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Probabilistic Accident Consequence Uncertainty Analysis

Food Chain Uncertainty Assessment

Appendices

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Abstract

The development of two new probabilistic accident consequence codes, MACCS and COSYMA, was completed in 1990. These codes estimate the risks presented by nuclear installations based on postulated frequencies and magnitudes of potential accidents. In 1991, the US Nuclear Regulatory Commission (NRC) and the European Commission (EC) began a joint uncertainty analysis of the two codes. The ultimate objective was to develop credible and traceable uncertainty distributions for the input variables of the codes.

The study was formulated jointly and was limited to the current code models and to physical quantities that could be measured in experiments. An elicitation procedure was devised from previous US and EC studies with refinements based on recent experience. Elicitation questions were developed, tested, and clarified. Internationally recognized experts were selected using a common set of criteria. Probability training exercises were conducted to establish ground rules and set the initial and boundary conditions. Experts developed their distributions independently.

After the first feasibility study on atmospheric dispersion and deposition parameters, a second expert judgment exercise was carried out on food chain parameters. This report refers only to the food chain part of the study. The work relating to external doses is described in a companion report. The goal again was to develop a library of uncertainty distributions for the selected consequence parameters. Sixteen experts from eight countries were selected and two expert panels were set up—one to evaluate soil/plant transfer processes and one on food intake and radionuclide transport processes in animals. Their results were processed with an equal-weighting aggregation method, and the aggregated distributions will be processed into the code input variables of the food chain models in use for COSYMA (called FARMLAND) and for MACCS (called COMIDA).

Further expert judgment studies are being undertaken to examine the uncertainty in other aspects of probabilistic accident consequence codes. Finally, the uncertainties will be propagated through the codes, and the uncertainties in the code predictions will be quantified.

Contents

Preface

This volume is the second of a two-volume document that summarizes a joint project by the US Nuclear Regulatory Commission and the Commission of European Communities to assess uncertainties in the MACCS and COSYMA probabilistic accident consequence codes. These codes were developed primarily for estimating the risks presented by nuclear reactors based on postulated frequencies and magnitudes of potential accidents. This two-volume report, which examines mechanisms and uncertainties of transfer through the food chain, is the first in a series of five such reports, the remaining four of which examine the areas of: fate and effects of deposited materials; internal dosimetry; early health effects; and somatic health effects. A panel of sixteen experts was formed to compile credible and traceable uncertainty distributions for food chain transfer that affect calculations of offsite radiological consequences. Seven of the experts reported on transfer into the food chain through soil and plants, nine reported on transfer via food products from animals, and two reported on both. The expert judgment elicitation procedure and its outcomes are described in these volumes.

This volume contains seven appendices. Appendix A presents a brief discussion of the MACCS and COSYMA model codes. Appendix B is the structure document and elicitation questionnaire for the expert panel on soils and plants. Appendix C presents the rationales and responses of each of the members of the soils and plants expert panel. Appendix D is the structure document and elicitation questionnaire for the expert panel on animal transfer. The rationales and responses of each of the experts on animal transfer are given in Appendix E. Brief biographies of the food chain expert panel members are provided in Appendix F. Aggregated results of expert responses are presented in graph format in Appendix G.

Volume 1 contains background information and a complete description of the joint consequence uncertainty study.

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The authors would like to acknowledge all the participants in the expert judgment elicitation process, in particular the expert panel on the food chain. While we organized the process, processed the results, and wrote and edited the report, the experts provided the technical content that is the foundation of this report. Dr. Detlof von Winterfeldt is acknowledged for his contribution as elicitor in several expert sessions. We would also like to express our thanks for the support and fruitful remarks from Dr. G. N. Kelly (EC/DG XII), and Ms. C.H. Lui (NRC).

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List of Acronyms

BIOMOVS	International Biosphere Model Validation Study
CEC/FARM	EC research program on transfer of radionuclides through farm animals (or EC/FARM, or FARM Group, or EC Animal Group)
CEN/SCK	Centre d'Étude de l'Énergie Nucléaire/Studiecentrum Voor Kernenergie, Belgium
COMIDA	food chain model in MACCS (developed at Idaho National Engineering Laboratory, US)
COSGAP	Gaussian plume dispersion model in COSYMA (developed at NRPB)
COSYMA	European probabilistic accident consequence code
EC	European Commission
ECP	Experimental Collaboration Project under the EC, Russian Federation, Belarus and Ukraine Joint Program on the consequences of the Chernobyl accident (1991 - 1995)
ECOSYS	food chain model used in COSYMA (developed at GSF)
FAO/UNESCO	Food and Agriculture Organization/United Nations Education Scientific and Cultural Organization
FARMLAND	food chain model used in COSYMA (developed at NRPB)
FZK	Forschungszentrum Karlsruhe, Germany
GPM	Gaussian plume model
GSF	Forschunszentrum für Umwelt und Gesundheit, Germany
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICSTM	Imperial College Science Technology and Medicine
ISOLA	Gaussian plume dispersion model used in COSYMA (developed at FZK)
IUR/UIR	International Union of Radioecologists
MACCS	US probabilistic accident consequence code
MAFF	Ministry of Agriculture, Fisheries and Food, UK
MARC	UK probabilistic accident consequence code (developed at NRPB)
MARIA	EC research program on Methods of Assessing the Radiological Impact of Accidents
MESOS	Trajectory dispersion model used in COSYMA (developed at ICSTM)
MUSEMET	Gaussian plume dispersion model used in COSYMA (developed at FZK)
NRC	US Nuclear Regulatory Commission
NRPB	National Radiological Protection Board, UK
ONDRAF/NIRAS	Organisme national des déchets radioactifs et des matières fissiles, Belgium
PATHWAY	food chain model (developed at Colorado State University, US)
RESSAC	EC research program on Rehabilitation of Soil and Surfaces after an Accident
RIMPUFF	Gaussian puff dispersion model used in COSYMA (developed at Riso National Laboratory, Denmark)
SPADE	UK food chain model (developed for MAFF)

TF	Transfer factor within the food chain
UFOMOD	Probabilistic accident consequence code (developed at FZK)
VAMP	IAEA coordinated research program on validation of model predictions

APPENDIX A

Summary of the MACCS and COSYMA Consequence Codes

Summary of the MACCS and COSYMA Consequence Codes

Introduction

The information developed in this study will be used to perform uncertainty studies using the European Commission (EC) consequence code COSYMA and the US Nuclear Regulatory Commission (USNRC) code MACCS. COSYMA and MACCS model the offsite consequences of postulated severe reactor accidents that release a plume of radioactive material to the atmosphere. These codes model the transport and deposition of radioactive gases and aerosols into the environment and the potential resulting human health and economic consequences. They calculate the health effects, impact of countermeasures and economic costs of the releases. The processes considered in the calculations, and the routes of exposure following accidental releases to atmosphere, are illustrated in Figure A-1. The calculations are divided into a number of steps, illustrated in Figure A-2. COSYMA and MACCS are modular codes, with different modules addressing the different stages of the calculation. However, while Figure A-1 illustrates the steps in the calculation, the modules of the codes do not correspond exactly with the boxes shown.

The following sections give brief descriptions of the COSYMA and MACCS codes.

Brief Description of MACCS and COSYMA Dispersion and Deposition Models

COSYMA and MACCS both employ a Gaussian plume model (GPM) for atmospheric dispersion. At a given downwind distance and given atmospheric conditions, the Gaussian model predicts the time-integrated concentration at various horizontal and vertical displacements from the center-line of the plume. When the plume is not constrained by the ground or the inversion layer, the basic Gaussian plume equation for determining the concentration relative to the release rate is:

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right)$$

where:

χ = time-integrated air concentration,
Q = the source strength,
y = the horizontal displacement relative to the plume centerline,
z = the vertical displacement,
h = the vertical height of the plume centerline,
$\bar{u}$ = the average wind velocity, and
σ_y and σ_z are plume expansion parameters.

In MACCS and COSYMA, the plume expansion parameters, σ_y and σ_z, are modeled by the following power law:

$$\sigma_y = a_y x^{b_y} \; ; \sigma_z = a_z x^{b_z}$$

where x = the downwind distance from the plume release point.

Currently, constant values for a_y, b_y and a_z, b_z are provided in the codes. The values for the parameters are determined by the atmospheric stability class and the roughness length of the terrain.

Two types of deposition are modeled in the MACCS and COSYMA codes: wet and dry. Dry deposition incorporates removal from the plume by diffusion, impaction, and settling; it is modeled through a dry deposition velocity, which is a user input. The dry deposition velocity depends on particle size; therefore, if the aerosol size distribution is divided into ranges, a dry deposition velocity must be specified for each range. The washout of radioactive material from the plume, wet deposition, is modeled as dependent on the rain intensity. The fraction of material, f_w, that remains in the plume is given by:

$$f_w = \exp\left\{-a\, I^b\, \Delta t\right\}$$

where I is the rain intensity and Δt is the amount of time the plume is exposed to the rain. The parameters a and b are the user-specified parameters that determine the amount of material washed from the plume as a result of rain intensity. Rainout, in which droplets nucleate on the aerosol particles, is not modeled.

Summary of the MACCS Radiological Consequence Code

The MACCS code was originally developed under NRC sponsorship to estimate the offsite consequences of

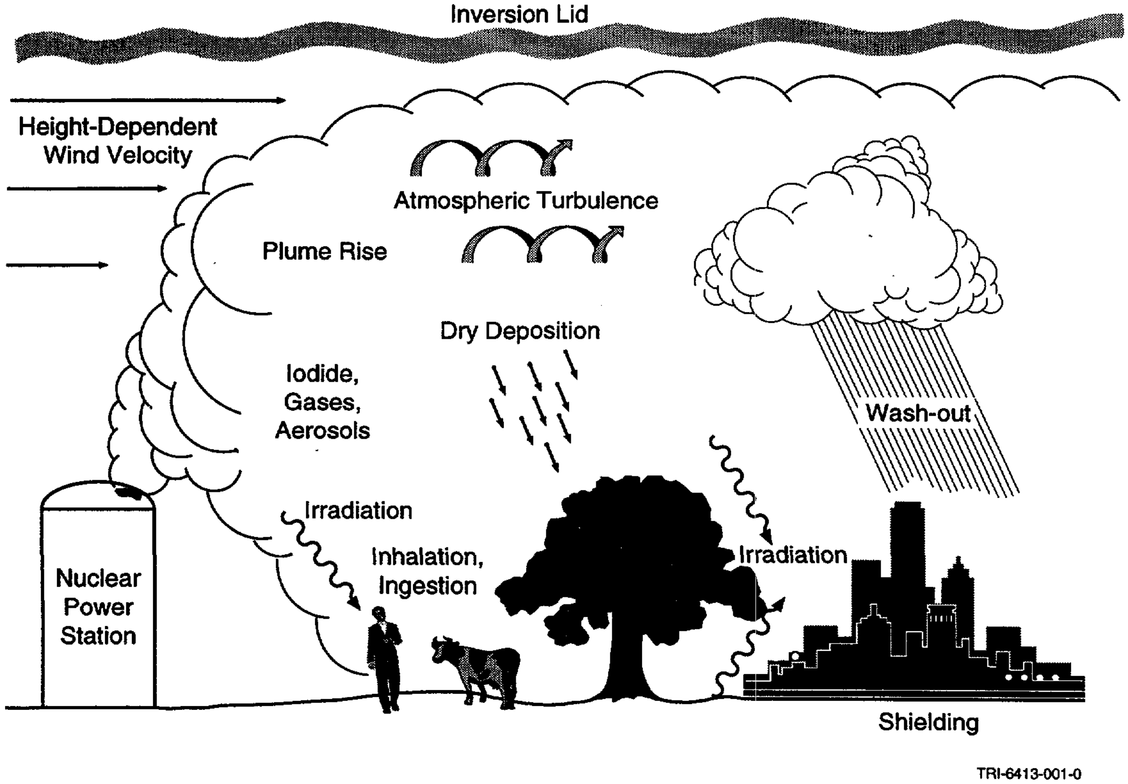

Figure A-1. Dispersion and deposition phenomena considered in an accident consequence analysis.

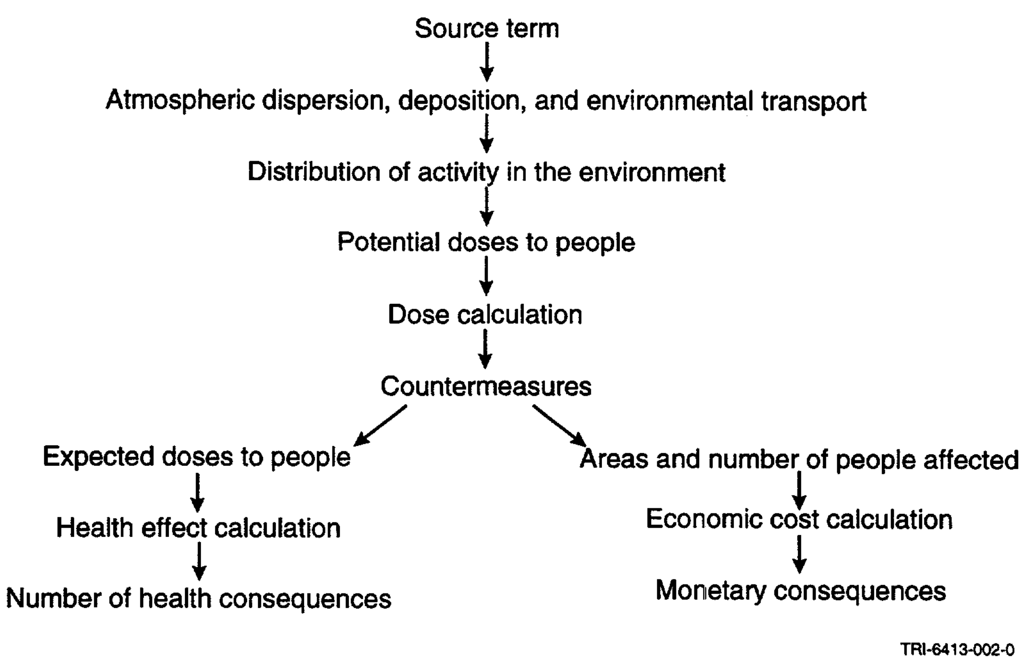

Figure A-2. Basic features and relationships of an accident consequence analysis.

potential severe accidents at nuclear power plants by using meteorological data that vary on an hourly basis. The code models the transport and dispersion of plumes of radioactive material released from the facility to the atmosphere. As the plumes travel through the atmosphere, material may be deposited on the ground via wet and dry deposition processes. There are seven pathways through which the general population can be exposed: cloudshine, groundshine, direct inhalation, resuspension inhalation, ingestion of contaminated food, ingestion of contaminated water, and deposition on skin. Emergency response and protective action guides for both the short and long term are also considered as means for mitigating the extent of the exposures. As a final step, the economic costs that would result from the mitigative actions are estimated. Variability in consequences as a result of weather may be obtained in the form of a complementary cumulative distribution function.

