuff become obvious. On the other hand, all these countermeasures presume the collaboration of the farmers and their acceptance by both farmers and consumers (e.g. application of prussian blue compounds). Another important requirement is the ability of the farmer to carry out the recommendations of the authorities.

Concerning meat, its contamination may be decreased effectively by a delay in the slaughtering of animals combined with a period of supply of uncontaminated feeding stuff. In the case of a contamination with short-lived radionuclides, storage will clearly be very effective for most foods. If food contamination does not exceed the derived intervention levels by factors of more than about two to four, adequate changes in food processing may decrease the contamination level sufficiently. Effects of certain processes on radioactivity levels are important and they may be considered in an emergency situation. However, technological and economical consequences of such an intervention may be very complex and difficult to assess. Also, more attention should be given to these consequences in regular scientific programmes.

In certain cases, use of food as raw material for industrial processes may be an alternative to avoid doses to the population.

Costs of countermeasures depend on the amount of food involved. Removal of food from trade may change prices. Costs in this report are assessed without taking into account changes in costs and prices due to the accident, to the authorities' intervention, or to public reactions. Thus, assessed costs only present a rough indication of the economic impact as economical consequences may deviate considerably. In addition to technical or economical considerations, experience shows that the feasibility of an intervention depends also on other aspects. Once again, reactions of the public may have a large impact on food economy; indeed important trade disruptions may occur in situations where intervention is still far from being implemented. Moreover, certain interventions may raise ethical questions.

In brief, a number of different countermeasures are feasible and the best options depend on a variety of factors that need to be taken into account by the national authorities. In a specific situation, a certain combination of countermeasures will be the most efficient way to effectively minimize the ingestion dose.

11 EXECUTIVE SUMMARY - UNDERLYING DATA FOR DERIVED INTERVENTION LEVELS

11.1 AIM OF THE PROJECT

After accidental releases of radioactive material to the atmosphere leading to significant off-site contamination, various countermeasures will need to be introduced to reduce the radiation exposure of the population. These countermeasures may include: sheltering, evacuation and the issuing of stable iodine, together with the imposition of restrictions on agricultural production and relocation of the affected population. In many cases the banning of foods would be an important countermeasure. This report is concerned with the underlying information that is required for calculating derived intervention levels (DILs) for foodstuffs.

The introduction of countermeasures affects the normal lives of the people concerned, and therefore undesirable social or economic consequences may follow. It is the task of the competent authorities to make decisions, taking into account the positive as well as the negative effects of planned countermeasures.

The International Commission on Radiological Protection (ICRP) has specified the most important criteria to be considered when planning an intervention as follows:

- Serious non-stochastic effects should be avoided.

- The risk of stochastic effects should be limited by introducing countermeasures which achieve a positive net benefit to the individuals involved.

- The overall incidence of stochastic effects should be limited by reducing the collective dose equivalent until the consequences of further reducing the health detriment in the affected population is balanced against the cost of further countermeasures.

The ICRP approach has been accepted, in general, by national and international authorities as the basis for emergency management and this has led to Derived Intervention Levels generally expressed in terms of projected individual effective dose equivalents. However, positive as well as negative consequences of countermeasures may change with local, seasonal and other conditions. Thus, the result of a cost-benefit analysis will depend on the specific situation. This inhibits the setting of one level dose at which a specific countermeasure has to be introduced. Therefore, ICRP and the Commission of European Communities (CEC) have proposed two dose levels for intervention, the Emergency Reference Levels. The lower value is the dose below which the countermeasure is not likely to be justifiable. "Derived intervention levels should be given as well, expressed in terms that are applicable to the results of the measurements that form part of a special monitoring programme" (IAEA 1982). In the case of contaminated food this might be radionuclide concentrations in food products. For practical reasons the CEC and other International Organizations, such as FAO or WHO, have taken the lower level as the basis for deriving levels for foodstuffs.

Prior to the Chernobyl accident, several international organizations defined emergency reference levels of dose (ERLs). However, no general guidance is available for setting derived intervention levels (DILs) for food. The problem was addressed by the Commission of the European Communities, through the Article 31 Group of Experts who proposed a methodology for determining derived intervention levels for different classes of foods.

The concept is described by the equation:

$$A = \frac{E}{V * D * f} \qquad \text{Eq. 1}$$

A Derived intervention level in Bq/kg (Bq/l);
E Intervention level of dose in Sv/a;
D Effective dose per unit ingested activity in Sv/Bq;
V Consumption rate of foodstuffs of concern in kg/a (l/a);
f Relative contamination factor, definition according to the Group of Experts: fractional contamination of a foodstuff in relation to the considered intervertion level; $0<f<=1$.

The need was recognised for a compilation of data that would allow more detailed calculations and an examination of the adequacy of the proposals of the Article 31 Group of Experts.

In 1987, the Commission of the European Communities set up a programme of work to consider underlying data for derived intervention levels. This report represents the results of this programme of work. The areas considered are data on radioecological models, distribution and consumption of foods, internal dosimetry, critical group considerations, emergency management, and the effects of countermeasures on doses.

11.2 FOOD CHAIN MODELLING

A number of dynamic models for the transfer of radioactivity through the terrestrial foodchain exist in the European Community (EC). One of the aims of this programme of work was to make recommendations on a general model suitable for use in the EC. This model could then be used to calculate derived intervention levels in the absence of site specific information. Two dynamic foodchain models, ECOSYS and FARMLAND formed the basis of this work. ECOSYS was developed at the Gesellschaft für Strahlen- und Umweltforschung (GSF) in the Federal Republic of Germany, and FARMLAND was developed at the National Radiological Protection Board (NRPB) in the United Kingdom.

11.2.1 Model Validation

Predictions of both ECOSYS and FARMLAND were compared with sets of environmental measurements to test the validity of the models in a variety of situations as a first step in recommending a general model.

Data sets for model validations were readily available for FRG and the UK, but no suitable data are available for the Mediterranean countries where the climate and agricultural practices are different than those in the UK and FRG. The majority of data available for the model validation studies were for the pasture-cow-milk pathway.

The model predictions of ECOSYS were compared with measured data in four areas: the interception of wet deposited activity; the pasture-cow-milk pathway; and the transfer of activity to meat and to grain.

The measured and predicted interception factors agreed with many measured results within 10 percent, with the largest differences being about a factor of two. The predictions of the transfer of cesium and iodine to milk were in generally good agreement, usually within a factor two of the measurements and often closer. Good agreement was also obtained comparing ECOSYS predictions against results from feeding experiments concerning the transfer of cesium from feed to beef. Concentrations of caesium-137 in the various types of grain were measured in the Munich area following the Chernobyl accident. Assuming an average deposition for the area, concentration in grain was predicted by ECOSYS. Given the large local variations in deposition, the predictions agreed well with the measured concentrations.

For validating the FARMLAND model, data sets were used for the pasture-cow-milk pathway, the activity in beef, the activity in sheep meat and the activity in grain. In comparing the FARMLAND predictions with measurements for the pasture-cow-milk pathway, the overall transfer was broken down into components.

In general, the predicted concentrations of I-131, Sr-90, and Cs-137 in grass agreed well with the measured concentrations, but in cases where the deposition occurred during heavy rainfall, large differences between measurements and predictions could be observed. In comparing the data on activity in sheep and beef the overall agreement was reasonable, taking into account the boundary conditions of the measurements. For grain, the predicted concentration fell within the range of measured concentrations for the various cereal types.