MACCS is organized into three modules. The ATMOS module performs the atmospheric transport and deposition portion of the calculation. The EARLY module estimates the consequences of the accident immediately following the incident (usually within the first week), and the CHRONC module estimates the long-term consequences of the accident. A schematic representation of these modules and the input files that provide information to them is shown in Figure A-3. The following sections describe the phenomena modeled in MACCS in more detail.

Atmospheric Dispersion and Transport

The release of radioactive materials to the atmosphere can be divided into successive plume segments, which can have different compositions, release times, durations, release heights, and amounts of sensible heats. The plume segment lengths are determined by the product of the segment's release duration and the average windspeed during release. The initial vertical and horizontal dimensions of each plume segment are user-specified.

A lift-off criterion based on a critical windspeed determines whether or not a plume is subject to buoyant plume rise. Momentum plume rise is not modeled. If the windspeed at release is greater than the critical windspeed, plume rise is prevented.

After release from the facility, windspeed determines the rates at which plume segments transport in the downwind direction, and the wind direction at the time of release determines the direction of travel. MACCS neglects wind trajectories, as do most other consequence codes. Sixteen compass-sector population distributions are assumed to constitute a representative set of downwind exposed populations. The exposure probability of each of the 16 compass-sector population distributions is assumed to be given by the frequency with which the wind blows from the site into the sector. During transport, dispersion of the plume in the vertical and horizontal directions is estimated using an empirical model, the GPM. In this model, dispersion depends on atmospheric stability and windspeed. Horizontal dispersion of the plume segments is unconstrained. However, vertical dispersion is bounded by the ground and by the mixing layer, which are both modeled as totally reflecting layers. A single value for the mixing layer is specified by the user for each season of the year and is constant during a calculation. Eventually the vertical distribution of each plume segment becomes uniform and is so modeled.

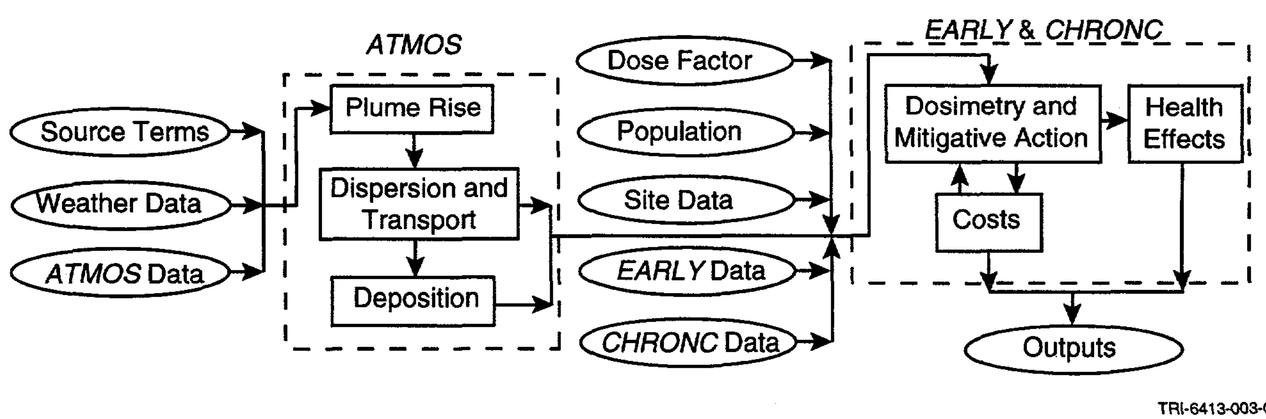

Figure A-3. Progression of a MACCS consequence calculation.

Deposition, Weathering, Resuspension, and Decay

As noted earlier, two types of deposition are modeled in MACCS: wet deposition and dry deposition. Weathering, resuspension, washoff, and radioactive decay decrease the deposited concentrations of radioactive materials. Radioactive decay treats only first generation daughter products.

Weather

Plume rise, dispersion, downwind transport, and deposition depend on the prevailing meteorological conditions. These conditions can be modeled as time-invariant or as varying hour-by-hour. If they are modeled as variable, the user may specify them directly or through an input file.

Dosimetry

The MACCS dosimetry model consists of three interacting processes: (1) the projection of individual exposures to radioactive contamination for each of the seven exposure pathways modeled over a user-specified time, (2) mitigation of these exposures by protective-measure actions, and (3) calculation of the actual exposures incurred after mitigation by protective-measure actions. For each exposure pathway, MACCS models the radiological burden for the pathway as reduced by the actions taken to mitigate that pathway dose. The total dose to an organ is obtained by summing the doses delivered by each of the individual pathways.

Dose Mitigation

The time after accident initiation is divided into three phases: (1) an emergency phase, (2) an optional intermediate phase, and (3) a long-term phase. During the emergency phase, which can last up to seven days, doses are reduced by evacuation, sheltering, and temporary relocation of people. During the intermediate phase, doses may be avoided by temporary relocation of people. During the long-term phase, doses are reduced by decontamination of property that is not habitable, by temporary interdiction of property that cannot be restored to habitability by decontamination alone, by condemnation of property that cannot be restored to habitability at a cost below or equal to the worth of the property, by disposal of contaminated crops, and by banning farming on contaminated farmland.

Exposure Pathways

MACCS models seven exposure pathways: (1) exposure to the passing plume (cloudshine), (2) exposure to materials deposited on the ground (groundshine), (3) exposure to materials deposited on skin, (4) inhalation of materials directly from the passing plume (inhalation), (5) inhalation of materials resuspended from the ground by natural and mechanical process (resuspension inhalation), (6) ingestion of contaminated foodstuffs (food ingestion), and (7) ingestion of contaminated water (water ingestion). Ingestion doses do not contribute to the doses calculated for the emergency phase of the accident. Only groundshine and inhalation of resuspended materials produce doses during the optional intermediate phase of the accident. Long-term doses are caused by groundshine, resuspension inhalation, water ingestion, and food ingestion. Ingestion of contaminated food or water generates doses to people who reside at unknown locations both on and off of the computational grid.

Population Cohorts

People on the computational grid are assigned to three groups: (1) evacuees, (2) people actively taking shelter, and (3) people who continue normal activities. Shielding factors for each of the groups are specified by the user.

Health Effects

Health effects are calculated from doses to specific organs using dose conversion factors. Early injuries and fatalities (those occurring within one year of the accident) are estimated using nonlinear dose-response models. Latent cancers are estimated using a piecewise linear dose-response model that is discontinuous. Two equations are implemented in the code, one for high exposures and one for low exposures.

Economic Effects

Economic consequences result from the implementation of mitigative actions. The following costs are considered in this estimate: (1) evacuation costs, (2) temporary relocation costs, (3) costs of decontaminating land and buildings, (4) lost return-on-investments from temporarily interdicted properties, (5) value of crops destroyed or not grown, and (6) value of condemned property. Costs associated with damage to the reactor, the purchase of replacement power, medical care, life-shortening, and litigation are not considered.

Summary of COSYMA Radiological Consequence Code

COSYMA was developed by the National Radiological Protection Board (NRPB) of the UK and Forschun–

gszentrum Karlsruhe (FZK) of Germany, as part of the European Commission's MARIA project (FZK and NRPB, 1991). It represents a fusion of ideas from the NRPB program MARC (Hill et al., 1988), the FZK program system UFOMOD (Ehrhardt et al., 1988) and input from other MARIA contractors. The program package was first made available in 1990 for use on mainframe computers, and several updates have been released since then. A PC version was first released in 1993 and has since been updated (Jones et al., 1995).

COSYMA is a system of programs and data bases, rather than a single program. The mainframe version contains three main accident consequence assessment programs together with a number of preprocessing and evaluation programs. The three main sub-systems of COSYMA are known as the NE, NL, and FL sub-systems (Figure A-4). The NE (near, early) sub-system is limited to calculating early health effects and the influence of emergency actions to reduce those effects and applies to the region near the accident site. The NL (near, late) subsystem is limited to calculating late health effects and the associated countermeasures, and applies mainly to the region near the site. The FL (far, late) sub-system calculates late health effects and appropriate countermeasures at greater distances from the site. Each of these programs is subdivided into a series of modules for the various steps in the calculation. PC COSYMA incorporates the NE and NL sub-systems of the mainframe version.

The main endpoints of COSYMA are the numbers of health effects, the impact of countermeasures, and the economic costs resulting from the accidental release. A large number of intermediate results are obtained in the process of calculating the major endpoints; these results include activity concentrations, individual and collective doses, and the countermeasures assumed at different locations. COSYMA contains a series of evaluation programs that allow these results to be presented in a variety of ways.

Following an accidental release to atmosphere, people can be irradiated by a number of exposure paths. Those considered in COSYMA are cloudshine, groundshine, exposure to materials deposited on skin, direct inhalation of plume material, inhalation of resuspended materials, and ingestion of contaminated foods.

COSYMA includes some models directly within the various modules or subsidiary programs, such as atmospheric dispersion models. In other cases, COSYMA uses data libraries giving the results of other models which are not part of COSYMA itself, but whose uncertainty is considered within the current study.

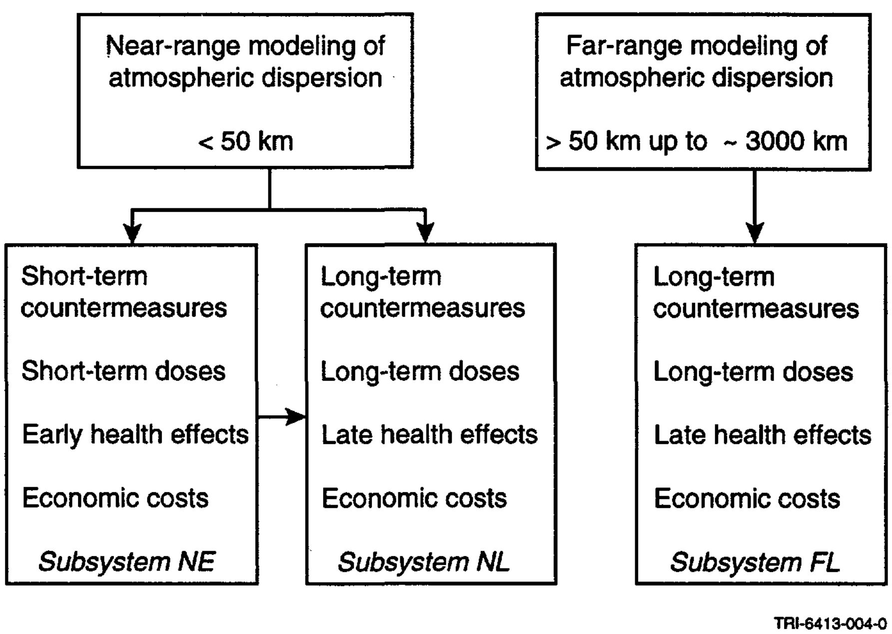

Figure A-4. General structure of the COSYMA program system.

Atmospheric dispersion and deposition

Mainframe COSYMA contains five different models of atmospheric dispersion that are appropriate for different applications or are based on different assumptions and approximations (Panitz et al., 1989).

The NE and NL sub-system include the MUSEMET (Straka et al., 1981) model, originally written at Forschungsanlage Julich and extensively modified at FZK for use with COSYMA. This is a segmented Gaussian plume model allowing for changes of atmospheric conditions and wind direction during plume travel. This model derives the sequences of atmospheric conditions affecting the plume from hourly averages for wind speed and direction, stability category, precipitation intensity and mixing layer depth. It allows for the effects on the subsequent dispersion of plume rise and buildings near the release point. It also includes the effects of wet and dry deposition of the dispersing material. This model is also included in PC COSYMA.

The NE and NL sub-systems can also be used with the COSGAP or RIMPUFF dispersion models, which are provided as separate programs. COSGAP (Jones and Charles, 1982) is a Gaussian plume dispersion model, which is similar to MUSEMET but does not consider changes of wind direction during plume travel. It is based on the dispersion model in MARC. RIMPUFF (Mikkelsen et al., 1984), developed by Risø National Laboratory, Denmark, is a Gaussian puff trajectory model which derives the atmospheric conditions affecting the plume by interpolating between data from a number of meteorological stations in the region of interest.

The NL sub-system also contains the ISOLA (Hübschmann and Raskob) model for very long release durations. This uses statistics of atmospheric conditions and is only appropriate for releases that are sufficiently small that no countermeasures and no early health effects would be expected.

The FL sub-system is linked to the Mesos model (ApSimon and Goddard, 1983), developed by Imperial College, UK. This is a trajectory model for dispersion over long distances using meteorological data for a large area, such as the whole of Europe.

Accident consequence assessment programs need to consider that the accident could occur in any of a wide range of atmospheric conditions. It is not possible to calculate the consequences for every sequence of conditions that might arise, so a method of sampling a representative set of conditions from those possible is needed. Both the mainframe and PC versions of COSYMA include a flexible program to conduct this sampling.

Dose calculations

As stated earlier, COSYMA does not include dosimetric models but uses information from data libraries which are calculated with these models. The libraries include information on doses from 197 nuclides.

The data library used for calculating external exposure from activity deposited on the ground contains outdoor doses per unit deposit for a series of times. These doses are mitigated by location factors describing the reduction in exposure due to shielding by buildings. The library is drawn from a number of sources, using results of models developed at NRPB (Charles et al., 1982; Crick and Brown, 1990) and Forschungszentrum für Umwelt und Gesundheit (GSF) (Jacob et al., 1988), Germany. The doses for major contributing nuclides in a fission reactor accident are derived from a model describing the deposition patterns in urban areas and the subsequent transfer of material between the different surfaces.

The doses from internal irradiation following ingestion or inhalation are calculated using data libraries of dose per unit intake derived using models which are consistent with those in International Commission on Radiological Protection (ICRP) publications 56, 67 and 69 (ICRP, 1990, 1994, 1995). COSYMA requires information on the dose received during different periods after the accident, which is included in the data libraries. Because the method used for calculating doses and risks of health effects in the mainframe version of COSYMA allows for the variation of dose per unit intake with age at intake, the libraries contain information on doses for different age groups in the population. The PC version, however, uses a simpler method which considers only the doses to adults.

Food chain models

COSYMA requires information on the concentration of material in foods as a function of time after the accident. It does not include a food chain model, but uses the results of such models through data libraries which give concentrations for a range of radionuclides in a number of foods at a series of times following unit deposition. The concentration of material in foods depends on the time of year at which the deposition occurs. COSYMA uses two data libraries for deposition in summer and in winter.

COSYMA uses libraries derived from the NRPB model FARMLAND (Brown and Simmonds, 1995) and the GSF model ECOSYS (Matthies et al., 1982). The libraries were created using accepted values for the food chain parameters for application within the EC, but differences exist because of other modeling assumptions made and because of the foods considered in each. The foods which can be considered with FARMLAND are: milk; meat and liver from cattle; pork; meat and liver from sheep; green vegetables; grain products; and potatoes and other root vegetables. The foods which can be considered with ECOSYS are: milk; beef; pork; grain products; potatoes and other root vegetables; and leafy and non-leafy green vegetables.

The intakes of these foods are calculated within COSYMA using one of two assumptions about the distribution of food between harvest and consumption. One method assumes that all food consumed is produced locally, and is used in calculating individual ingestion doses. The other method uses information on the amount of food produced in the area of interest, and calculates collective doses on the assumption that all food produced is consumed somewhere.

Countermeasures

COSYMA allows the user to consider the effects of a wide range of countermeasures in reducing the exposure of the population, and gives the user considerable freedom in specifying the criteria at which the actions will be imposed or withdrawn (Hasemann and Ehrhardt, 1994).

Sheltering alone or combined with evacuation may be implemented automatically or on the basis of dose. The distribution of iodine tablets, automatically or on the basis of dose, can also be considered. These actions are assumed to be implemented sufficiently rapidly to reduce the risks of both early and late health effects. Relocation is considered as an action to reduce doses and risks over longer time periods. It can be implemented on a dose criterion, as can return from evacuation or relocation. The effects of decontamination in reducing the period of relocation can be considered. If these actions are initiated on the basis of dose, the user can specify the intervention levels, organs and pathways to be considered, and the time over which the dose is to be integrated. The behavior of the population considered in the dose criteria can also be described using location factors.

Food bans can also be considered (Steinhauer, 1992). They can be implemented or withdrawn on the basis of doses received within specified time periods or on the basis of the instantaneous concentration of radionuclides in foods.

Health effects

COSYMA considers both early and late health effects in the population, using methods recommended by NRPB (Edwards, pers. comm; NPRB, 1993), the USNRC (Evans et al., 1990) and GSF (Paretzke et al., 1991).

The risk of early health effects is calculated using "hazard functions." The method allows for the variation of risk with the rate at which dose is accumulated over the first few days following the accident. Ten different fatal and non-fatal effects are considered.

The risk of late health effects is calculated using the linear dose response relationship. COSYMA considers the risk of fatal and non-fatal cancers in ten organs, as well as the risk of leukemia. It also considers the risk of hereditary effects. The method adopted in the mainframe version of COSYMA allows for the variation of risk with age at exposure (Ehrhardt et al., 1995). PC COSYMA uses a simpler method which only considers the doses and risks to adults. The mainframe version of COSYMA can provide information on the numbers of cancers in the people alive at the time of the accident, and in their descendants. It also gives information on the times at which the cancers occur.

Economic effects

COSYMA can calculate the off-site economic effects of the accident, considering the costs arising from the countermeasures and the costs of health effects. The assumptions and models are described in Haywood et al. (1991) and Faude (1992). The countermeasures for which costs are considered are movement of the population, food restrictions, and decontamination. The costs arising from lost production in the area from which people are moved can be assessed in terms of the per capita contribution of the relocated population to gross domestic product (GDP) or in terms of the value of the land affected. For longer periods of relocation, the lost capital value of the land and its assets may be calculated. The costs of food bans include contributions to GDP as well as the lost capital value and the disposal costs of the food affected. The cost arising from health effects may be calculated in terms of the treatment costs and the lost economic productivity of the affected individuals, or an estimation of the cost of health effects may be obtained using a more subjective approach to the valuation of life.

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APPENDIX B

Structure Document and Elicitation Questionnaire for the Expert Panel on Soil and Plant Transfer and Processes

ELICITATION QUESTIONS

Expert Panel on Soil and Plants

EC/USNRC Joint Project on
Uncertainty Analysis of Consequence Assessment Programs

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General Conditions

The results of the analysis will be used to make estimates of the uncertainty associated with the collective dose from ingestion and the consequences of banning food that are representative of the majority of reactors within Europe and the US. Inevitably, given the diversity of siting land for reactors within Europe and the US, the results can not be universally applicable. In this study the regions of interest are restricted to those typical of warm temperate climates, for example northwestern Europe, and northeastern/southeastern US. Mediterranean countries, arid areas of the US and areas subject to arctic conditions are not included. The estimates of uncertainty made by the experts should be applicable to the main agricultural production areas in these regions. Areas such as semi-natural environments should only be considered in so far as they contribute to the food production for the regions of interest in this study.

In general, the questions are asked for the generic case and the expert is asked to define the assumptions he or she has made in determining a generic value. In some cases, more detailed information is asked for, such as a parameter value as a function of soil type. The uncertainty considered in answering the elicitation questions should include the effects of typical variations of weather conditions (e.g., amounts and frequencies of rain) and soil type (where appropriate). In general, the ranges provided should include the uncertainty resulting from the possible range of values for all conditions which are not specified in the information given with the question. For each question a list of conditions are given which are not specified in the question. This list is not exhaustive and does not preclude the experts considering other factors which they believe are important in contributing to the uncertainty.

The quantity used in the models is the best estimate of the value for the various parameters. The uncertainty ranges specified must correspond to this. In this context, the quantity required is the uncertainty on the average value for the region described above. For example, this means that where a parameter refers to the behavior of material in animals, the ranges given must describe the uncertainty on that quantity averaged over a group or groups of animals in the region of interest, rather than the variability between animals in these groups. Where a parameter refers to behavior in crops, then it must reflect the average over different crop growing areas and different stages of the growing season, and not the variability between areas or times of the year.

Some questions refer to transfer from "average" or "generic" soils to crops. In these cases, the experts must consider which types of soil are likely to support the crop under consideration in the region described above and take into account the relative amounts of these in deriving the generic value.

Unless otherwise stated the effect of radioactive decay should not be taken into account.

For the crops considered in COSYMA and FARMLAND the generic terms green vegetables, grain and root vegetables are used. Green vegetables include all leafy green vegetables and brassicas, e.g., cauliflower and cabbages. Grain is representative of cereals grown for human consumption which are dominated by wheat. Root vegetables include potatoes and other vegetables such as carrots and onions. The consumption of root vegetables is typically dominated by potatoes and this should be taken into account in answering the questions relating to root vegetables.

Some additional questions were asked of the experts to perform additional research on the merits of alternative weighting schemes. The quantitative assessments are not included in the rationales, but qualitative information in response to the questions is included for the reader's benefit. A similar approach is taken for dependency information which was requested from the experts. Quantitative information will be provided in follow-up documentation dealing specifically with alternative weighting techniques and dependencies.

1. Soil migration

(a) Following a single deposition (1 Bq m^{-2}) of caesium and of strontium on to the surface of undisturbed soil, how long does it take for 50% of the initial deposit to migrate to below depths of 1 cm, 5 cm, 15 cm and 30 cm? Please provide values for a generic soil which you believe is representative of soils which support pasture grass in the regions described above within Europe and, in addition, for typical sand and highly organic, e.g., peat soils. Please give details of your assumptions on soil types. Please indicate whether your answer would change if you were considering a generic soil representative of soils in similar regions in the US and, if so, how would it change.

You should assume that the area of soil considered is used for growing pasture, and so is not affected by ploughing or other mechanical disturbances. You should allow for the effects of rain in causing the material to move down the soil column. The effects of typical variations of rain intensity and duration must be considered and included in the ranges of values provided, as must the differences between rain patterns at different times of the year.

Not specified: *composition of generic soil*

Generic soil in region of interest within Europe

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm						
Below 5 cm						
Below 15 cm						
Below 30 cm						

Generic soil in region of interest within the US

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm						
Below 5 cm						
Below 15 cm						
Below 30 cm						

Sandy soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm						
Below 5 cm						
Below 15 cm						
Below 30 cm						

Highly organic soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm						
Below 5 cm						
Below 15 cm						
Below 30 cm						

2. Fixation of caesium and strontium in soil

What fraction of caesium and strontium in soil becomes unavailable for uptake by plants after 1 year, 3 years, 5 years and 10 years following deposition to the soil surface? Please provide values for a generic soil which you believe is representative of soils which support pasture grass in the regions described above within Europe and, in addition, for typical sand and highly organic, e.g., peat soils. Please give details of your assumptions on soil types. Please indicate whether your answer would change if you were considering a generic soil representative of soils in similar regions in the US and, if so, how would it change.

Not specified: *composition of generic soil*

Generic soil in regions of interest within Europe

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year						
3 years						
5 years						
10 years						

Sandy soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year						
3 years						
5 years						
10 years						

Highly organic soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year						
3 years						
5 years						
10 years						

Generic soil in regions of interest within the US

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year						
3 years						
5 years						
10 years						

3. Root uptake concentration factors

(a) Following a single deposit what are the concentrations (Bq kg^{-1}) of Sr and Cs in grain, green vegetables, pasture grass, root crops and potatoes at maturity which are grown on soil which contains 1 Bq kg^{-1} of Sr and Cs as a function of time following deposition? Please provide values for a generic soil which you believe is representative of soils which support the above crops in the regions described above within Europe and, in addition, for typical sand and highly organic, e.g., peat soils. Please indicate whether your answer would change if you were considering a generic soil representative of soils in similar regions in the US and, if so, how would it change.

The radioactive material is assumed to be well mixed throughout the soil volume in the root zone of the crops. The concentration ratio should be for the total activity in the soil, i.e., including the effect of fixation on the transfer to plants. The concentration ratio should be determined over 6 months, 1 year, 3 years and 10 years following deposition to take into account the effect of fixation in the soil on the uptake to plants. The concentration is that in the edible portion of the plants (wet weight) for unit concentration in soil (dry weight). Soil contamination of the crop should not be included.

Assume percentage dry matter content of crops as follows:

green vegetables	20%
cereals	90%
root vegetables and potatoes	20%
pasture grass	20%

Not specified: *composition of generic soil*
type of deposit, e.g., hot particles

6 months after deposition

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

1 year after deposition

Generic soil regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Generic soil regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

3 years after deposition

Generic soil regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Generic soil regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

10 years after deposition

Generic soil regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

Generic soil regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables						
Grain						
Root vegetables						
Potatoes						
Pasture grass						

(b) For pasture grass growing on soil which has remained undisturbed for a number of years prior to deposition, would you expect the concentration ratio to be the same as that in question a)? If not, what difference would you expect?

4. Interception factors

Some radioactive material is deposited on a unit area of ground on which either pasture grass, grass grown for silage/hay, green vegetables or root vegetables are growing. What fraction of this material is deposited onto the plant surface at maturity?

The ranges of values specified should include an allowance for deposition in wet or dry conditions, with typical rainfall intensities and frequencies, and for dry deposition to plants which are wet from earlier rain or from dew. The ranges should take into account the physical form of the deposit, i.e., particulate or vapor. The deposition can occur at any time of the year and at any time of the day or night. The ranges should include any uncertainty from these sources. The quantity refers to the whole of the crop, and not just to the edible portion. The yields of the crops that should be assumed are:

Green vegetables	1×10^6 kg km^{-2} fresh weight
Root vegetables (tuber)	3×10^6 kg km^{-2} fresh weight
Pasture grass (grass density)	5×10^5 kg km^{-2} fresh weight
Grass for silage/hay	3×10^5 kg km^{-2} dry weight

NB. An assumption should be made on the fraction of the root vegetable yield that is the haulms.

Not specified: *physical form of material deposited*
type of deposition, i.e., wet or dry
rainfall intensities

Crop	5%	50%	95%
Green vegetables			
Grain			
Root vegetables			
Grass for hay/silage			
Pasture			

Change to elicitation question for US experts

The following information was given to the US experts:

The yields of the crops that should be assumed are:

Grain (seed) 4×10^5 kg km^{-2} fresh weight

An assumption should be made on the yield of the haulms for the given root vegetable yield and the yield of the cereal plant for the given grain seed yield. Any information on the α in the equation: Int factor = 1 $e^{-\alpha B}$ would be appreciated.

5. Resuspension factor

What is the resuspension factor over the entire growing period of a typical surface crop which results from resuspension of a fresh deposit to soil by wind driven processes?

What is the mean resuspension factor for pasture grass which results from resuspension of a fresh deposit to soil by wind driven processes?

Resuspension is the process whereby material which was originally deposited on the soil is transferred to growing plants. It excludes the contamination of the plants by soil during the harvesting process. The value required is the mean over the growing period of the crop and should take into account the time dependence of the resuspension process. For grass the integration time for the calculation of the resuspension factor should be taken as 6 months.

The resuspension factor is defined as: air concentration at a height of 1 m above the ground deposit in units of m^{-1}.

Not specified: *soil type*
weather conditions
type of plant
time dependence of resuspension

Resuspension factor

Crop	5%	50%	95%
Surface crop			
Pasture grass			

Change to elicitation question for US experts

The following information was given to the US experts:

You can exclude the arid and semi-arid regions. If any information is available on arid and semi-arid regions and is easy to access, please provide.

6. Retention times

Following deposition of material onto pasture grass, grass grown for silage/hay and green vegetables, how long is it before the activity remaining on the surface of the plant is reduced to half of its original value?

"Half" is defined in terms of deposit per unit area, and not per unit mass, and so effects caused by plant growth (such as following deposition on young seedlings) should not be considered. Weathering from rain and wind and that due to erosion of wax fragments from the leaf surface should be considered. For pasture grass you should assume that it is being grazed by animals.

Not specified: *physical and chemical form of material deposited*
type of deposition, i.e., wet or dry
rainfall intensities
agricultural practice

Uncertainty not included: effect of plant growth

Retention times

Crop	5%	50%	95%
Green vegetables			
Grain			
Root vegetables			
Grass for silage/hay			
Pasture			

7. Concentrations in grain at harvest

What is the concentration (Bq kg^{-1} wet weight) of Sr and Cs in the edible portion of grain at harvest, for a single deposition of 1 Bq m^{-2} to the ground occurring 15, 30, 60 and 90 days before the grain is harvested?

The deposition is the total amount deposited on the soil and the plants. The uncertainty should include that coming from the relative amounts of material intercepted by the different parts of the cereal plant, and the subsequent translocation to the edible portion of the grain taking into account biomass increases. The estimates of activity concentration in grain should make no allowance for material originally deposited on soil and subsequently taken up by the plant roots. Differences between the interception and uptake of material deposited in wet or dry conditions should also be included in the ranges, as should the differences caused by different yields within the range expected for north western Europe and the US.

If required the percentage dry matter content of cereals given in question 3 should be used.

Not specified: *type of deposition, i.e., wet or dry, rainfall rate*
stage of development of crop: however, this is implicit as crop only harvested at full maturity.
yield of standing crop and yield of edible grain

Time before harvest	5%	50%	95%
15 days			
30 days			
60 days			
90 days			

8. Concentrations in root crops

What is the concentration (Bq kg^{-1} wet weight) of Sr and Cs in the edible portion of root crops at harvest, for a single deposition intercepted by the plant of 1 Bq m^{-2} occurring 15, 30, 60 and 90 days before harvest?

The deposition given is the total amount intercepted by the plants. The uncertainty should be that on the translocation to the edible portion of the plant (i.e., the potato tuber or plant root) following deposition to the leaf portion of the plant. The estimates of activity concentrations should make no allowance for material originally deposited on soil and subsequently taken up by the plant roots.

Not specified: *stage of development of crop: however, this is implicit as crop only harvested at full maturity.*
yield of edible crop
type of root vegetable

Time before harvest	5%	50%	95%
15 days			
30 days			
60 days			
90 days			

Change to elicitation question for US experts

The question was extended for the US experts to include green vegetables.

9. Correlations between parameters

Some of the quantities for which ranges of values have been obtained are likely to be correlated. The final set of questions relate to the degree of correlation between these parameters.