In summary, both ECOSYS and FARMLAND were in reasonable agreement with measurement data in a variety of situations. FARMLAND has been developed as a general model and default model parameters were used in the comparisions. This tended to lead to greater differences than found using ECOSYS, a more detailed model that takes into account more site specific factors, notably relating to deposition.

11.2.2 Comparison of Model Predictions of ECOSYS and FARMLAND

Following the validation exercise, the two models ECOSYS and FARMLAND were compared in a number of situations.

The submodels for the prediction of the deposition of radionuclides to plant and soil are rather different. FARMLAND does not differentiate between dry and wet deposition, and seasonal variation due to the development of the plant canopies are not taken into account. For both wet and dry deposition, a constant interception factor is applied. In contrast, in ECOSYS dry deposition is modelled taking into account the stage of development of plants which is characterized by the actual leaf area index at the time of deposition. For the estimation of interception of activity deposited in rainfall, an approach is used considering the stage of crop development, the water storage capacity of plant leaves, and a parameter describing the ability of the radionuclide to be fixed on the plant. These different approaches in modelling dry and wet deposition are an important reason for the differences found in the comparison of the two models.

The translocation of radionuclides from the foliage to the edible parts is modelled in a similar way in ECOSYS and FARMLAND. In this comparison only winter and spring wheat is considered, and for winter wheat, especially at the beginning of the growing period, translocation rates are assumed in FARMLAND which are much higher than those assumed in ECOSYS.

The approach for estimating the contamination of plants due to root uptake is similar in both models. There are some differences in the soil-plant transfer factors but they do not lead to substantial differences in predicted concentrations. The assumptions made about the soil mass and the leaching of radionuclides out of the root zone cause differences in the predicted activity concentrations which are of minor importance. There are some differences in the parameters modelling the transfer of radionuclides to animal food products. For strontium the differences are of little importance, and for caesium the transfer factors for beef and cow's milk are more than a factor of 2 different.

11.2.3 Choice of a Default Model for the Transfer of Radionuclides in the Foodchain

Based on the results of the model validation and the model comparison, a model with default parameters for translocation, root uptake, transfer to animals, and agricultural practice which can be applied to all regions of Europe when no country-specific parameters are available. Different fields of applications are suggested due to the varying complexities of modelling of deposition and interception. FARMLAND uses a generic approach, and is therefore suitable for use in accident assessment codes and for situations is justified where only limited information about the deposition and the contribution of dry and wet deposition is available. ECOSYS uses a complex approach that is more appropriate for application in real-time dose assessment systems, for specific sites in emergency situations when different weather conditions have to be considered, and when information about the deposition characteristics is available from monitoring networks.

Using the default model and parameters, activity concentrations as well as time-integrated activity concentrations are calculated for spring and winter grain, potatoes, leafy vegetables, root vegetables, milk, beef, lamb and pork after deposition on 1st January, 1st May and 1st July.

After deposition during the growing period, the biggest part of the integrated activity concentrations result from the contamination in the first year, which is due to the effectivness of the foliar uptake. Exceptions are the activities of Sr-90 in potatoes and root vegetables. In most cases the integrals are significantly higher (up to more than an order of magnitude) after depositions in May or July compared to deposition in January.

There are significant variations in farming practice and growing periods of crops within the countries of the EC. To evaluate these effects on the concentrations in foodstuffs, Europe has been divided into four regions according to climatic conditions and farming practice. Concentrations in food were calculated for each region using the "default" foodchain model with the appropriate farming practice for each region. Results were obtained for winter wheat, spring wheat, potatoes, leafy vegetables, milk, and beef and sheep meat.

11.3 FOOD CONSUMPTION HABITS

Food consumption in the different countries of the European Community and consumption of different subgroups of the population were investigated and compared with the assumption made by the Article 31 Group of Experts.

Firstly, information on average annual consumption of ten classes of food and drink was collected for the entire population of each EC country. All quantities were expressed as consumption of the raw, unprepared product. In general, collected data refer to 1986.

Subsequently, variations in food consumption between subgroups of the population were studied due to influence of age, sex, social class, season, level of urbanization, regional habits and level of self-support.

Three sources of data on food consumption were used. Food supply balance sheets were available for all countries and were used for the evaluation of national food consumption. These food balance sheets use statistical data on production, imports, exports and stock variations to establish amounts available for consumption of individual inhabitants of the country, averaged by age, sex, etc. The calculated individual amounts usually overestimate real consumption, because losses at the retail shop and in the household (due to decay, damage, waste and use of food for pets) are not taken into account.

Household budget surveys and food consumption research data, which are often thought to give a more reliable estimate of real consumption, were available in some cases and used to study food consumption of subgroups in the population.

11.3.1 Food Consumption of Separate Countries

The estimates of the average annual food consumption rates for individuals in all EC countries for 1986 are based on food balance sheets. For application of the data in calculations, the national diets were generalized by grouping countries with a rather homogeneous diet and three groups of countries were defined.

Group 1 consists of the UK and Ireland (19% of the total population of the EC). The diet is characterized by a low consumption of fruit and a high consumption of potatoes and fresh dairy products.

Group 2 consists of Italy and Greece (21% of the EC population). Consumption of cereals, vegetables and fruit is high, and consumption of fresh dairy products is low.

Group 3 consists of France, Belgium plus Luxembourg (BLEU), the FRG, the Netherlands and Spain and accounts for 56% of the total population of the EC. The group is less homogeneous than the first 2 groups and represents intermediate consumption of most foodstuffs.

Two countries (Portugal and Denmark) could not be classified with any of the three groups. Portugal has the lowest individual total consumption per year (80% of the average of the entire EC). Consumption of cereals, potatoes, vegetables and fish is high, consumption of fruit, milk plus milk products and meat is low. Danish people favor milk products, pork and fish, and consume few cereals, potatoes, vegetables and fruit. For the three groups of countries and for the entire EC ("average EC citizen") mean diets were calculated.

When comparing the consumption rates of the "average EC citizen" with the assumed mean adult food consumption adopted by the Article 31 Expert Group for deriving intervention levels, the data for cereals, dairy products and meat agree rather well.

For cereals, an average consumption rate of 100 kg/a is assumed by the Article 31 Expert Group, the estimated mean value is 84 kg/a with a range between 58 kg/a in the Netherlands and 115 kg/a for Italy. A similar range has been found for meat: 55 kg/a in Portugal and 106 kg/a in France. In this case the mean assumed and estimated mean values are identical: 80 kg/a.

A wider range has been estimated for milk products. People in Portugal have a very low consumption rate of 55 kg/a; whereas the Irish consume 206 kg/a. For the derivation of ERLs a mean EC-value of 120 kg/a has been assumed by the Article 31 Expert Group compared with 124 kg/a which has been estimated for the average EC-citizen.