Please indicate below if you believe there are correlations between any of the parameters addressed in the previous questions including those between different elements for the same parameter. Please indicate if you believe there is a correlation whether it is strong or weak and positive or negative.

Additional Elicitation Questions

1. Soil migration

(a) For a site situated which has natural pasture growing on a clay soil, what fraction of a single deposit of cesium-137 would you expect to find a depth of 5 cm, 4 years and 7 years following deposition?

Typical summer rainfall in the area is 310 mm per month. The characteristics of the soil are:

organic matter approximately	15% wet weight
pH approximately	5 - 6
exchangeable K approximately	30 mg/100 g dry soil

	5%	50%	95%
Fraction of cesium-137 below 5 cm after 4 years			
Fraction of cesium-137 below 5 cm after 7 years			

b) Consider three soils supporting grassy uncultivated fields which are found within the region of interest of this study and which have been contaminated with cesium-137. The characteristics of the soil are given below with an activity profile with depth in the soil. For each soil please give the fraction of activity that you would expect to find below 1 cm, 5 cm and 10 cm after the subsequent times requested in the tables.

	Soil 1 (18 months)	Soil 2 (1 year)	Soil 3 (1 year)
Clay content, %			
pH			
Organic matter, %			
Depth profile:			
Below 1 cm, %			
Below 5 cm, %			
Below 10 cm, %			

Soil 1

Fraction of activity below depth after 3 years	5%	50%	95%
1 cm			
5 cm			
10 cm			

Soil 2

Fraction of activity below depth after 1 year	5%	50%	95%
1 cm			
5 cm			
10 cm			

Soil 2

Fraction of activity below depth after 2 years	5%	50%	95%
1 cm			
5 cm			
10 cm			

Soil 2

Fraction of activity below depth after 3 years	5%	50%	95%
1 cm			
5 cm			
10 cm			

Soil 3

Fraction of activity below depth after 1 year	5%	50%	95%
1 cm			
5 cm			
10 cm			

Soil 3

Fraction of activity below depth after 3 years	5%	50%	95%
1 cm			
5 cm			
10 cm			

Soil 3

Fraction of activity below depth after 6 years	5%	50%	95%
1 cm			
5 cm			
10 cm			

2. Root uptake concentration factors

(a) Consider a situation where land has been contaminated with strontium-90 and cesium-137 for a long period of time. The contamination is of marine origin but since isolation from the sea, the land has been subject to cultivation and is used for growing arable crops. What are the root uptake concentration ratios strontium-90 and cesium-137 in cabbage, potatoes and barely?

Your answer should be expressed as Bq kg^{-1} fresh weight per Bq kg^{-1} dry weight soil and should be for the edible portion of the crop. The soil type is basically sandy and has been improved by the regular application of organic matter and inorganic fertilizers over a number of years.

	Cesium-137			Strontium-90		
Crop	5%	50%	95%	5%	50%	95%
Cabbage						
Potatoes						
Barley						

(b) Consider a sandy soil and a loam soil with a relatively high organic matter content within the region of interest for this study which have been contaminated with cesium-137 following the Chernobyl accident. What is the concentration ratio for cesium-137 in grass for each soil type 4 years after deposition expressed in Bq kg^{-1} fresh weight grass/Bq kg^{-1} dry weight soil?

	5%	50%	95%
Sandy soil			
Loam soil			

APPENDIX C

Rationales and Responses of the Expert Panel on Soil and Plant Transfer and Processes

Rationales and Responses of the Expert Panel on Soil and Plant Transfer and Processes

EXPERT A

General Approach:

This effort involved a combination of reviewing published and some unpublished data, indirect calculations in some cases, general experience with field data and observations, and model testing exercises. With regard to the published literature, my focus was on review/synthesis articles that embodied more extensive reviews of individual papers. Several such reviews have been carried out in recent years and it was deemed more efficient to work with these rather than to attempt a comprehensive search of the primary literature. The latter would require considerably more time than was available. Where appropriate, these reviews as well as primary papers are cited in this report. A limited amount of unpublished data with which the author was involved in gathering was used to form judgments in some cases where published data were not located. It is also true that some judgment was based on a general familiarity with many papers read over the years but which were not specifically located and cited for this elicitation. Much of the experience called upon in this task was the development and testing of the foodchain transport model PATHWAY (Whicker and Kirchner, 1987). Of great importance was the performance of this model against sets of independent data (Kirchner and Whicker, 1984). Although this model was originally parameterized for conditions pertinent to the western US, it has been extensively compared with data sets from locations elsewhere in the US and Europe. The latter was accomplished through the international model testing program called BIOMOVS (Nielsen, Kohler, and Peterson, 1990). A certain degree of confidence has evolved in this model, as well as the basic parameters embodied in it. The actual parameter distributions selected in this study made allowances for the goal of achieving data relevant to the eastern US where most reactors are located, although the uncertainty ranges include conditions relevant to the entire continental US (Alaska and Hawaii excluded). My experience, and therefore the rationale used, varied for the specific questions.

Questions On Soil and Plants:

Question 1. Soil Migration:

The primary basis for these distributions is unpublished observations by the author and recollections of published data on observed depth profiles of Cs and Sr in soils of various types at various times after global fallout deposition. Some observations were on sandy soil at the Savannah River Site in South Carolina, and on the lake bed of Par Pond after it was partially drained in 1991 (Whicker et al., 1993). Retardation factors (Baes and Sharp, 1981; IAEA, 1994) based on precipitation, evapotranspiration, and K_d values (Sheppard and Thibault, 1990) for Cs and Sr in various types of soils were also used to check the reasonableness of the estimates. However the retardation factor approach does not account for mechanisms such as soil cracking and vertical migration caused by soil invertebrates and roots, so the distributions were modified to reflect such phenomena. Ratios of the 5th, 50th and 95th quantiles of distributions were based on ranges of K_d values from literature summarized by Sheppard and Thibault (1990); however these were modified somewhat arbitrarily based on judgment. The latter data were also used to scale organic soils to sandy or generic (loamy) soils.

For equivalent soil types and climate, I would expect similar migration times for Europe and the US.

Question 2. Fixation of Cs and Sr in Soil:

The primary rationale embodied in the distribution estimates for fixation of Cs and Sr relates to the well-known ability of micaceous clay minerals to irreversibly bind Cs in the lattice structures. Cs and Sr will also bind to particle surfaces and frayed edge sites on clay minerals, but cations can displace these atoms and they are thus available for uptake by plants, but to varying degrees depending on soil chemistry, moisture, plant species, etc. Organic matter in soil will bind Cs and Sr, but availability of these elements depends not only on the fraction actually incorporated within the matter (as opposed to that which is ionically bound to surface sites), but also on the rate at which the organic matter is decomposed by microorganisms. Microbial decomposition releases elements from the matrix, allowing most of it to be available, at least for a time.

I have not personally worked on the scientific aspects of this problem, so I consulted with Dr. Tom Hinton at the Savannah River Ecology Laboratory, Aiken, SC, who has been doing sequential extractions of various types of soils with a variety of extractants to estimate availability of Cs. Although there are fairly standard methods of sequentially extracting elements from soil, little work has apparently been done on precisely how this relates to availability for plant uptake. For all soil types studied by Hinton, even after extractions that break down carbonates, Fe/Mn oxides, and organic matter, there is an unavailable residue that amounts to some 30-70% of the original soil activity. It was my judgment that a somewhat smaller fraction of Sr would be unavailable, although I did not take time to research this.

Question 3. Root Uptake Concentration Factors:

A rather large body of data is available concerning the uptake of radionuclides from soil by plants. Unfortunately, much of the data must be interpreted with caution due to the fact that it is not always possible to separate root uptake from resuspension/foliar deposition. Furthermore, the root uptake process is modified by the solubility of the radionuclide, nature of the soil, species of plant, etc. In most aerial deposition scenarios, direct deposition on plant surfaces dominates over root uptake, at least initially, and often for some period of time. Ultimately, for long-lived radionuclides, the soil becomes the primary reservoir, and root uptake becomes the dominant transport mechanism for radionuclides that are at least partially in soluble form and available.

An extensive, recent review of the plant uptake literature was prepared by Frissel (1992) and these values were adopted in a parameter handbook released by the IAEA (1994). My estimates were based on this information, as well as a recent study of Cs uptake on sandy soils at the Savannah River Site by Seel, Whicker and Adriano (1995) and unpublished data on Sr at the same site. It was assumed that Cs would become somewhat less available after the first six months, so the expected plant to soil ratios were arbitrarily decreased to 0.8 the six month values. This assumption was not made for Sr. The ratio of the 50th/5th and 95th/50th quantiles was assumed to be a factor of 10, based on the Frissel (1992) review. It was believed that this range of uncertainty would cover most instances of varied soil chemistry, competing nutrient (K, Ca) levels, etc. It was assumed that for similar crops, climate, and soil conditions, generic soils in the US would exhibit similar root uptake values as those in Europe, since the mechanisms would be the same.

Question 4. Interception Factors:

This factor has been shown in sensitivity analyses to be very important (Breshears, Kirchner, and Whicker, 1992). For dry deposition, the classic method of estimating the interception factor (F_i) is to compute $1\text{-}e^{-B}$ where α = the interception coefficient (m^2/kg) and B = the plant biomass (dry basis). This formulation was originated by Chamberlain (1970) and it has been used extensively ever since. Specific wet plant biomass values were given in the problem, and these were converted to a dry mass basis using dry/wet mass ratios provided in question 3. Alpha is a function of particle size of the aerosol (Simon, 1990) and no doubt the nature of the leaf surface, although no literature on the latter was located. Based on the work of Lindberg et al. (1959), Romney et al. (1963), several papers cited in IAEA (1994) and Simon (1990), the 5th, 50th, and 95th quantiles chosen for alpha were 0.3, 3.0, and 10 m^2/kg, respectively. These, along with the biomass values, were used to compute F_i quantiles based on the Chamberlain (1970) equation. Other literature consulted was Pinder (1988) and Breshears et al. (1989).

For wet deposition, interception fractions were estimated from tabulated estimates of F_i/B (IAEA, 1994) and the biomass values provided in the question. Some 43 estimates of F_i/B were used to compute a mean of 3.35 m^2/kg and 5th and 95th quantiles of 0.3 and 8.7 m^2/kg. These were multiplied by the given biomass values to estimate the distribution statistics for F_i (wet deposition).

For unknown deposition, the means of wet and dry interception fractions were used for the 50% quantile. The 5th and 95th quantiles employed the extremes for all the data.

An unsupported assumption was made that the fraction intercepted by grain would be 0.01 and 0.1 that intercepted by green foliage for dry and wet deposition, respectively. The rationale was that the grain is covered by a sheath prior to harvest and is thus protected. Wet deposition might allow for some solubilization of the contaminant and subsequent transport to grain. Near zero interception fractions were arbitrarily assumed for root crops since most tubers are totally or largely underground, and in any case they have a relatively low surface to volume ratio.

Question 5. Resuspension Factors:

Resuspension can be an important process, particularly soon after a fresh deposit under dry, windy conditions in open areas. It is influenced by many variables and thus measurements have exhibited variations extending over several orders of magnitude (Sehmel, 1980). It has a pronounced time dependence that results primarily from the downward percolation of contaminants into the soil. Anspaugh et al. (1975) have shown that this time dependence can be described by an exponential decline in the resuspendible material, the half-time of which is about

35 days for the first several months. The initial value used in the PATHWAY model (Whicker and Kirchner, 1987) was 10^{-5}/m, a value which tended to provide relatively good model predictions for arid and semi-arid regions in the Western US. For the eastern US, it is believed that resuspension is somewhat less, due to wetter, more heavily vegetated conditions on average. I thus used 0.5×10^{-5}/m as the initial value. Assuming a 60 day integration time for crops, and a 35 day percolation half-time, a value of 3×10^{-6}/m is estimated as the 50% quantile. To capture the wide range of possible values over the US, a factor of 50 was used to estimate the 5th and 95th quantiles. A further adjustment for pasture grass was made, based on a longer integration period (180 days) as well as an assumed lower initial resuspension factor (10^{-6}/m). The latter was rationalized on the basis of less bare soil for pasture than for surface crops (on average through the growing season).

Question 6. Retention Times:

The retention half-time of radionuclides on vegetation is a very important parameter in food chain models. Fortunately, there has been a considerable amount of research on the topic and the uncertainty spread tends to be smaller than for many other parameters. There is not much evidence for significant differences between crops and half-times do not seem to vary greatly under different environmental conditions. Most radionuclides are retained with a half-time of around 14 days (Hoffman and Baes, 1979; IAEA, 1994) although I is retained with a half-time of only about 10 days due to volatilization (review by Snyder et al. 1992). If time dependent measurements are based on activity per unit mass, grazing does not affect the retention half-time; if based on activity per unit area however, the retention is reduced by an amount dependent on the intensity of grazing. My estimates for pasture grass with grazing assumed a plant biomass grazing loss of about 0.01/day.

Question 7. Concentrations in Grain at Harvest:

This question asks for the concentration of Cs or Sr in grain (Bq/kg) per unit deposition on the ground (Bq/m^2) at various times prior to harvest. My approach was first to estimate the fraction of the deposit intercepted by the grain plant using the Chamberlain (1970) model with an α value of 3 m^2/kg and a dry biomass of 0.1 kg/m^2. The uncertainty in these numbers produced 5%, 50%, and 95% quantiles for the deposit on the grain plant of 0.02, 0.25, and 0.87 Bq/m^2, respectively. These values were then multiplied by translocation factors (m^2/kg) tabulated for grain as a function of time before harvest in IAEA (1994). Several references were used in the IAEA review, but the work of Aarkrog (1969, 1975) and Middleton (1959) was largely used. The translocation factors would include interception plus translocation as the primary mechanism. The research work used soluble tracers, so material deposited in less soluble forms would not be as efficiently translocated to grain. The lower bound (5%) of 0.1 the 50% value should cover this situation. The 95% quantile was based on differences in experimental results.

Question 8. Concentrations in Root Crops/Green Vegetables:

This question asks for the concentrations of Cs and Sr in root crops and green vegetables (Bq/kg wet) per unit deposition on the plant (Bq/m^2) at various times prior to harvest. The primary source found for this particular measurement was some work by Middleton (1959) for potatoes. These values were scaled from potatoes (root crops) to green vegetables using data from Seel et al. (1995). The ratios between quantiles was set at 10 rather arbitrarily, but in consideration of the experimental error in this and similar work.

Question 9. Correlations:

To my knowledge, direct experiments or statistical analyses to test for correlations among the parameters elicited have not been carried out. However, some of the parameters affected by the same functional processes should exhibit some degree of correlation. For example, the degree of radionuclide fixation in soil should have a strong effect on both soil migration and root uptake. The correlation would not be expected to be perfect because only a portion of the radionuclide becomes fixed, and other processes or conditions also affect migration and root uptake. There should be a number of other correlations among parameters but most should be only moderate to weak.

Some parameters are not radionuclide specific, such as foliar interception and resuspension. In this case a value chosen for Cs would also apply to Sr, for example, thus inducing a correlation. Soil differences, e.g., clay vs. sandy soil will affect the mobility of both radionuclides in a generally similar way.

Additional Questions – Soil and Plants

1. (a) Soil Migration

This was estimated using the soil retardation equation presented by Baes and Sharp (1981) which computes a leaching rate constant for loss from a given soil thickness based on net infiltration of water and a retardation term dependent on the soil K_d and volumetric water content. A K_d value for Cs of 1,800 ml/g was based on a review of K_d values by Sheppard and Thibault (1990). The computed values were used as the 50% quantiles. The 95% quantiles used the rationale that biological and mechanical forces could hasten the rate of migration.

1. (b) Soil Migration.

This was not attempted.

2. (a) Root Uptake Concentration Factors.

The requested units were Bq/kg plant per Bq/m^2 soil. Thus soil penetration is important. Time is not specified, nor is the fertilizer regime. For these reasons, this question was not attempted.

3. (b) Root Uptake Concentration Factors.

The rationale and values would be the same as for pasture grass in question 3. This was indicated to be Chernobyl fallout, but the distance from Chernobyl was not specified. My expectation would be that the solubility of Chernobyl fallout particles would increase with distance (and possibly over time) from the accident site. I believe the ranges would cover the uncertainty in the initial particle solubility.

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1. Soil migration

Generic soil in region of interest within the US

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.4	2	10	0.14	0.7	3.5
Below 5 cm	4	20	100	1.4	7	35
Below 15 cm	30	150	750	10	50	250
Below 30 cm	60	300	1500	20	100	500

Generic soil in region of interest within Europe

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.4	2	10	0.14	0.7	3.5
Below 5 cm	4	20	100	1.4	7	35
Below 15 cm	30	150	750	10	50	250
Below 30 cm	60	300	1500	20	100	500

Sandy soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.1	1	10	0.03	0.3	3
Below 5 cm	7	10	100	0.3	3	30
Below 15 cm	7.5	75	750	2.5	25	250
Below 30 cm	15	150	1500	5	50	500

Highly organic soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.1	1	10	0.1	0.6	6
Below 5 cm	1	10	100	0.5	5	50
Below 15 cm	7.5	75	750	4	40	400
Below 30 cm	15	150	1500	8	80	800

2. Fixation of Cesium and strontium in soil

Generic soil in regions of interest within the US

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.2	0.4	0.7	0.05	0.3	0.5
3 years	0.2	0.5	0.8	0.05	0.3	0.5
5 years	0.2	0.6	0.9	0.05	0.3	0.5
10 years	0.2	0.7	0.9	0.05	0.3	0.5

Sandy soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.3	0.6	0.05	0.2	0.4
3 years	0.1	0.4	0.7	0.05	0.2	0.4
5 years	0.1	0.5	0.8	0.05	0.2	0.4
10 years	0.1	0.5	0.8	0.05	0.2	0.4

Highly organic soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.3	0.6	0.05	0.3	0.5
3 years	0.1	0.4	0.7	0.05	0.3	0.5
5 years	0.1	0.4	0.7	0.05	0.3	0.5
10 years	0.1	0.4	0.7	0.05	0.3	0.5

Generic soil in regions of interest within Europe

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.2	0.4	0.7	0.05	0.3	0.5
3 years	0.2	0.5	0.8	0.05	0.3	0.5
5 years	0.2	0.6	0.9	0.05	0.3	0.5
10 years	0.2	0.7	0.9	0.05	0.3	0.5

3. Root uptake concentration factors

6 months after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.004	0.04	0.4	0.05	0.5	5
Grain	0.0009	0.009	0.09	0.01	0.1	1
Root vegetables	0.0008	0.008	0.08	0.02	0.2	2
Potatoes	0.001	0.01	0.1	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.03	0.3	3	0.1	1	10
Grain	0.003	0.03	0.3	0.02	0.2	2
Root vegetables	0.008	0.08	0.8	0.04	0.4	4
Potatoes	0.008	0.08	0.8	0.006	0.06	0.6
Pasture grass	0.01	0.1	1	0.04	0.4	4

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.2	2	0.005	0.05	0.5
Grain	0.007	0.07	0.7	0.002	0.02	0.2
Root vegetables	0.008	0.08	0.8	0.004	0.04	0.4
Potatoes	0.008	0.08	0.8	0.0004	0.004	0.04
Pasture grass	0.01	0.1	1	0.007	0.07	0.7

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.004	0.04	0.4	0.05	0.5	5
Grain	0.0009	0.009	0.09	0.01	0.1	1
Root vegetables	0.0008	0.008	0.08	0.02	0.2	2
Potatoes	0.001	0.01	0.1	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

1 year after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.03	0.3	0.05	0.5	5
Grain	0.0007	0.007	0.07	0.01	0.1	1
Root vegetables	0.0006	0.006	0.06	0.02	0.2	2
Potatoes	0.0008	0.008	0.08	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.2	2	0.1	1	10
Grain	0.002	0.02	0.2	0.02	0.2	2
Root vegetables	0.006	0.06	0.6	0.04	0.4	4
Potatoes	0.006	0.06	0.6	0.006	0.06	0.6
Pasture grass	0.008	0.08	0.8	0.04	0.4	4

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.2	2	0.005	0.05	0.5
Grain	0.006	0.06	0.6	0.002	0.02	0.2
Root vegetables	0.006	0.06	0.6	0.004	0.04	0.4
Potatoes	0.006	0.06	0.6	0.0004	0.004	0.04
Pasture grass	0.008	0.08	0.8	0.007	0.07	0.7

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.03	0.3	0.05	0.5	5
Grain	0.0007	0.007	0.07	0.01	0.1	1
Root vegetables	0.0006	0.006	0.06	0.02	0.2	2
Potatoes	0.0008	0.008	0.08	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

3 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.03	0.3	0.05	0.5	5
Grain	0.0007	0.007	0.07	0.01	0.1	1
Root vegetables	0.0006	0.006	0.06	0.02	0.2	2
Potatoes	0.0008	0.008	0.08	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.2	2	0.1	1	10
Grain	0.002	0.02	0.2	0.02	0.2	2
Root vegetables	0.006	0.06	0.6	0.04	0.4	4
Potatoes	0.006	0.06	0.6	0.006	0.06	0.6
Pasture grass	0.008	0.08	0.8	0.04	0.4	4

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.2	2	0.005	0.05	0.5
Grain	0.006	0.06	0.6	0.002	0.02	0.2
Root vegetables	0.006	0.06	0.6	0.004	0.04	0.4
Potatoes	0.006	0.06	0.6	0.0004	0.004	0.04
Pasture grass	0.008	0.08	0.8	0.007	0.07	0.7

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.03	0.3	0.05	0.5	5
Grain	0.0007	0.007	0.07	0.01	0.1	1
Root vegetables	0.0006	0.006	0.06	0.02	0.2	2
Potatoes	0.0008	0.008	0.08	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

10 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.03	0.3	0.05	0.5	5
Grain	0.0007	0.007	0.07	0.01	0.1	1
Root vegetables	0.0006	0.006	0.06	0.02	0.2	2
Potatoes	0.0008	0.008	0.08	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.2	2	0.1	1	10
Grain	0.002	0.02	0.2	0.02	0.2	2
Root vegetables	0.006	0.06	0.6	0.04	0.4	4
Potatoes	0.006	0.06	0.6	0.006	0.06	0.6
Pasture grass	0.008	0.08	0.8	0.04	0.4	4

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.2	2	0.005	0.05	0.5
Grain	0.006	0.06	0.6	0.002	0.02	0.2
Root vegetables	0.006	0.06	0.6	0.004	0.04	0.4
Potatoes	0.006	0.06	0.6	0.0004	0.004	0.04
Pasture grass	0.008	0.08	0.8	0.007	0.07	0.7

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.03	0.3	0.05	0.5	5
Grain	0.0007	0.007	0.07	0.01	0.1	1
Root vegetables	0.0006	0.006	0.06	0.02	0.2	2
Potatoes	0.0008	0.008	0.08	0.003	0.03	0.3
Pasture grass	0.002	0.02	0.2	0.02	0.2	2

4. Interception factors

Wet deposition

Crop	5%	50%	95%
Green vegetables	0.06	0.67	0.95
Grain	0.01	0.10	0.30
Root vegetables	0	0.01	0.10
Grass for hay/silage	0.02	0.20	0.52
Pasture	0.03	0.34	0.87

Dry deposition

Crop	5%	50%	95%
Green vegetables	0.06	0.45	0.87
Grain	0.001	0.007	0.01
Root vegetables	0	0.01	0.02
Grass for hay/silage	0.02	0.17	0.45
Pasture	0.03	0.26	0.63

Unknown deposition

Crop	5%	50%	95%
Green vegetables	0.06	0.56	0.95
Grain	0.001	0.054	0.3
Root vegetables	0.000001	0.01	0.1
Grass for hay/silage	0.02	0.19	0.52
Pasture	0.03	0.3	0.87

5. Resuspension factor

Resuspension factor

Crop	5%	50%	95%
Surface crop	6×10^{-8}	3×10^{-6}	1×10^{-4}
Pasture grass	6×10^{-9}	3×10^{-7}	1×10^{-5}

6. Retention times

Retention times

Crop	5%		50%		95%	
	Cs/Sr	I	Cs/Sr	I	Cs/Sr	I
Green vegetables	8	4	14	10	20	18
Grass for silage/hay	8	4	14	10	20	18
Pasture grass without grazing	8	4	14	10	20	18
Pasture grass with grazing	5	3	12	9	20	16

7. Concentrations in grain at harvest

Strontium

Time before harvest	5%	50%	95%
15 days	0.001	0.013	0.13
30 days	0.001	0.014	0.14
60 days	0.0002	0.002	0.02
90 days	2E-07	0.000002	0.00002

Cesium

Time before harvest	5%	50%	95%
15 days	0.002	0.024	0.24
30 days	0.005	0.045	0.45
60 days	0.004	0.04	0.4
90 days	0.002	0.015	0.15

8. Concentrations in root crops

Strontium

Time before harvest	5%	50%	95%
15 days	0.000001	0.00001	0.0001
30 days	1.4E-06	0.000014	0.00014
60 days	3.4E-06	0.000034	0.00034
90 days	9.6E-06	0.000096	0.00096

Cesium

Time before harvest	5%	50%	95%
15 days	0.0008	0.008	0.08
30 days	0.001	0.012	0.12
60 days	0.0015	0.015	0.15
90 days	0.003	0.03	0.3

8a. Concentrations in green vegetables

Strontium

Time before harvest	5%	50%	95%
15 days	0.000002	0.00002	0.0002
30 days	0.000003	0.00003	0.0003
60 days	0.000007	0.00007	0.0007
90 days	0.00002	0.0002	0.002

Cesium

Time before harvest	5%	50%	95%
15 days	0.002	0.02	0.2
30 days	0.002	0.02	0.2
60 days	0.003	0.03	0.3
90 days	0.006	0.06	0.6

EXPERT B

Question 1. Soil Migration

As the basis for estimating soil migration half-times, the soil leaching coefficient (Baes, 1979) was calculated using the following equation:

$$\lambda_s = \frac{V_a}{d\left(1 + \frac{K_d \cdot Q}{\phi}\right)} \qquad (1)$$

where:

λ_s = soil leaching coefficient (a^{-1})
d = depth of soil layer considered (m)
V_a = velocity of soil water percolation ($m\ a^{-1}$)
K_d = solid liquid distribution coefficient ($cm^3\ g^{-1}$)
ρ = soil bulk density ($g\ cm^{-3}$)
ϕ = soil water content ($g\ g^{-1}$)

This approach is used in many recognized radioecological models within the European context, such as SPADE (Coughtrey, 1988) and ECOSYS 87 (Müller and Pröhl, 1993). It was considered that of the five parameters required by this equation, the solid-liquid distribution coefficient (K_d) is most likely to exhibit the largest degree of variability and hence sensitivity. Table 1 indicates the likely ranges of K_d values for both Cs and Sr for a variety of soil types.

Table 1. Estimates and ranges of K_d values for both Cs and Sr for various soil types

Radionuclide(s)	Solid-Liquid Distribution Coefficient	Notes	Source
^{137}Cs	5530	24.5% clay	Staunton (1994)
^{137}Cs	57800	51.4% clay	"
^{137}Cs	44600	41.5% clay	"
^{137}Cs	11600	41.5% clay	"
^{137}Cs	5000 - 10000	sandy loam	Rajec
Cs	0.2 - 10000	sand soil	and
"	560 - 61287	loam soil	Shaw
"	37 - 31500	clay soil	(1994)
"	0.4 - 145000	organic soil	Sheppard
Sr	0.05 - 190	sand soil	and
"	0.01 - 300	loam soil	Thibault
"	3.6 - 32000	clay soil	(1990)
"	8 - 4800	organic soil	"
			"
			"
			"
			"

It was considered that upper and lower limits should be set for this exercise within the ranges of K_d values suggested by the available data. For ^{137}Cs, the lower limit chosen was 1000 (the default K_d value used by the ECOSYS model), while the upper limit chosen was 57800 (a "high" K_d estimate made for a clayey soil by Staunton, 1994). For ^{90}Sr, the lower limit chosen was 500, while the upper limit chosen was 10000. These were somewhat arbitrary choices, being well within the possible ranges defined by Sheppard and Thibault (1990). However, the leaching rates predicted using these K_d estimates bracketed the rates observed by Frissel and Penders (1983; see below).

For a given soil layer thickness (i.e., 1, 5, 15 or 30 cm) the λ_s value was calculated using equation 1. From this estimate the migration half-time for the radionuclide in question (τ_r) from:

$$\tau_r = \frac{\ln(2)}{\lambda_s} \qquad (2)$$

This estimate of τ_r can be used to estimate the migration velocity for a soil layer of a given thickness:

$$V_r = \frac{d}{\tau_r} \qquad (3)$$

This velocity is usually expressed in units of $cm\ y^{-1}$. Conversely, if the average migration velocity of a radionuclide within a soil is known, the residence half-time for a soil layer of a given thickness can be estimated as:

$$\tau_r = \frac{d}{V_r} \qquad (4)$$

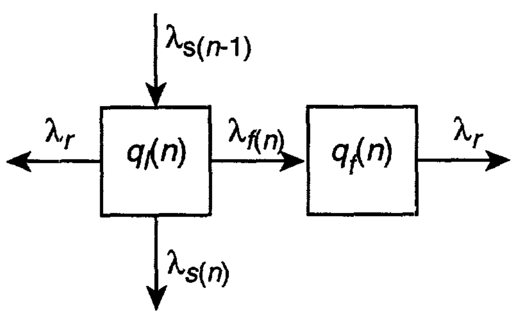
Frissel and Penders (1983) made estimates of mean soil migration velocities for both ^{137}Cs and ^{90}Sr of 0.5 $cm\ y^{-1}$ and 1 $cm\ y^{-1}$, respectively. The estimate for ^{90}Sr, derived for a series of soils at 14 sites in the Netherlands, West Germany, Italy, Greece, France and the UK, is particularly reliable. This is of considerable importance due to the relative lack of data on ^{90}Sr migration when compared with that on ^{137}Cs migration. Estimates of ^{90}Sr migration half-times for a "generic" soil are therefore based around this migration velocity.