Discrepancies can be observed for vegetables and fruit. The Article 31 Group assumes a total consumption of vegetables and fruit of 100 kg/a. This might be a suitable value for one of the food groups but not for both. The consumption of vegetables ranges between 71 kg/a in Denmark and 156 kg/a in Greece and Italy (mean in EC: 110 kg/a), and the consumption of fruits between 52 kg/a in the UK and 172 kg/a in Greece (mean in EC: 106 kg/a). The mean consumption rate of potatoes is 81 kg/a for the whole EC with a range from 35 kg/a (Italy) to 126 kg/a (Ireland). As the Article 31 Group did not consider potatoes in their derivation and their assumptions for fruits and vegetables are low, their figure for the total diet of 550 kg/a is 20% lower than actual values for the average EC-citizen.

11.3.2 Food Consumption of Subgroups of the Population

Regional differences and differences in age and in level of urbanisation appear to have the largest influence on food consumption. Total consumption increases regularly with age from 1-year-old infants to 18-year-olds, with only little changes in later years. Infants of 1-year-old consume about 50% of the total adult diet; for 5- and 10-year-old children this figure is 60 and 80%, respectively. The percentages apply to the total diet as well as to separate classes of food, except for consumption of milk and milk products which remain rather constant with age.

Within a country, regional consumption of a certain class of food may vary from 70 to 130% of the average national consumption. Consumption of potatoes and fruit may even be twice as high in a given region.

Consumption in rural and urban areas was compared with the entire country. In urban areas consumption varies from 70 to 100%, with a high consumption of fruit (up to 130%). In rural areas the values range from 100 to 140%, with fruit consumption being lower (80 to 110%).

Effects of the factors sex, social class and season are rather small.

The influence of sex on total food consumption and on consumption of separate foodstuffs increases with age, from no difference at the age of one, up to a difference of around 20% at the age of 10 and older. Females always consume less, except for fruit and vegetables.

The only differences in consumption during the four seasons were observed for vegetables and fruit. Consumption was smallest in those months when supply was low, which is often at the end of spring.

People with a low income have, for some foodstuffs, relative consumption which can be 10 to 50% lower or higher than consumption of people with a higher income. However, for most foodstuffs the differences are small.

Self-sufficiency and consequent possible increased consumption may cause relatively high doses in case of a local contamination.

Self-sufficiency in vegetables and drinking milk from the local farm is considerable for the BLEU, the FRG, France, Italy and Ireland. Greece has a significant level of self-sufficiency in wheat, and consumption of milk and cheese from local farms. Self-suffiency seems to be more important in the south of the EC.

Consumption by critical groups will not be dependent on separate factors but on combinations of factors. The uncertainty involved in quantifying effects of combinations of factors is large because the different factors are often correlated. Therefore, only the most important factors are considered, except for age, which should not be correlated with the other factors studied. When the influence of region and level of urbanisation are combined, the average amount of food consumed by a specific group may vary between 50% and 200% of the average amount consumed by the total population.

Investigations of consumption habits in critical groups in Southern Bavaria indicate a relatively small deviation from the EC-assumption.

11.4 DISTRIBUTION OF FOOD

The Article 31 Group of Experts introduced the relative contamination factor in establishing Derived Intervention Levels (DILs) for activity in foodstuffs (see eq. 1). The factor was assumed to be 0.1 and should be applied to the full value of the DIL. Scenarios for which the value of 0.1 is satisfactory are for instance: the annual intake of food is uncontaminated for 90% and for 10% only contaminated up to the DIL; or, the activity concentration does not surpass 10% of the DIL when averaged over the whole year. So the factor is partly determined by the radioactive decay of the nuclides present, and partly by the dilution of contamination due to the distribution of foodstuffs. Dilution can occur in two ways: export of contaminated food, and a decrease of local contamination by import of uncontaminated food from other regions or countries.

When calculating doses due to ingestion, it is generally assumed that consumed amounts are all produced locally. This hypothesis is valid for a limited number of people living in rural areas with low population density and a large production of foodstuffs. It is less valid for most of the people living in areas with high population density, where local production is insufficient and foodstuffs must be imported from other regions of the same country, from other EC countries, or even from non-EC countries. Therefore, distribution and local production need to be studied, areas of production and consumption have to be determined, and the dilution factors have to be estimated. Another reason for studying the transportation of foodstuffs is that the importance of exchanges within the Community and other countries needs to be known when authorities have to decide on a countermeasure which might temporarily limit or ban trade in certain foods.

The European Community has achieved a high level of self-sufficiency for the main foodstuffs with its policy for agriculture. In general, most countries overproduce many different products and they are self-supporting. A low percentage of imports come from countries outside the European Community.

Self-sufficiency is higher than 80% for all animal products (milk and milk products, butter and cheese, meat and eggs) in almost all countries. As a result, imports are low compared with production; in general less than 25%. More than 80% of imports by Community countries come from within the EC. There are a few countries which show large deficits for a given product: Italy for all dairy products, the United Kingdom for butter and cheese, Greece and Italy for meat, and the Federal Republic of Germany for eggs.

Self-sufficiency varies much more for the different plant food products. It rises to 90% for potatoes in all countries with the exception of Ireland (80% only). Moreover, 90% of the potatoes imported in each country come from within the EC. Viewing the EC as a whole, imports represent no more than 10% of production and more than 90% come from within the EC. But there are large discrepancies between countries: overproduction in the southern countries and the Netherlands with large deficiencies in Denmark, Ireland, the UK, and the FRG (more than 50% of the usable amount of fresh vegetables is imported in the FRG). For fruit there is a general deficit in the EC: imports represent one-third of the production and are equally supplied by non-EC countries and EC countries (Greece, Italy and Spain). Regarding wheat, importation rises to 20% of production. BLEU, Ireland, Italy, the Netherlands, and Portugal show severe deficiencies; 80% of these

requirements are provided for with wheat from EC countries, principally France and the UK.
The Netherlands has a very efficient agriculture system which makes it the largest exporter of potatoes, vegetables, all dairy products, and all kinds of meat and eggs. The other countries show a more complex situation: they are exporters for certain products and importers for others. For instance, all southern countries export vegetables and fruit but they lack meat or certain dairy products; France is the major exporter of wheat but lacks pork.

A general deficit of foodstuffs exists in all regions that are highly urbanized and industrialized. These regions correspond also to small areas without agriculture but with intense trade and distribution networks. For their imports, the preference that is commonly shown at the country level for EC products is generally less notable.

The analysis of regional exchange estimated from French data leads to some conclusions of general values about the loading practices. Fresh vegetables and fruit are transported twice on the average, at first from the region of production to the region with market installations, and then from the market to the region of consumption. The ratio of transported to produced amounts is 3:2 for raw milk. For other dairy products numerous loadings must be expected and the same holds true for meat. In contrast, grain is transported once from the grain elevator to the region of milling and transportation distances are short.

In summary, on average 84% of the resources are provided for by national production, 13% by production from other EC-countries, and only 3% coming from the non-EC-countries. On the basis of these average figures, imports of uncontaminated food from foreign countries are unlikely to decrease the contamination level of food by more than 20% when national production is contaminated. But, contamination will probably not be homogenous for large countries. The regional exchanges that always take place will have considerably more importance. Thus, high dilution factors can be reasonably expected for foodstuffs produced and consumed regionally; they will depend on regional self-sufficiency and they can be estimated by national authorities on a case-by-case basis. Such considerations for large regions do not hold for small areas that can be severely affected as they are in the near field of an installation where a large accident has occurred.