In using the simple leaching coefficient, the process of soil fixation (which is especially important for ^{137}Cs in mineral soils) is ignored. While this process is poorly understood from the modeling standpoint, its effects are usually incorporated into soil leaching models as a first-order rate process for which a coefficient of fixation (λ_f) can be estimated. Table 2 shows estimates of both ^{137}Cs and ^{90}Sr fixation rate coefficients.

Table 2. Estimates of fixation rate coefficients (lf) for ^{137}Cs and ^{90}Sr in soil

Radionuclide(s)	Fixation Rate Coefficient, λ_f (d^{-1})	Notes	Source
^{137}Cs	0.00022	ECOSYS default	Frissel and Koster (1987)
^{137}Cs/^{134}Cs	0.00180	sandy loam	ICSTM lysimeter data (Pearce, 1992)
^{90}Sr	0.00009	ECOSYS default	Frissel and Koster (1987)

These rate coefficients were used to modify the migration half-time estimates obtained directly from λ_s using equation 2. This was achieved by running a compartmental leaching model (SLM) to calculate effective radionuclide migration over the desired depth increments. SLM has a structure similar to that described by Bunzl et al. (1994) which these authors used to estimate effective migration half-times for Cs, Pu and Np in German soils. The structure of the model for the nth soil layer is:



for which the reaction rates are represented as a pair of first-order differential equations.

$$\frac{dq_1(n)}{dt} = [\lambda_s(n-1) \bullet q_1(n-1)] - [\lambda_f(n) \bullet q_1(n)] - [\lambda_s(n) \bullet q_1(n)] - [\lambda_r \bullet q_1(n)]$$

$$\frac{dq_f(n)}{dt} = [\lambda_f(n) \bullet q_1(n)] - [\lambda_r \bullet q_1(n)]$$

The complete system of equations is solved numerically using an Euler algorithm. The model therefore uses (i) leaching rate coefficients (λ_s), (ii) fixation rate coefficients (λ_f) and (iii) radioactive decay rate coefficients (λ_r). The latter were set to zero for the present exercise as the question concerned the fate of 50% of the original surface deposit. It was felt that interpretation of the physical migration rates would be confused by the addition of radioactive decay, although this can be readily incorporated.

The fixation rates used by the SLM calculations were those of Frissel and Koster (1987). For even moderately high K_d values, fixation without radioactive decay can reduce migration velocities to near zero values and the use of the ICSTM λ_f values resulted in extremely retarded migration rates.

As a final check on the migration half-times, estimates were compared with reported soil profiles in the literature from migration half-times could be inferred. These were placed within the framework of estimates derived using the process described above.

The results are shown in Tables 4 and 5 which formed the basis for estimates made of cesium and strontium migration half-times in the range of soils of interest.

Notes on estimates provided for "seed variable" questions

The estimates provided for "seed variable" question 1(a) were obtained by running the SLM model with appropriate leaching rate parameter estimates, assuming that all the radionuclide inventory was initially contained within the surface 1-cm layer.

Question 1(b) required a more involved procedure. The method adopted was to use the three vertical radiocesium distributions provided to calibrate the SLM model, which was then run over the required time periods to estimate the effect of leaching parameter changes over the ranges explored above.

The success of this technique clearly depends on the initial calibration of the model to the data provided. For soils 1 and 3 this proved possible within "acceptable" margins, although in order to reproduce the given profiles a relatively rapid leaching rate had to be used in conjunction with a fixation rate >0 in the topmost (1 cm) soil layer. This may reflect the fact that in the type of pasture for which the profiles were provided, recycling of radiocesium within the grass may cause a preferential retention in the surface soil layer.

The profile presented for soil 2 proved more difficult to reproduce and the author wishes to point out that the *estimates provided for the evolution of the radiocesium activity profile in soil 2 should be treated with caution.*

Table 3. Framework of soil migration half-times (years) used in generic assessment of ^{137}Cs leaching rates

Soil Depth (cm)	K_d = 1.0E+03	K_d = 5.5E+03	K_d = 5.5E+03	Bunzl et al. (1994)	K_d = 5.78E+04
	*	*		¤	*
1	0.0665	0.366	0.38	1.50	3.84
5	0.332	1.83	2.25	11.75	19.2
15	0.997	5.48	11.00	41.00	57.6
30	1.994	10.97	-	64.50	115.3

* Estimates of half-times from leaching rate coefficients. Soil fixation included (rate coefficient 2.2E-04/d).
¤ Half-times calculated using *effective* residence half-times reported for Bavarian "pasture soil".
** Caput et al. (1990) — "pasture soils," eastern France
Howard et al. (1990) — peat soil, Cumbria UK
Konshin (1992) — "soddy-podzolic" soil, Byelorussia
Howard et al. (1990) — brown earth, Cumbria, UK
Colgan et al. (1990) — peaty podzol and organic heath soils
Frissel and Penders (1983) — fitted average for fallout ^{137}Cs in Dutch clay soil

Table 4. Framework of soil migration half-times (years) used in generic assessment of ^{90}Sr leaching rates

Soil Depth (cm)	K_d = 5.0E+02	K_d = 5.0E+03	K_d = 5.5E+03	Frissel and Penders	K_d = 1.0E+04
	*	*		¤	
1	0.03	0.33	0.38	0.50	0.69
5	0.17	1.66	2.13	2.50	4.00
15	0.50	4.99	8.00	7.50	16.75
30	1.00	9.97	19.50	15.00	>100

* Estimates of half-times from leaching rate coefficients. Soil fixation included (rate coefficient 9.0E-05/d).
¤ Based on average migration velocity of 1 cm/y.

Question 2. Fixation of cesium and strontium in soil

Two starting assumptions were made in this section of the evaluation.

The first was that the initial fraction available for plant uptake was less than 100% (considerably so in the case of cesium), and the second was that the fixation rates given in Table 2 could be applied to indicate the time trend of fixation of the initially available cesium and strontium.

One problem encountered in this part of the elicitation was the definition of availability to plants. This has been taken to be equivalent to a chemically extractable fraction, usually defined as the fraction exchangeable with a monocationic salt applied in excess (commonly ammonium acetate).

Based on the author's own experience, "best estimates" for the starting percentages which are extractable in this way are 15% for cesium and 90% for strontium. These estimates are based on a sandy loam soil. Estimates of the time dependency of fixation are based on these starting values modified by the first order fixation rates reported in Table 2.

Question 3. Root uptake concentration factors

Root uptake concentration factors were taken from the International Union of Radioecologists (IUR) database. In the 1989 report from the IUR meeting at Grimselpass, Switzerland, the database is given in printed form. This database contains approximately 7700 individual soil-to-plant transfer factors, although for individual combinations of crops and soil types the number of available data may be considerably less. Nevertheless, all these data have been collected according to a strict protocol established by the IUR and the database represents probably the most comprehensive collection of such data.

As a starting point in the derivation of suitable values for the present exercise, the IUR's recommended soil-to-plant transfer factor (TF) values were taken. These are given in the 1989 report for all the vegetable types and all the soil types required for the current exercise. Furthermore, 95% confidence ranges are presented around the "best estimates" (geometric means calculated by multiple linear regression) of the database.

The major problem in applying this database to the current exercise is that of the time dependency of TF values. The 1989 IUR report provides a summary of a comprehensive multivariate statistical analysis for soil-to-plant transfer factors for radiocesium and radiostrontium, carried out by

Frissel and Heisterkamp. The two main factors included in this analysis were soil pH and the residence time of the radionuclide in the soil, for which the following expression is presented:

$$TF_{corr} = TF_{std} \bullet CF_t^{(T-2)} \bullet CF_{pH}^{(pH-6)} \qquad (5)$$

where

TF_{corr} is a corrected transfer factor,

TF_{std}* is a "standard" transfer factor relating to a soil of pH 6 which has been contaminated for 2 years. The TF_{std} used in these calculations is the recommended value given by Frissel and Heisterkamp (1989).

CF_t is a correction factor relating to the residence time of the radionuclide within the soil

CF_{pH} is a correction factor relating to the soil pH, and

T is the residence time (in years) of the radionuclide within the soil.

For the current exercise the radionuclide residence time within the soil was considered as the prime variable, although a correction had also to be applied to the IUR transfer factor values to convert them from a dry weight basis to a wet weight basis. The correction adopted, therefore, was:

$$TF_{corr} = TF_{std} \bullet CF_t^{(T-2)} \qquad (6)$$

where $\frac{DW}{WW}$ is the dry weight to wet weight ratio.

Question 4. Interception Factors

Two sets of model calculations were run in order to evaluate the ranges of interception factors attributable to (i) dry and (ii) wet deposition.

(i) Dry Deposition

Chamberlain's (1970) equation describing the exponential filtration of aerosols and vapors by plant canopies of different densities was used to predict ranges of dry interception factors:

$$f = 1 - \exp^{-\mu W} \qquad (7)$$

Here W is the herbage density (defined in the elicitation questionnaire) and μ is an "absorption coefficient." This latter parameter may be assigned a range from 2.30 to 3.33 $m^2\ kg^{-1}$, according to Chamberlain's experimental findings. This range of values was used in conjunction with the prescribed plant densities to give a predicted range of dry interception factors. This was then compared to and supplemented by a range of dry interception factors obtained from MAFF/ICSTM data library of wind tunnel-derived deposition data (Goddard et al., 1993).

(ii) Wet Deposition

Müller and Pröhl's (1993) expression describing the variation of wet interception with:

leaf area index (LAI)
retention coefficient (S, mm) and
rainfall amount (R, mm)

was used to define the likely range of the wet deposition factor, f:

$$f = \frac{LAI \bullet S}{R}\left[1 - \exp\left(\frac{-\ln(2)}{3S} \bullet R\right)\right] \qquad (8)$$

estimates of the likely range of LAI were made from the herbage density values provided. The ranges of rainfall were based on 1-hr precipitation events using upper and lower limits for rainfall intensity of 1 mm h^{-1} and 10 mm h^{-1}. These values were culled from Simmons (1980) who describes the former as being typical for frontal rain within the UK (the most common type of rain) while the latter is more typical of less frequent storm events.

The final range of values of the interception factor under both dry and wet conditions were combined to give the (admittedly large) range of values presented.

Question 6. Retention Times

Ranges of retention times were simply taken from a variety of published papers on the topic. It is clear that they vary very widely and there is little apparent pattern between types of deposit or between plant types. For this reason the same range of retention half-times was applied to each of the crop types requested. Principal data sources were Fraley et al. (1993), Kinnersley et al. (1996), Kirchner (1994), Miller and Hoffman (1982) and Simmonds (1983).

Question 7. Concentrations in Grain at Harvest

In order to estimate ranges of radionuclide concentration in grain at harvest following different periods of translocation from foliar surfaces, two models and one set of translocation ratios were employed. The models used were from Aarkrog (1983):

i. $\mu(t) = Ae^{-k(t-b)2}$ (9)

where

$\mu(t)$	=	the activity in mature grain at harvest (Bq kg^{-1})
A	=	$\mu(t)_{max}$ (when t = b)
k	=	a constant determining the gradient of the curve
b	=	the time when a single deposit will result in maximal contamination of the grain
t	=	the time before harvest when the crop has received 1 Bq m^{-2}.

from Shaw et al. (1992):

$$\text{ii.} \quad TF(t) = \frac{k_{fa}(0)}{k_{lg} - 1} \left(e^{-lt} - e^{-k_{lg} \bullet t}\right) \quad (10)$$

where

TF(t)	=	the foliage → grain translocation factor (Bq kg^{-1} / Bq kg^{-1})
k_{fa}	=	a rate coefficient of foliar absorption, taken to be 1.0 at the time of contamination
k_{lg}	=	a rate coefficient of radionuclide loss from the grain tissue
λ	=	a rate coefficient of loss of radionuclide from foliar surfaces
t	=	time following contamination.

Estimates of $\mu(t)$ obtained using equation 9 provided Bq kg^{-1} values of direct applicability to the question. Aarkrog (1983) reported relationships for both radiostrontium and radiocesium which were based on considerably detailed experimental studies in Denmark using field crops sprayed with soluble radionuclide sources. These data are considered to be very reliable, although no ranges of parameter values were given and, as the relationships are purely empirical, it is impossible to express uncertainties around the predictions of equation 9. This relationship was therefore used to provide the 50% estimates shown in the results table.

TF(t) values obtained using equation 10 had to be modified to provide suitable answers to question 7. The initial capture of the total 1 Bq m^{-2} deposit by the crop canopy had first to be estimated and then expressed as a Bq kg^{-1} value to which the TF(t) could be applied. Using the spread of interception fraction values reported in question 4 in conjunction with the range of crop biomass densities used to generate these values, a range of initial crop contamination values (Bq kg^{-1}) was generated. This was used as the basis for setting 5% and 95% limits on the grain contamination estimates. However, while Shaw et al. (1992) reported values for the constants used in calculating radiocesium translocation factors they consistently found no measurable radiostrontium contamination.

The same range of initial crop contamination values as described above was used in conjunction with Müller and Pröhl's (1993) reported foliage to grain translocation factors to give a further set of estimates of 5% and 95% limits on grain contamination estimates. These authors reported translocation factors for "mobile" and "immobile" elements. Cesium can be taken to belong to the former class while strontium belongs to the latter. Müller and Pröhl translocation factors for strontium allowed the establishment of 5% and 95% limits about the 50% estimates for strontium contamination determined using Aarkrog's model. It should be noted, however, that for strontium contaminating wheat 90 days before harvest, Müller and Pröhl translocation factors are zero, in accordance with Shaw et al.'s (1992) finding.

For cesium the final ranges of values were set using the lowest or highest (according to whether the 5th or 95th percentile was being considered) grain contamination estimates obtained from Shaw et al.'s model and Müller and Pröhl translocation factors, taken in combination.

Question 8. Concentrations in Root Crops

In the case of translocation from foliage to root crops, experimental work at Imperial College consistently showed zero movement of radiostrontium (Pearce, 1992). In accordance with this finding is the use by Müller and Pröhl (1993) of "no translocation" values for "immobile elements" contaminating the foliar surfaces of root crops at any time before harvest. On this basis, no data are presented for strontium.

Translocation ratios for radiocesium from foliage to root crops are available from both Müller and Pröhl publication and the Imperial College experiments. These have been used as the basis for the answers given to question 8, although they are more limited and no distinction is made between 15 and 30 day, and 60 and 90 day contamination events.

The ranges of values reported are based on combined translocation factor estimates from Müller and Pröhl(1993) and Imperial College, applied to a situation in which the initial capture by the crop of the 1 Bq m^{-2} deposit varies according to the interception fraction ranges given in answer to question 4. The initial Bq kg^{-1} value is calculated on the basis of these interception fractions and the assumption that the standing biomass of the above ground tissues of the crops is 1 kg m^{-2}.

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1. Soil migration

Generic soil in region of interest within Europe

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.3	1.5	4	0.05	0.4	0.7
Below 5 cm	1.8	12	19	0.2	2	4
Below 15 cm	5.5	40	58	0.7	7	15
Below 30 cm	10	65	115	1.5	15	30

Sandy soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.07	0.5	2	0.02	0.07	0.3
Below 5 cm	0.33	2	14	0.1	0.35	2
Below 15 cm	1	5.5	45	0.4	1	6
Below 30 cm	2	12	70	0.75	2.5	10

Highly organic soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.1	0.4	3.8	0.03	0.3	0.4
Below 5 cm	0.5	3	19	0.17	1.7	2.25
Below 15 cm	1.5	6	55	0.5	4.5	8.5
Below 30 cm	3	15	100	1	10	20

2. Fixation of Cesium and strontium in soil

Sandy soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.63	0.81	0.91	0.06	0.12	0.22
3 years	0.68	0.84	0.92	0.12	0.18	0.27
5 years	0.73	0.86	0.93	0.17	0.24	0.32
10 years	0.82	0.9	0.95	0.28	0.35	0.42

Highly organic soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.35	0.67	0.82	0.1	0.18	0.66
3 years	0.44	0.72	0.84	0.14	0.23	0.68
5 years	0.53	0.77	0.87	0.18	0.29	0.7
10 years	0.68	0.8	0.91	0.2	0.4	0.75

Generic soil in regions of interest within Europe

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.72	0.85	0.95	0.08	0.12	0.27
3 years	0.76	0.88	0.96	0.12	0.18	0.32
5 years	0.8	0.9	0.97	0.18	0.24	0.36
10 years	0.86	0.93	0.98	0.3	0.35	0.46

3. Root uptake concentration factors

6 months after deposition

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.002	0.017	0.157	0.042	0.203	1.005
Grain	0.01	0.065	0.48	0.122	0.556	2.449
Root vegetables	0.0001	0.007	0.087	0.027	0.128	0.607
Potatoes	0.007	0.048	0.388	0.015	0.069	0.335
Pasture grass	0.007	0.048	0.339	0.109	0.482	2.093

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.01	0.104	0.004	0.021	0.2
Grain	0.005	0.044	0.349	0.012	0.057	0.292
Root vegetables	0.0001	0.004	0.056	0.001	0.008	0.1
Potatoes	0.001	0.034	0.5	0.001	0.008	0.1
Pasture grass	0.004	0.029	0.242	0.01	0.052	0.5

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.014	0.145	0.021	0.147	0.837
Grain	0.008	0.057	0.436	0.075	0.377	2.073
Root vegetables	0.0001	0.005	0.1	0.02	0.105	0.6
Potatoes	0.006	0.046	0.363	0.008	0.052	0.272
Pasture grass	0.005	0.039	0.315	0.067	0.335	1.779

1 year after deposition

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.002	0.016	0.148	0.041	0.2	0.99
Grain	0.009	0.061	0.45	0.121	0.547	2.412
Root vegetables	0.0001	0.007	0.082	0.027	0.126	0.598
Potatoes	0.007	0.045	0.364	0.014	0.068	0.33
Pasture grass	0.006	0.045	0.318	0.107	0.474	2.062

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.009	0.098	0.004	0.021	0.2
Grain	0.005	0.041	0.327	0.012	0.056	0.288
Root vegetables	0.0001	0.004	0.052	0.001	0.008	0.1
Potatoes	0.001	0.032	0.5	0.001	0.008	0.1
Pasture grass	0.003	0.027	0.227	0.01	0.052	0.5

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.013	0.136	0.021	0.144	0.825
Grain	0.007	0.053	0.409	0.074	0.371	2.041
Root vegetables	0.0001	0.005	0.1	0.02	0.103	0.6
Potatoes	0.005	0.043	0.341	0.008	0.052	0.268
Pasture grass	0.005	0.036	0.295	0.066	0.33	1.753

3 years after deposition

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.012	0.114	0.039	0.188	0.931
Grain	0.007	0.048	0.348	0.113	0.515	2.27
Root vegetables	0.0001	0.005	0.063	0.025	0.118	0.563
Potatoes	0.005	0.035	0.282	0.014	0.064	0.31
Pasture grass	0.005	0.035	0.246	0.101	0.446	1.94

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.007	0.076	0.004	0.019	0.2
Grain	0.004	0.032	0.253	0.011	0.052	0.271
Root vegetables	0.0001	0.003	0.04	0.001	0.008	0.1
Potatoes	0.001	0.25	0.5	0.001	0.008	0.1
Pasture grass	0.003	0.021	0.176	0.01	0.049	0.5

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.01	0.106	0.019	0.136	0.776
Grain	0.006	0.041	0.317	0.07	0.349	1.921
Root vegetables	0.0001	0.004	0.09	0.02	0.097	0.6
Potatoes	0.004	0.033	0.264	0.008	0.049	0.252
Pasture grass	0.004	0.028	0.229	0.062	0.31	1.649

10 years after deposition

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.005	0.047	0.031	0.152	0.752
Grain	0.003	0.019	0.142	0.092	0.416	1.834
Root vegetables	0.0001	0.002	0.026	0.02	0.096	0.455
Potatoes	0.002	0.014	0.115	0.011	0.052	0.251
Pasture grass	0.002	0.014	0.101	0.082	0.361	1.567

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.0001	0.003	0.031	0.003	0.016	0.2
Grain	0.002	0.013	0.104	0.009	0.042	0.219
Root vegetables	0.0001	0.001	0.017	0.001	0.006	0.1
Potatoes	0.001	0.01	0.4	0.001	0.006	0.1
Pasture grass	0.001	0.009	0.072	0.008	0.039	0.5

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.0001	0.004	0.043	0.016	0.11	0.627
Grain	0.002	0.017	0.129	0.056	0.282	1.552
Root vegetables	0.0001	0.001	0.08	0.016	0.078	0.5
Potatoes	0.002	0.014	0.108	0.006	0.039	0.204
Pasture grass	0.002	0.012	0.094	0.05	0.251	1.332

4. Interception factors

Unknown deposition

Crop	5%	50%	95%
Green vegetables	0.24	0.5	0.86
Grain	0.28	0.56	0.97
Root vegetables	0.24	0.5	0.9
Grass for hay/silage	0.24	0.48	0.82
Pasture	0.23	0.46	0.78

5. Resuspension factor — not addressed.

6. Retention times

Retention times

Crop	5%	50%	95%
Green vegetables	2	14	50
Grass for silage/hay	2	14	50
Pasture grass without grazing	2	14	50
Pasture grass with grazing			

7. Concentrations in grain at harvest

Strontium

Time before harvest	5%	50%	95%
15 days	0.0018	0.038	0.058
30 days	0.0011	0.021	0.036
60 days	0.00018	0.0018	0.0058
90 days	NR	NR	NR

Cesium

Time before harvest	5%	50%	95%
15 days	0.008	0.061	0.854
30 days	0.009	0.096	0.441
60 days	0.009	0.041	0.118
90 days	0.0005	0.0017	0.0315

8. Concentrations in root crops

Cesium

Time before harvest	5%	50%	95%
15 days	0.0001	0.0055	0.019
30 days	0.0001	0.0055	0.019
60 days	0.0018	0.0525	0.144
90 days	0.0018	0.0525	0.144

EXPERT C

Introduction

The author of this report was invited to participate in the EC/USNRC Expert Judgment Study, as a participant in the Food Chain Panel on Soil and Plant. Participation required responding to the elicitation questions provided by J. Brown and J.A. Jones. Subsequent sections of this report present the rationale supporting the responses to the questions that fall within the author's competence. The questions themselves and the responses are presented as an appendix.

Question 4: Interception

Introduction

This question asks for estimates of the fraction of deposited material that is intercepted by pasture or certain crops. The conditions of deposition, whether wet or dry, and the chemical and physical nature of the contaminant, are not specified.

The approach adopted makes use of the "filtration" model of Chamberlain (1970). He showed that the fraction intercepted, f, increases with the density of vegetation (specified by the dry weight of above-ground vegetation, B) according to the relationship

$$f = 1\text{-}\exp(-\mu B),$$

where μ is called the interception coefficient and is approximately constant for a given crop, contaminant and weather condition. Measurements of interception have been used to deduce values of μ for a range of common crops, particulate and vapor contaminants and conditions, and relevant values from the literature are discussed briefly in the next subsection.

Since we must consider deposition in rain and in dry weather, it has been necessary to consider the implications of various weather conditions for interception, selecting appropriate values and combining them according to the frequency of occurrence of the various conditions for the season of the year important for each crop. Further details of this approach are described below.

Available Data

Chamberlain and Garland (1991) reviewed available data on interception. Few results were found for particles below 30 μm diameter. In addition, interception of wet deposition was sparsely represented in the data. Since the review, a few more results have become available for dry deposited particles (Pomeroy et al., 1993).

Chamberlain and Garland (1991) found that a value for the interception coefficient, (μ) of about 3.0 $m^2\ kg^{-1}$ explains interception by grass and grain of dry deposited particles up to about 30 μm, and of wet deposition unless the amount of rainfall is substantial. For larger particles, the interception coefficient could be much smaller, say about 0.3 $m^2\ kg^{-1}$, where particles of 50 to 200 μm deposit in dry conditions. Pomeroy et al., found that the interception of particles in the range 4.1 to 22 μm was independent of particle size. However, for mature, harvestable wheat the interception factor was about 0.35 to 0.5, the interception coefficient having fallen from about 3.9 $m^2\ kg^{-1}$ as the crop grew and matured. For lettuce, Pomeroy et al. (1993) found that the filtration model worked well, but the interception coefficient was near 20 $m^2\ kg^{-1}$.

For wet deposited material, Hoffman et al. (1989) found that the results depended on physico-chemical form. Particles of 3 to 25 μm diameter had values of f/B ($\sim\mu$, when $f \leq 0.3$) mostly in the range 1 to 5 $m^2\ kg^{-1}$; the median was about 2.5 $m^2\ kg^{-1}$ for up to 5 mm of rain. The results were similar for ^7Be in solution. For larger amounts of rain (10 to 30 mm) f/B decreased by about a factor of 2. The interception of I as iodide or periodate was much more sensitive to rain amount, decreasing from about 2 $m^2\ kg^{-1}$ at 1 mm of rain, to about 0.08 $m^2\ kg^{-1}$ at 30 mm. It seems a reasonable approximation to assume that μ is independent of type of deposition for particles and cations but inversely proportional to rainfall for anions.

One point regarding data quality is that in a number of the reported experiments in the literature the amount of deposition occurring to plants may have been reported in place of the total deposition on plant and soil. If this is the case, then the use of a deposition velocity based on such results with an interception factor in principle will underestimate the amount intercepted. However, the data which may have been reported in this way probably refer to thick canopies, and the effect is therefore probably small.

The Question and Assumptions

The question states that the deposition occurs at any time of year, but also asks for the fraction intercepted at maturity. Here, it is assumed that the crop is mature at the time of deposition; this will generally imply deposition in summer or autumn for silage grass and grain. However, green and root vegetables may mature at any time of the year.

The possible occurrence of rain at the time of deposition does not have much impact on the values quoted. It rains about 7 or 8% of the time, but the frequency of sufficiently heavy rain to suppress the interception factor is probably insufficient to affect the 5-percentile point. (This would not necessarily be true if the frequency of an event were weighted by the amount or intensity of deposition local to the accident.) The crop surface is assumed to be wet for about 15% of the time in summer or autumn and 50% in winter.

The effect of particle size and surface wetness has been noted above. The decrease in μ for large dry particles to dry vegetation is represented by decreasing the value used by a factor of 10 for all crops. Wet conditions or a fine aerosol are characterized by the higher values of μ. As large particles are likely to be released in some kinds of accidents, and no information is given about the kind of accident or size of particles, it is assumed that in 50% of accidents only small particles are released, and that in the other 50% similar amounts of large and small particles are released: since the deposition will be dominated by large particles close to the site of the accident, only large particle interception is considered in the second kind of event. On these assumptions, large particles depositing onto dry surfaces give low interception factors, and this occurs in 42.5% of cases in summer or autumn and 25% in winter.

Since the total probability of these conditions is 34%, the required values of μ for the 5-percentile point of the distribution of interception correspond to the 14% point of the distribution of μ in dry, large particle conditions. The median involves either wet surfaces or a fine aerosol or both, and corresponds to about the 25% point of the distribution of the larger values of μ. The 95% point of the combined distribution is at about the 83% point of the distribution of values for large μ. For each of these scenarios, values averaged over northwestern Europe and their uncertainties have been estimated.

Green vegetables may be typified by lettuce, for which some observations of interception are available (see previous section), and data for lettuce are assumed to be appropriate for cabbage. The dry weight to wet weight ratio for lettuce is lower (~0.05) than for most other crops (e.g., cabbage or cauliflower, ~0.08) and the interception factor for cabbage on a dry weight basis is therefore expected to be about 10 or 12 $m^2\ kg^{-1}$.

For root vegetables, little information was accessible on the mass of haulms. A dry weight of haulms at maturity of 1×10^5 kg km^{-2} is assumed as an upper limit, and a value of 8×10^3 kg km^{-2} is taken as a lower limit of the normal range. These assumptions may be erroneous. Better information could be obtained by consulting agriculturalists if more time were available. Potatoes lose most or all of their haulms late in the season, and may not be harvested until this has happened. (One measurement by Cawse and Baker, private communication, showed a ratio of dry weight of haulms to fresh weight of crop of 0.008 for potatoes in September.) For small particles or wet surfaces, the possible range of μ is taken to be $10\ m^2\ kg^{-1}$ (based on results for lettuce, but corrected for the higher dry to wet weight ratio in most foliage) to $2.5\ m^2\ kg^{-1}$ (somewhat lower than the typical value for grass). These values are assumed to encompass the range of possible leaf geometries, including broad and largely horizontal leaves associated, say, with turnips or beets, and the feathery leaves of carrots.

One complication arises because the yields are specified in the question in fresh weight, while the experimental data on interception are mostly quoted for dry weight. Data from Spector (1956) and other published results have been used for the fresh to dry weight ratio, in order to make the conversion where necessary.

Table A1 in Appendix 1 shows the estimated values for the interception coefficient for large and small particles in wet and dry conditions. The results for this Question were obtained via a simulation of the weighted average of these data taking into account the occurrence of surface wetness at different times of the year and the dependencies between large and small particle interception.

Correlations for Question 4

Interception is likely to be a complex function of crop architecture, pollutant characteristics and weather. There is insufficient information in the literature to allow the variability in measured interception fractions to be allocated to these factors, with only one or two exceptions. The following notes and judgements are therefore speculative, based on only a general knowledge of the mechanisms involved.

Correlations between interception factors

(i) small and large particles in wet conditions.

Variations within each of these categories may arise due to changes in crop density and structure, and variations in the weather that occur within the conditions that result in wet foliage (current rainfall, or surfaces wetted by previous rainfall). All are likely to influence interception of small and large particles in the same direction. The conditional probability that the interception factor for large particles in wet conditions exceeding the median value given that the factor for small particles exceeds its median, is estimated at 0.7.

(ii) dry small and dry large particles

Positive correlation trends are due to crop density and structure. It is possible that increasing wind speed increases bounce-off of large particles, (and giving lower interception) while increasing interception of small particles. The conditional probability that dry small particles display an interception factor greater than the median, given that factor for dry large particles is greater than its median, is estimated at 0.6.