11.5 INTERNAL DOSIMETRY OF INGESTED RADIONUCLIDES

The International Commission on Radiological Protection recommended biokinetic parameters and dosimetric models for calculating radiation doses for occupationally exposed adults following intakes of radionuclides by inhalation and ingestion. These parameters are, however, not necessarily appropriate for calculating radiation doses to members of the public following the release of radionuclides into the environment. For the calculation of doses to members of the general public, it is necessary to take account of the effect of age on the biokinetics of radionuclides, as well as on anatomical and physiological parameters. Incorporation of radionuclides into foodstuffs may also result in changes in their absorption within the gastrointestinal tract. Information is also needed on the transfer of radionuclides to the developing embryo and fetus following intakes of radionuclides by the mother.

The radionuclides for which values of dose-per-unit intake given are: isotopes of strontium, ruthenium, iodine, cesium, plutonium and americium. In each case, the age groups included in the main calculations are 3-month-old infants, 1-, 5-, 10- and 15-year-old children and adults. Doses to the fetus are considered separately. Variability and uncertainty in the calculation of dose-per-unit intake are estimated for cesium, iodine-131 and plutonium-239. A summary of the general approach is given below followed by a brief discussion of biokinetic parameters and values of dose-per-unit intake for the individual radionuclides.

11.5.1 General Approach

The calculations of doses for adults are generally consistent with the approach taken by the ICRP to internal dosimetry. For children, doses are affected by the smaller body size and organ masses. In addition, for all but non-penetrating radiation, it is likely that the proportion of decay energy delivered to different tissues will change. These physical differences are taken into account using calculations based on a series of anthropomorphic phantoms.

Doses to the gastrointestinal tract from ingested radionuclides are calculated using the ICRP model for adults. There is insufficient information available to allow the use of age-specific residence times; it is considered that the use of adult values will tend to overestimate doses to children.

The values of gut absorption (f_1) recommended by the ICRP for the calculation of doses to workers apply in general to inorganic forms of the elements. The possibility that different values may be appropriate for absorption from food has, therefore, been considered. The absorption of radionuclides tends to be greater in the newborn, although the results of animal experiments suggest that the enhancement of gut transfer decreases progressively with increasing age, reaching adult values by about the time of weaning in most cases. Adult f_1 values are taken to apply to children of one-year of age and older. For infants in the first year of life, a Nuclear Energy Agency (NEA) Expert Group has recently recommended a general approach which is consistent with the available animal and human data and is adopted in this report. For f_1 values between 0.01 and 0.5 in the adult, an increase by a factor of two is assumed, but for the elements with f_1 values of 0.001 or less, a value 10 times the adult value is assumed.

After absorption from the gastrointestinal tract to body fluids, the distribution and retention of radionuclides depends on the element concerned. The turnover of radionuclides in children may be more rapid than in adults and this needs to be taken into account. In the case of bone-seeking elements, plutonium and americium, which deposit on bone surfaces, age-dependent models have been developed. These take into account bone recycling which leads to the gradual burial of surface deposits, release of activity from bone, and some transfer to bone marrow. Similarly, bone turnover has been taken into account in a biokinetic model for strontium which deposits throughout the bone volume. These models are used in this report in place of the ICRP model which assumes that the initial deposition pattern remains unchanged.

The possibility of intake of radionuclides by pregnant women requires estimates be made of doses to the developing fetus. This is complicated by the rapid growth and differentiation of the fetus such that the consequences of an intake are likely to depend on the period of gestation during which the intake occurs. Although it is necessary for many radionuclides to rely on animal data concerning placental transfer, differences in placental structure indicate that care is needed in extrapolating results to man. Preliminary dose estimates are given in this report for chronic maternal intake throughout the year including pregnancy.

11.5.2 Strontium

The ICRP f_1 value of 0.3 has recently been endorsed by an expert group for use in calculating doses to members of the public including children from one-year of age. A f_1 value of 0.6, twice the adult value, was also recommended for children in the first year of life, following the approach explained above. These values are adopted in this report. For strontium absorbed in body fluids, the age-dependent model for skeletal uptake and retention development by Leggett has been adopted. The committed effective dose equivalent (CEDE) is dominated by the contributions from the dose equivalents to bone surfaces and red bone marrow. Dose-per-unit intake is greatest for 3-month-old infants and 1-year-old children because of their lower skeletal mass and high strontium-90 uptake during rapid bone growth. Dose per unit intake is lower in older children and adults but a peak value at 15 years of age corresponds to a renewal of rapid bone growth during adolescence.

Estimates of doses to the fetus from strontium-90 have been made by assuming that strontium uptake by the fetus will be related to that of calcium, but that a placental discrimination factor will apply. For chronic ingestion of strontium-90 by the mother for the year including pregnancy, and taking into account the activity present in the child at birth, the total committed effective dose equivalent is similar to that of the mother. The in-utero dose contributes half of the total CEDE.

11.5.3 Ruthenium

An f_1 value of 0.05, as recommended by ICRP (1979) and the NEA (1988), is considered appropriate for ruthenium incorporated in food and drinking water by adults and children from one year of age. For infants in the first year of life, the NEA (1988) value of 0.1 has been adopted. For ruthenium absorbed into body fluids, animal data have shown that the subsequent tissue distribution is fairly uniform. Biological half-times have been derived from these data for adult animals; no information is available on the retention of ruthenium as a function of age. In the absence of information on the effect of age on tissue distribution and retention, the greater values of dose-per-unit intake for younger children is due solely to their lower body mass. The values of dose-per-unit intake for 3-month-old infants also takes into account the increased gut transfer. However, the increase in f_1 from 0.05 to 0.1 results in only a small increase in dose-per-unit intake because 70 - 80% of the CEDE, in each case, is due to doses from unabsorbed Ru-103 and Ru-106 in the large intestine.

Doses to the fetus have been calculated for chronic maternal intake of Ru-103 and Ru-106 during the year including pregnancy. For Ru-106, the CEDE to the child is about 70 times less than the maternal CEDE. This estimate includes both in-utero irradiation, based on a placental discrimination factor of 0.1, applying throughout gestation, and the dose from activity present at birth. For Ru-103, because of its penetrating photon emissions, fetal irradiation is very largely from activity in the maternal tissues, and the discrimination factor does not apply. On this basis, the estimated dose to the child is similar to the maternal dose.

11.5.4 Iodine

Iodine absorption from the gastrointestinal tract is rapid and virtually complete. An f_1 of 1.0 is applied to intakes of the iodine in food and water at all ages. The biokinetic model for the uptake of iodine by the thyroid and its subsequent distribution and retention, is that adopted by the ICRP (1979). Information on age-related changes in the retention of radioiodine in the thyroid is taken into account. Although the data are available, they indicate that the turnover of iodine decreases with increasing age. Shorter biological half-times have therefore been adopted for children and infants. The dose is delivered very largely to the thyroid with much lower doses to other tissues. For the long-lived isotope, iodine-129 (half-life of 1.6 E7 years), the reduction in dose at younger ages due to shorter biological half-times counteracts the effect of smaller thyroid mass which leads to similar values of dose-per-unit intake for 3-month-old infants and 1-, 5- and 10-year-old children, with slightly lower values for 15-year-old children and adults. For iodine-131, because of its shorter half-life (8 days), the effect of changes in retention times is reduced and the dominant factor determining the age-dependence of dose-per-unit intake is thyroid mass. Values of dose-per-unit intake therefore show a progressive increase with decreasing age, with about an order of magnitude difference between adults and 3-month-old infants. Similarly, for iodine-132 (half-life of 2.4 hours) the effect of thyroid mass result in one order of magnitude greater values of dose-per-unit intake in infants than in adults.

Estimates have been made of fetal doses after chronic maternal intake of iodine isotopes throughout the year including pregnancy. The assumption that the concentration of radioiodine in the fetal thyroid will be twice that of the maternal thyroid from the 11th to 38th week of gestation, results in fetal doses very similar to annual maternal doses.

11.5.5 Caesium

Soluble forms of caesium are virtually completely absorbed from the gastrointestinal tract. There is some evidence from human studies that absorption from food may not always be complete, but an f_1 value of 1 is applied here to all ages. Caesium is distributed uniformly throughout body tissues. The biological half-times recommended by the ICRP (1979) for adults have been adopted. There is good evidence that the rates of loss of caesium from the body is greater in children than adults, and shorter biological half-times have therefore been used for children (Leggett, 1986) and infants. In general, the shorter biological half-times at younger ages counteract the effect of lower body mass, resulting in values of dose per unit intake that are largely independent of age; the maximum difference is about a factor of two.

Doses to the fetus have been calculated for chronic maternal intakes of Cs-134 and Cs-137 throughout the year, including pregnancy. In-utero doses are taken to be the same as the greatest doses to maternal tissues during the 38 weeks of pregnancy. The overall dose estimates for the child are very similar to maternal doses from the year's intake.

11.5.6 Plutonium and Americium

ICRP recently revised its biokinetic models for plutonium and related elements (ICRP, 1986). On the basis of an extensive view of animal data on gut transfer, together with limited human data, an f_1 of 0.001 was recommended as a cautious value to apply to intakes in food. For infants in the first year of life, a value of 0.01 was recommended. These values have been used in this report. For plutonium and americium absorbed to body fluids, the main sites of deposition are the liver and skeleton. The ICRP biokinetic model, which specifies the initial distribution between organs and biological half-times, takes no account of bone remodelling as discussed above. Leggett and his colleagues have developed models which take into account bone turnover (Leggett and Eckerman, 1984, Leggett and Warren, 1987). The models also apply to children, taking into account greater initial deposition on bone surfaces and greater bone turnover. These have been used in this report and compared with ICRP assumptions. In each case, the CEDE is due largely to doses received by bone surfaces, red bone marrow, liver and gonads. The use of the Leggett models, in comparison with ICRP parameters, has little effect on dose-per-unit intake for adults; the greatest effect is for infants with a maximum reduction in a dose of about a factor to two for Am-241. The dose-per-unit intake values for infants take account of greater gut transfer of 0.01 compared with 0.001 for children of one year of age and older. This results in a proportional increase in the doses to the skeleton, liver and gonads.

Doses to the fetus have been calculated for chronic maternal intakes of Am-241 and isotopes of plutonium. Estimating fetal doses on the basis of a placental discrimination factor of 0.1 between the 8th and 38th week of gestation, and taking into account activity in the child at birth, the CEDE to the child is about two orders of magnitude less than the maternal CEDE.

11.6 ESTIMATES OF INDIVIDUAL DOSES IN EC-COUNTRIES DUE TO INGESTION OF CONTAMINATED FOOD

The default foodchain model was used to calculate concentrations in leafy vegetables, grain, potatoes, other root vegetables, fruit, milk, beef and sheep meat. The default parameter values and agricultural practices were used in these calculations.

A number of different sets of individual doses have been calculated. For most of these the "default" chain model and agricultural practice were used to estimate the concentrations in food. However, the effect of using food concentrations estimated assuming appropriate agricultural practices for each country is also considered. Adult average individual doses were calculated for a number of sets of the dietary intakes. The diets considered are those appropriate for each country individually, then those for groups of countries in the EC, and finally for an "EC" diet, weighted according to the population in each country. The variation of individual doses with age is estimated by calculating average individual doses for 5- to 10-year-old children based on the "EC" weighted dietary intake. For these calculations the dose-per-unit intake data for children and adults discussed previously were used.

In these calculations account was taken of the loss of activity due to waste, as well as losses during processing and culinary preparation, but no account was taken of delays between production and consumption.

From the estimates of individual doses presented it is possible to make a number of general points. The differences in doses following deposition at different times of the year are quite marked. These seasonal differences are seen both for the total ingestion doses and also in those foods which contribute most to the total dose.

The foods that contribute most to individual doses for deposition at a particular time of year depends, to some extent, on the mix of radionuclides considered. For deposition of strontium-90, iodine-131 and cesium-137 in January, the intake of fruit and green vegetables dominated the resulting ingestion doses. For deposition in May the important foods are different for the three radionuclides considered. For strontium-90 potatoes, green vegetables, milk and cheese are important, for cesium-137 it is cereals, milk and meat that are important, while for iodine-131 the important foods tend to be potatoes, vegetables, fruit and milk. For deposition on 1st July the important foods are again different. Cereals but not potatoes are now important for strontium-90, while potatoes are no longer important for iodine-131. Different foods contribute most to the dose in the different countries in the EC depending on the consumption pattern. For countries with a higher consumption of sheep and/or goat meat (Greece, Ireland and the UK) this food becomes important, contributing 10 to 15% of the dose for a deposition in May. In many cases consumption of pork has been found to be an important contributor to dose, notably for deposition in July. However, this finding should be treated with caution as it has been assumed that the diet of pigs comprises 100% contaminated winter grain. Pigs are often given a variety of different feedstuffs, some of which are imported from some distance, and so would not necessarily be contaminated following an accident. The doses from ingestion of pork may therefore have been overestimated. The relative importance of intake of fruit should also be treated with caution. The intake of fruit includes a large component due to the consumption of fruit juices, and in many countries these are imported from outside the EC. The intake of offalls was not included in the dose assessment but additional calculations have shown that their inclusion would increase the doses by only a few percent.

Calculations are also made of the ingestion doses for 5- to 10-year-old children and the results compared with those of adults. The differences with age were found to be small. For deposition of iodine-131 alone the doses calculated for 5-year-old children were about a factor of three higher than for adults. However, for deposition of strontium-90 or caesium-137, doses to adults were calculated to be higher than those for children.

The effect of using an appropriate regional agricultural practice in calculating ingestion doses, compared with a "default" European practice, has also been investigated. The effects are genarally small and indicate that for many situations assuming a default agricultural practice is adequate. However, for the Mediterranean countries (South France, Italy, Greece, South Spain and South Portugal) differences up to a factor of four are estimated for deposition in July. In this case regional agricultural practices should be taken into account. The same foodchain model parameters have been used for all regions; using more site specific parameter values could have an effect on the result presented here.

11.7 CHARACTERIZATION OF CRITICAL POPULATION GROUPS

The model parameters that characterize the pattern of food supply assume consumption habits which are representative for the whole Community and do not consider special situations, such as individual consumption patterns or a regionally bound high level of self-sufficiency in an above-average contaminated area. As it is not known to what degree the range of consumption habits is covered by the model data, a survey has been carried out to investigate the food consumption of critical groups.

The study was conducted in a region bordering the Alps in Southeast Bavaria, where the highest deposition of radiocaesium (>42000 Bq/m^2 Cs-137) from the Chernobyl accident occurred within the Federal Republic of Germany. There, the origin, type and amount of dose-relevant and season-dependent food items were determined in self-sufficient groups, including hunters and mushroom-pickers, and compared with those who were not self-sufficient and chosen as reference group. To examine the influence of consumption habits on the internal dose by ingestion, simultaneous whole-body-counting measurements were conducted in time intervals of 1.5 - 2 months and the contamination of critical foodstuffs with radiocesium was measured by random criterion.

11.7.1 Consumption Habits

Depending on the season and the population group, the milk consumption deviates from German consumption statistics by a factor 0.5 - 2.2. In agreement with observations during recent years, including 1989, the highest milk consumption was observed among those who were self-sufficient. Among the dose-relevant products, raw milk was the most critical food during the first 1-2 years after the nuclear accident of Chernobyl, because raw milk is consumed regularly in large amounts without a radiological control.

For all groups, more fresh vegetables were consumed than could be expected according to national statistical data. The daily consumption rates exceeded the average German and EC-value by a factor 1.8 and 1.2, respectively. The hunters consumed twice the amount of fresh meat indicated by German statistical budget surveys, due to a larger supply of locally produced pork, sheep, and locally killed game. The average German consumption rate of only 1 kg/a for game is a small dietary component, but for hunters it ranks as a major foodstuff because its consumption of 15 - 22 kg/a is comparable with the statistical values for the consumption of beef and pork and other meat. For mushroom-pickers the consumption rate of mushrooms falls in the range of major foodstuffs: the consumption rate in autumn and spring is about 60% of that in summer and is in total equivalent to about 15 kg/a. During the one-year-period of analysis and according to the type of population, the following food classes are underestimated by the European Statistical EC data: vegetables and fruit in each examined population group, milk products in the group of self-supporters, as well as fresh meat in the group of hunters. With the exception of vegetables, the population-specific differences are balanced out when the group-specific consumption rates are averaged over the total population groups and the whole period of investigations. Additionally, the regional data on food items are in the same range as the values for the analogue food classes consumed in the 3 main groups of the EC countries.

11.7.2 Origin of Food

For self-sufficient groups the fraction of raw milk and milk products produced regionally is 100% and 75%, respectively. The local production of vegetables contributes in spring and summer as much as 60% to the needs of the population groups. Also 20-40% of meat (pork, lamb, mutton, beef, veal) are obtained from the region. Data on maximum amounts of regional foodstuffs consumed are computed for milk and milk products for self-sufficient groups, followed to a lesser extent by game for the group of hunters. This means that the dilution of activity by distribution of the foodstuffs is relatively small for a part of the population in rural areas, as consumption of local products, especially milk, is preferred.

According to the present study, self-supporting groups obtain about 75% of the relevant foodstuffs from the region, while non-self-supporting groups obtain only about 35%.

11.7.3 Dose to Man

In the first year after Chernobyl the mean internal dose was 570 μSv to non-self-supporting groups in Southeast Bavaria. The main contribution to the dose results from the consumption of locally produced milk. During the following years the individual doses declined in parallel with the decrease in the contamination of the major foodstuffs, to 10 μSv for self-supporting groups and 6 μSv for non-self-supporting groups in 1989. Due to the reduction of radiocesium activity in major foodstuffs, the relative importance for the dose to man from activity in wild mushrooms and game increased from 1986 to 1989.

In 1988 the dose to game hunters, mushroom eaters and self-supporters was about the same, but in 1989 game hunters were the most critical group followed by mushroom eaters. This is due to reduced consumption of contaminated mushrooms. The mushroom eaters reacted to the results from the first whole-body-measurements with special caution by selecting less contaminated wild-mushrooms for meals and by avoiding highly contaminated species, such as Boletus badius. Dietary duplicates of mixed mushrooms (Boletus edulis, chanterelle, russula, model) were contaminated up to the same level as game in the range of 200 - 500 Bq/kg.

The results indicate that in any emergency situation, as a first approximation self-supporters should be classified as the most critical population group in the first instance. The self-supporters were selected in the vicinity of conveniently-situated medium-sized towns and often have their working place in the urban environment. In view of this it is unlikely that these persons represent a minority in at least some countries. Rather they constitute an important section of the population that should be quantified and considered in the introduction of protective measures to avoid supply problems.

11.8 EMERGENCY MANAGEMENT

After radioactive contamination of the environment a considerable reduction in the exposure of the public may be achieved by temporary countermeasures introduced by national public health authorities.

Besides dose reduction, countermeasures always lead to intervention in the normal daily practice and, therefore, undesirable social or economical consequences are involved. It is the task of the competent authorities to make decisions taking into account the positive as well as the negative effects of planned countermeasures. An outcome of the research is a methodology to derive intervention levels for food and a set of realistic countermeasures to be considered when intervention is needed.

11.8.1 Methodology Aspects

ICRP and IAEA have based their derived intervention levels for food on the basis of two intervention levels of dose and on the ALARA (As Low As Reasonably Achievable) principle. Above the upper dose level, a countermeasure aiming at a reduction of dose in nearly all cases is necessary, whereas below the lower dose level, the countermeasure is not justified. Between both levels, advantages and disadvantages of a countermeasure have to be balanced in order to justify its implementation.

The methodology was elaborated on the basis of dosimetric considerations as described above, and of an economic approach based on the ALARA principle.

11.8.2 Possible Countermeasures

In order to make decisions on countermeasures, a detailed survey has to be available on costs, effectiveness and feasibility aspects related to implementation of the various countermeasures.

The Chernobyl accident showed that such a detailed survey was lacking. During the subsequent years, information has become available that should be added to the present knowledge. In this report an overview is presented of effects related to the implementation of the most important countermeasures.

Countermeasures may be classified as preventive or curative. Preventive countermeasures in food production will be implemented primarily in the agricultural environment. Examples are fertilisation, deep ploughing and liming of the soil. Curative countermeasures may be taken during food processing, storage or food trade.

11.8.3 Preventive Countermeasures

It is generally agreed that preventive countermeasures on radioactive contamination of food should be preferred because they cause less disturbance in the chain of production, preparation, distribution and consumption of food. However, food contamination interventions associated with actions such as liming, ploughing or fertilisation are often not effective or reliable. Other possible curative countermeasures such as removal of the top soil layer or stabilisation by a foam may be more efficient, but these countermeasures are impractical for large contamination areas due to the amounts of waste and costs involved. In certain cases one might change to crops with a lower or no transfer of radionuclides to the human diet, such as grain, oils, sugar or cotton. One has also to consider that implementation of preventive countermeasures will change food contamination, not immediately, but after a period of several weeks or months.

A very effective and simple countermeasure to reduce the contamination of animals is the feeding of uncontaminated feeding stuff. Contamination of animal products can often be reduced by about 2 orders of magnitude. Nowadays, a change towards qualitative better fodder just before slaughtering is indeed common practice in intensive cattle breeding. A change towards less contaminated feeding stuff has been implemented after the Chernobyl accident, but even such a simple measure could severely disturb farming planning and economy. Furthermore, availability of uncontaminated feeding stuff could be limited.

Quite a number of additives have been examined to determine their capacity to reduce uptake or to increase excretion of radionuclides. The use of prussian blue could reduce the cesium contamination of animals by about a of factor 10. Alginates may reduce the uptake of strontium by about a factor of 4 without negative side effects.

11.8.4 Curative Countermeasures

The experience after the Chernobyl accident revealed a need for curative countermeasures other than destruction alone.

In the case of contamination with short-lived radionuclides, storage may be a simple, cheap and very effective intervention. After transformation into products with better storage possibilities, such as canning or the production of cheese, the maximum storage time, which will not negatively affect food quality, will be about 2 years. By this countermeasure, contamination by all radionuclides with half-lives of 50 days or less will be decreased by three orders of magnitude or more. One has, however, to consider the capacities for storage and processing in the period after the accident.

Doses due to ingestion of radionuclides may be reduced by changes in food processing, by optimised decontamination procedures, or by differentiation in processing and final destination of foods according to their contamination level.

During the production of cheese about 80% of the radionuclides are concentrated in whey. Stimulation of the production of cheese could be accompanied by a higher production of butter and cream, which are also less contaminated. Decontamination of milk could, in certain accidental situations, decrease levels of radioactivity by one or even two orders of magnitude. Techniques based on the use of ion-exchange resins were well developed in the sixties and a new technique based on complexation by hexacyanoferrate was used after Chernobyl. However, the possibilities for the implemention of such a technique are limited due to the large quantities of fresh milk produced daily which have to be processed within a short time, and the large amount of capital which is necessary for construction and maintenance of the decontamination capacities.

For meat, certain ways of pickling or marinating may result in contamination levels of Cs which are about an order of magnitude lower while the taste remains good. For other types of food normal ways of processing often lead to a removal of 20 to 60% of the radionuclides present in it, but attempts to decontaminate food further rendered, in general, only poor decontamination results combined with negative effects on taste, appearance, and nutritional value of the food.

Distribution and mixing of food, although cheap and feasible, does not affect collective doses and are, therefore, not considered in this report. However, social and economic consequences of non-intervention might, in certain cases, favour mixing of food with different contamination levels.

Use of contaminated food as feed for animals may be an alternative to destruction. Compared to destruction the economic loss will be smaller. However, use of contaminated feed for livestock will result in contaminated animal products like meat and milk which may cause a considerable distrust amongst farmers and population, and may even affect food trade. The contamination of animal products can, as discussed before, be reduced by a period of feeding with uncontaminated fodder before slaughtering, and the contamination of animal products will be considerably lower than the corresponding contamination of the feeding stuff.

Contaminated food may be used as raw material for industrial processes, such as production of distilled beverages, starch, gluten, glucose or cardboard. If the final product is not food, a nearly complete dose reduction will be accomplished. Possibilities to use contaminated food for non-food products are, however, limited.

In general, dose reductions obtained by destruction of food will be nearly complete. Destruction as radioactive waste is by far the most expensive, at least 0.47 ECU per liter. Normal refuse destruction costs only about 0.026 ECU/kg. Also, the destruction capacity for radioactive waste is limited. Nevertheless, if a small area is extremely contaminated, destruction of its production as radioactive waste might be the best countermeasure. In general, destruction on the field could be easier to implement than destruction of large food stocks. However, ecological effects and consequences for future crops must be well known before food can be destructed on the field. Contamination of future crops will be orders of magnitude lower than contamination of the first crop as soil uptake is a less effective contamination pathway when compared to direct deposition on the foliage.

11.8.5 Selection of Countermeasures

For most countermeasures, cost, effectiveness and feasibility will change with the type of food and the accidental situation. A selection of relevant countermeasures has thus to be made for each type of food separately and it has to be executed for each emergency situation again.

However, several situations are valid for a wide variety of accidental situations and food products, and may facilitate an eventual selection of countermeasures in the future.

Important factors influencing a decision are the half-life of the radionuclides involved, the contamination level of the food product and the fraction of the food production involved.

The first criterion for a countermeasure to be selected is, of course, its capacity to reduce food contamination below the reference level. In general, destruction of overproduction may be a common "cheap" countermeasure. For short-lived radionuclides storage is a good alternative for destruction, whereas for long-lived radionuclides, food processing or decontamination may be important to save food when the contamination level is no more than about 5 times the intervention level. If the contamination level is high, withdrawal from normal food trade is practically the only way to intervene. In this case, destruction and use as animal fodder are the most relevant intervention modes.

Often it will not be possible to select just one countermeasure for a large amount of contaminated food. The contamination level will not be constant over the entire amount of food, and capacities for storage, destruction, processing, etc., have to be taken into account. An intervention aiming at a minimum of disruption and costs involved may take into account a number of countermeasures, specific for the typical situation in the affected areas.

11.9 EFFECTS OF COUNTERMEASURES ON INGESTION DOSE

The food chain model ECOSYS has been used to estimate the effectiveness of some selected countermeasures, especially of food bans, the application of derived intervention levels, and measures concerning the feed management.

After nuclear accidents during the vegetation period, food bans can reduce ingestion doses significantly. The activity concentrations in many foodstuffs have a pronounced peak in the harvest following the accident due to the effective uptake of radionuclides via the foliage. Food bans can reduce the potential intake of short-lived radionuclides more effectively than of long-lived radionuclides. For short-lived nuclides, the intake with milk and leafy vegetables dominates, therefore temporary bans of these foodstuffs affects the total intake significantly. For long-lived radionuclides a greater part of the intake is due to the contamination of cereals, fruit, meat, etc., which can be influenced by temporary food bans only to a relatively small extent.

Bans on milk and leafy vegetables are more effective the earlier the bans start after the deposition, due to the short delay between production and consumption. A fast response after a nuclear accident requires well equipped facilities for the detection of increased levels of artificial radioactivity in air and rain.

The reducing effect of the application of derived intervention levels on dose reduction is dependent on the total activity, as well as on the deposition pattern (contribution of dry and wet deposition), and on the season. In so far as the spatial distribution of the deposition is not homogeneous over very large areas, and the population does not eat exclusively locally produced food, the application of derived intervention levels can probably ensure that an ingestion dose of 5 mSv in the first year is not exceeded. In reality foodstuffs above the intervention level would not come on to the market, and for the food consumed, the intervention level would be the upper limit of the activity concentration in foodstuffs.

Countermeasures concerning the feed management such as application of additives, change of feeding diets are appropriate to reduce the activity concentration in foodstuffs considerably, or to reduce the potential dose due to highly contaminated foodstuffs. On the other hand, all these countermeasures presume the collaboration of the farmers and the acceptance of the countermeasure by the farmers and consumers (e.g., application of prussian blue compounds). Another important presumption is the existence of a well-organized feed management which is able to realize the recommendations of the authorities on the farms.

In real accidental situations, a situation-specific combination of countermeasures should be the most effective way for a minimization of the ingestion dose.

11.10 CONCLUSIONS

When comparing the diet of the "average EC citizen" with the values on food consumption adopted by the Article 31 Group of Experts for the derivation of intervention levels, there is good agreement for dairy products and for meat. The value of the Article 31 Group adopted for fruit and surface vegetables is about one-third lower than the value of the "average EC citizen", whereas the value for cereals is about 25% higher.

The influence of several factors on food consumption have been considered. Differences in age, in region, and in level of urbanisation seem to have the largest effects. Effects of gender, social class and season are rather small.

Within one country, regional consumption of certain foods may vary by 30% from the average national consumption. Consumption of potatoes and fruit may even be twice as high in a given region. Consumption in rural and urban areas, when compared with that of the entire country, varies from 20 to 50%, and are higher in rural areas for most products.

Self-sufficiency influences the amounts consumed by individuals which are increased in general for population groups. Self-sufficiency seems to be more important in the south of the European Community than in the north; it may play a very important role in case of local contamination in rural areas.

Distribution of foodstuffs is recognized as of major importance for two reasons. Firstly, exporting contaminated food and importing uncontaminated food from other regions or countries will decrease local contamination. Secondly, authorities need to know the importance of exchange within the Community and with other countries in the event of deciding countermeasures which might temporarily limit or ban the trade of foodstuffs.

However, the importance of exchanges between EC countries should not be overestimated. Indeed, in each EC country a high level of food products has been achieved for the main foodstuffs, and in general most countries face overproduction. However, a general deficit of foodstuffs exists in all regions that are highly urbanized and industrialized. This also applied to small areas without agricultural vocation but with intense trade and distribution networks; and for their imports, the preference that is commonly given to EC products is generally less pronounced.

A case study was initiated after the Chernobyl accident which concerns critical groups such as self-supporters, game-hunters and mushroom-eaters. According to the study, 75% of the food consumed by the self-supporting groups comes from the region, whereas only 35% of the food for the non-self-supporters was produced locally.

Models to predict the transfer of radionuclides through terrestrial foodchains have a number of uses in the context of Derived Intervention Levels. These uses are both in deriving the levels and in applying them in the event of an actual accident. For example, results of foodchain models can be used to investigate the extent to which food countermeasures would be required in particular circumstances. They can also be used in the period following an accident before measurements are available, and to determine how long any countermeasure might be retained.

A default model has been suggested for use in the EC in the absence of site specific information. It is based on the models FARMLAND and ECOSYS. In any applications of the default model the variability in the results should be borne in mind. Variations in the predicted concentrations in food in different meteorological conditions are particularly important. The variations due to release at different times of the year and due to different agricultural practices are also significant. In addition, the uncertainty in the foodchain model results, due to lack of knowledge of the parameter values, should be recognised.

For most accident analyses, when full details of the meteorological conditions and other site specific data are available, a more detailed foodchain model such as ECOSYS is more appropriate. A model such as ECOSYS is also better if a knowledge of the likely range of possible food concentrations following a given accidental release is required, for example for emergency planning.

Illustrative calculations of individual doses from ingestion were intended to show the possible variation of individual doses between EC countries and to show which foods contribute to the doses following an accidental release at different times of the year.

The most significant difference in doses seen is that due to accidental releases occuring at different times of the year. These seasonal differences are observed both for the total dose and also in which foods contribute most to the total dose. Significant differences were found in foods that contribute most to doses in the different countries of the EC depending on the consumption pattern. Calculations were also made of the ingestion doses for 5- to 10-year-old children and the results compared with those for adults. The differences with age were found to be small.

Furthermore, it can be concluded that in most circumstances it is adequate to use dietary intakes that are representative of the EC as a whole in estimating doses. Also, in general it is not necessary to take into account regional agricultural practices in estimating doses. An important exception appears to be the Mediterranean countries and additional work is required to better characterise the food intakes, agricultural practices and foodchain transfers in the region.

In estimating doses from the ingestion of radionuclides by the general population, values of dose-per-unit intake have been calculated for 3-month-old infants, for 1-, 5-, 10- and 15-year-old children and for adults. The radionuclides considered were isotopes of strontium, ruthenium, iodine, cesium, plutonium and americium and, for each element, using approaches that are consistent with those of an ICRP Task Group on age-dependent dosimetry. The corresponding dose per unit intakes were calculated. Intakes of radionuclides by pregnant women and doses to the fetus have also been evaluated.

Although single values have been given for dose-per-unit intake for a particular radionuclide and age-group, it is further necessary to consider the variation between individuals and uncertainties in these estimates. These parameters have been quantified in this report for the examples of cesium isotopes, iodine-131, and plutonium-239.

Finally, a possible methodology to derive intervention levels for foodstuffs was developed. The methodology is based on general radiation protection concepts and on the ALARA (As Low As Reasonably Achievable) principle.

Information was provided on the effectiveness, costs and feasibility of a wide variety of countermeasures which may be considered when the contamination of food may exceed intervention levels.

The dosimetric effectiveness of a food ban, which is the most common decision, has been estimated by using the dynamic radioecological model ECOSYS. After accidental releases during the vegetation period, food bans can reduce ingestion doses significantly. They are more effective for short-lived than for long-lived radionuclides, and the shorter the time between the deposition and the start of the ban, the better the effectiveness is of the ban. This requires well equipped facilities for the detection of increased levels of artificial radionuclides in air and rain.

Using ECOSYS, the reduction of dose following the application of the DILs was assessed. The reduction is dependent on the total activity deposition as well as on the deposition pattern (contribution of dry and wet deposition) and on the season. In so far as the spatial distribution of the deposition, it is not homogeneous over large areas and people do not eat exclusively food that is produced locally. The application of DILs can probably ensure that an ingestion dose of 5 mSv in the first year is not exceeded.

In the case of a contamination with short-lived radionuclides, storage is very effective. In case of a contamination with long-lived radionuclides which is more than a factor 10 higher than intervention levels, destruction of food is the most effective intervention, although in certain cases (milk) decontamination procedures may be used. At lower contamination levels, it may be a good alternative to use contaminated food as fodder for animals. Indeed countermeasures concerning the feed management, such as application of additives, delay of slaughtering, and changes of feeding diets, are appropriate for the reduction of the activity concentrations in foodstuffs or of the potential dose due to highly contaminated foodstuffs. Also, when the contamination level is below 3 to 5 times the intervention level, food processing may result in a sufficient reduction of the activity.

In real accidental situations, one may expect that a situation specific combination of countermeasures should be the most effective way to minimize the ingestion dose.

Besides technical or economic considerations, experience shows that the feasibility of intervention depends on other aspects. Reactions of the public may have a large impact on food economy. Important trade disruptions may already occur in situations where intervention is still far from being considered. Public discussions about ethical question may also arise in accidental situations.

To conclude, the transfer of radionuclides in several parts of the human foodchain is very dependent upon the conditions of food production. Knowledge of the effects of possible countermeasures with regard to doses, and their economic and social consequences, should be available for decision-makers in an integrated, updated and readily interpretable way. This requires continuous attention by the responsible authorities and scientists.

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EUR 12553 — Underlying data for derived emergency reference levels
Post-Chernobyl action

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After an accidental release of radioactive material to the atmosphere leading to significant off-site contamination, various countermeasures are needed to reduce the radiation exposure of the population. These may include measures to reduce the consumption of contaminated foodstuffs. This report is concerned with the underlying information required for calculating when and if such countermeasures as regards foodstuffs should be introduced. The work in this report was sponsored by the Commission of the European Communities as one of a series of post-Chernobyl actions under its radiation protection programme.

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