(iii) small particles in wet conditions, and small particles in dry conditions

The major effect is likely to be due to canopy density. It is uncertain whether canopy structure has a similar effect in dry and wet weather - the effect on the correlation may be neutral. Effects of size and composition of the particles are not large in dry conditions, but contribute to some of the variability when wet, since soluble constituents behave differently according to ionic change: this is probably only important in (rare) heavy rain events. The conditional probability that small particles in wet conditions would have an interception factor greater than the median, given that the factor for the same particles when dry is greater than its median, is estimated at 0.7.

Question 5: Resuspension

Introduction

The required answer to this question is the resuspension factor for a typical crop or pasture grass, averaged over the growing period of the crop (for grass this period is to be taken as 6 months). Since resuspension is a complex phenomenon, it is essential to make use of experimental and field data to quantify the resuspension factor.

There are several categories of data for resuspension. Wind tunnel (e.g., Garland, 1979, 1982) or laboratory results help us understand the mechanisms of resuspension, and sometimes give useful indications of the intensity of resuspension to be expected in field conditions. Pre-Chernobyl field measurements gave information about resuspension in a number of areas, but little relevant to Europe. Most of these data were for arid areas of the US and there were also some data for Spain. After Chernobyl, data have been collected for resuspension across much of Europe and Scandinavia.

The results of these studies make it clear that several factors contribute to resuspension. In wind tunnel experiments it is clear that resuspension by the wind is the mechanism. However, in field observations other sources of disturbance may be dominant. These probably include traffic, agricultural activity, rain splash, the movements of people and animals.

The question clearly asks for the concentration in air that results from wind only. Wind tunnel measurements give an understanding of this mechanism. They show that resuspension increases with wind speed, but decreases with time after deposition. The effects of wind speed and time are complex, and are unlikely to be well simulated in the wind tunnel. In particular, variations of wind direction and velocity over a long period are not well represented in experiments where the wind direction and speed are often both kept constant. Also, few wind tunnel experiments have continued for more than a few days. For these reasons it is important to use field data as well as wind tunnel data in responding to this question. Fortunately, there have been a number of studies that show that resuspension was observable after Chernobyl over wide areas of Europe. This information probably gives the best long-term values for resuspension over NW Europe and is used in responding to the question.

Two reservations must be made regarding the results. The field data, and the model used here to estimate the value of resuspension factor include contributions from causes other than wind-driven resuspension. There are no suitable data for avoiding such unwanted contributions and getting representative estimates of resuspension in field conditions. Nevertheless, the values resulting are probably suitable for many purposes, provided that additions are not made for resuspension due to traffic, agriculture and other kinds of disturbance.

The second reservation relates to the use of the results. As explained below, estimates of the air concentration due to resuspension should not be combined with common models for deposition to calculate possible contamination of crops by resuspended radionuclides; the deposition velocities normally used are quite inappropriate for resuspended material, and in addition some models include parameters for soil contamination which probably include this effect, so there would be double counting of this contamination route.

Selected values

Wind tunnel results (Garland, 1982; Nicholson, 1993) show that the time dependence of the resuspension factor, $K\,(m^{-1})$, soon after deposition can be represented by a power law such as:

$$K = 10^{-6}\, t^{-1}$$

where t is the time in days after deposition. This expression has also been found to represent the results of a number of series of field observations (Meteorology Subpanel of the Interagency Nuclear Safety Review Panel) including those following the Chernobyl accident summarized by Garland and Pomeroy (1994).

A difficulty arises in averaging this expression over the period of 6 months as required by the question, since the expression has K rising to infinity at $t = 0$. This can only be overcome by setting a minimum time, before which resuspension is ignored. Here, this has been set to 1 day. That is to say that resuspension during the first day has not been included in the assessment, with the possible justification that in a nuclear accident of any severity, the release is likely to continue, or the cloud to be present, at any point where impact is of concern, for a period of this order. Then, during the first day, or some similar time interval, the air concentrations and deposition are likely to be dominated by direct dispersion from the site of the accident, and resuspension is likely to be insignificant. The mean value of K predicted by the expression given above for the period of 1 day to 180 days is about $3 \times 10^{-8}\ m^{-1}$. This result is not very sensitive to the choice of 1 day as the threshold time. The field observations that validate the expression used here include the influence of all mechanisms of resuspension, not only the wind.

Uncertainty

Experience across Europe following Chernobyl showed a wide range of estimates of the resuspension factor over the first months. Data for 12 sites where the initial deposition exceeded $300\ Bq\ m^{-2}$ (Garland and Pomeroy, 1994) show that over a period of a year the resuspension factor for various locations ranged from 0.6 to $25 \times 10^{-9}\ m^{-1}$. Given that we are asked for the mean resuspension factor over Europe, this site-to-site variability is not the measure of uncertainty required. However, it indicates that the geometric standard error in the mean, based on this data is equivalent to a factor of about 3.

Further uncertainty results from the large number of conditions which may influence resuspension, including surface, the nature of the released activity (particularly particle size, solubility, sorption characteristics in soil) and weather conditions. There is also the possibility of extreme events, such as forest fire increasing resuspension, but these are not likely to enter at the 5% level. Essentially nothing is known of the magnitude of most these influences. In averaging over a large area, the effect of most of these on the mean is likely not to be large, but the nature of the radioisotope will produce an overall bias.

Most of the data for Europe relates to ^{137}Cs from Chernobyl. Limited information (Garger et al., 1990) suggests that the resuspension of different isotopes close to the reactor accident did not vary substantially. However, in this area the isotopes may have been largely contained together in the same particles. Wind tunnel experiments show that large particles resuspend more rapidly than small ones. It is probable that the ^{137}Cs deposited across Europe in particles of about 1 μm diameter or less was soluble and became quickly associated with surface soil particles. Large particles of fuel, or insoluble refractory isotopes would have a larger resuspension factor, particularly during the period within a few days or weeks after deposition, and before the particles had become associated closely with soil material. Wind tunnel experiments suggest that the difference may be on the order of 30 to 60 over the first few days (Garland, 1982). This is likely to make a significant contribution to the median resuspension factor and to overall uncertainty, since the resuspension factor during the first few days makes a large contribution to the mean over 6 months (a period of 10 days at the beginning contributes nearly one-half of the total). To accommodate this important influence, the median value has been raised 3-fold; the range to 5% or 95% has been increased to 50.

Grass and arable crops

Although the roughness is expected to influence resuspension, moderate changes in the height of vegetation are not expected to make a noticeable difference to resuspension. The values discussed above are expected to apply without modification to pasture, since most of the measuring sites were located on areas of lawn or grass. The main effect of changing to an arable crop is expected to be the probability that the land will be tilled during the period considered. If such land is tilled once each year, the probability of this occurring during the first 20 days would be on the order of 5%. The reduction of resuspension by the wind after tilling would be great, so that the mean resuspension factor over 6 months would be reduced by about 50%. This affects only the 5% value for surface crops.

Use of the results

There are a number of related consequences of resuspension; of particular interest for the food pathway are crop contamination and inhalation by humans and grazing animals. It is particularly important to appreciate that deposition rates for resuspended material are not well described by the generic deposition factors commonly used in consequence models. At nine sites world-wide, Garland and Cambray (1988) deduced deposition velocities ranging from 0.01 m s^{-1} to 3.9 m s^{-1}, with a median of about 0.3 m s^{-1}. The resuspension factors reported here are probably suitable for estimating the airborne concentration over a field in the absence of substantial disturbance, but not for estimating deposition onto crops, or for the concentration to which agricultural workers are likely to be exposed. The latter often cause disturbance of the ground surface and may experience far higher concentrations.

Contamination of crops is often modeled by assuming that soil equivalent to some fraction of the crop yield is attached to the crop at the time of consumption. This probably includes any contribution from resuspension. Paretzke and Garland (1991) have summarized some available data.

Question 6: Retention

Introduction

The time which expires before intercepted activity is reduced to one half of the original amount is requested. No radioactive decay is assumed to contribute to the loss, and as the amount of activity is to be defined in terms of area of the ground, no dilution by growth is taken into account. However grazing of pasture is included.

In general, the question is answered by direct use of literature values. As no review of retention studies was known to the author, a brief summary of readily available literature was carried out to form the basis for the reply. The summary was far from comprehensive but probably was sufficient to reveal typical values. A feature of the results was that the loss from the crop was often not a simple exponential process, and any use of the times given as half lives in an exponential model could result in unrealistic estimates of the amount remaining on the crop after two or more "half-lives".

Information

A number of references have been scanned for information on retention (see table). It is important to differentiate between data given on an area basis and that given on a mass basis: the latter include the effect of growth dilution (Chamberlain and Chadwick, 1966). The available data include many measurements for grass, some for grain crops and only one or two for leaf crops such as cabbage and lettuce. There are also one or two for vegetation that do not relate to a crop, such as tree leaves; these are included to show the wide range of reported behavior.

A number of data sets give decay over a wide range, exceeding an order of magnitude in concentration. In some cases, the decay is apparently linear in log-linear coordinates, so that the data appear well approximated by exponential decay expressions. However, sometimes there is an initial rapid loss, followed by a progressively slower decay as time goes on. An example is given by the results of Eriksson (see table). Also, Hoffman (see table) showed data for the loss of ^{7}Be, ^{131}I and particles of 3, 9 and 25 μm diameter. The overall results are approximated by half-lives in the region of 7 to 15 days, over a period exceeding a month. During the first 3 or 4 days, however, some half to three quarters of the initial deposit was lost, with a half-life of only 2 or 3 days. The loss of Be was more rapid than that of I, and the particles were lost least rapidly.

Table 1. Data on Retention

Ref.	Crop	Season	Contaminant or particle size, μm	Biological half-life, d
1	grass and nettles	May-June	I	10
1	grass and nettles	May-June	Cs	14
1	grass and nettles	May June	Ru	8
2	Poplar, pine, grass	not given	Cr_2O_7	<3, (60-75%) then 28-42
3	grass		Sr	12.8
4	grain crops-spring varieties	July-Sept.	Sr	18.7
4			Ce, Mn	30
4			Cs	probably >30
5	barley	May-June	Cr, Fe, Co, Zn, Hg, Pb	16±14
5		June-Sept.		42±38
6		summer		19
6		winter		49
7	grass, wet deposition	August--	Sr, 40-60 micron	17
7	grass, wet deposition	mid-May--	Cs, Fe, 40-63,100-200 micron	>30 21 or more, strongly dependent on rainfall
7	grass, dry deposition	July-August	40-63, 63-100, 100-200,	generally ~10 or more
8	cabbages		Mn, Sr, Zr, Ru, I, Cs, Ce	8.7
9	wheat	August-September	4.1,9.6,22.1	6.5 ±9.4,13 ±18, 26 ±38
9	lettuce	September-October		60,70,14
10	grass	May	Cs, I	14.3,14.4
11	grass		I	13
12	grass	spring & summer	I	20
13	fescue grass		I	2 (for 4 days) then 15
			Be	2.2 (for 4 days) then 7.4
			3 to 25 μ particles	2 to 3 (for 4 days) then 15
14		summer	actinides in sea spray	30 ±15
14		winter	actinides in sea spray	90 ±30
15	purple sprouting broccoli	May	Chernobyl Cs, Ru, wet deposition	11±1 7.5±2.5

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The question, assumptions and selection of values

The question asks for the time for the activity on the crop to drop by half on greens and grass for hay and pasture, due to weathering and including grazing for pasture only.

The data reviewed for this question indicate that, contrary to the assumptions of some models, the form of the depositing material does have an influence on the retention time. The loss rate is sometimes not well described by a simple exponential, and there may be rapid initial loss in some cases, but this does not always occur.

Data for cabbages, lettuce and broccoli are applied for green vegetables. The results show that very long retention is possible for particles, at least in dry conditions, but suggest that soluble substances have more modest retention. The wide variability present in the wider range of data for grass and cereal probably also applies for green vegetables. Although averaging over Europe would reduce the spread due to different crops, climate and local conditions, the variation related to the properties of material released in a particular incident and time of year contribute importantly to uncertainty. The possibility of very rapid loss of the first 50% is also taken into account.

Hay or silage are grown in the summer months. Values for grass and grain crops have been considered to be relevant. Interception and retention in the winter are assumed to be of no significance, and the very long retention times reported in some studies have therefore not been represented in the values selected. The wide spread indicated in the selected values includes the very rapid loss seen in some studies, the long retention observed when growth is slow and also the range of behavior of different soluble and particulate contaminants.

For pasture, it is assumed that in good growing conditions the standing crop can be replaced roughly every 10 days, implying that a removal time constant of 0.1 d^{-1} can be sustained. This is probably faster than the normal rate of grazing, but has little impact in comparison with the

5-percentile point chosen for the retention time for hay. A slower rate, of 0.05 d^{-1}, has been assumed for the median point. No grazing loss has been included for the 95-percentile of retention time for pasture, since deposition occurring at the beginning of the season, before grazing has begun, may be significant in causing contamination of pasture grazed soon after. These rates have been applied to modify the retention time distribution deduced for hay and silage, and it is assumed that the result is applicable to grazed pasture.

Question 7: Concentration in Grain at Harvest

Introduction

The question relates to the concentration in the edible parts of a grain crop at harvest, after contamination by atmospheric deposition during the growing season. The deposition is specified, and also the time in days before harvest, but the deposition mechanism, the climate, species, foliage yield and grain yield are not specified. The result required is the transfer to grain, averaged over an area of Europe, or the croplands of the US, which might be affected by an accident. Thus, interspecies differences are largely averaged out, but the effects of the characteristics of the deposited material will remain important contributors to uncertainty. Results are requested for Sr and Cs.

The contribution of root uptake is not to be taken into account. The concentration at harvest is taken to depend on interception and translocation. In the following paragraphs information on translocation is summarized. The literature points to a model of Aarkrog (see below) which is successful in describing the results, and has been used as the basis for deducing the answers given.

Information

There are a few references in the literature relevant to the translocation of contamination from leaf surface to grain. All report the uptake and translocation of radionuclides applied by spraying of solutions onto growing crops. Scott Russell comments that studies of foliar uptake of nutrients show that substances can only be taken up if they are in solution.

Quantitative results were provided by Middleton (1958, 1959), who determined the fraction of intercepted Sr and Cs that was present in wheat grain at harvest. A much larger fraction of Cs than of Sr was translocated.

Aarkrog (1969) reported the fraction of initially intercepted Cs, Sr and other radionuclides that was present in the grain of wheat, rye, barley and oats at harvest. Interspecies differences were important. For example, for Cs, the fraction of intercepted Cs that appeared in grain at harvest, when application by spraying had occurred "just" beforehand (probably 2 days before to allow for drying, in fact) was 1.1% for wheat, 7 to 8% for barley and rye and 14.4% for oats. Uptake of Cs was greatest when application preceded harvest by 30 to 60 days, while for Sr uptake was greater for application only 15 to 34 days before harvest.

In a later publication Aarkrog (1983) summarized results for several years of investigations on translocation in barley. He provided a model to predict the concentration in grain, μ, t days after unit deposition:

$$\mu(t) = A \exp[-k(t-b)^2]$$

with the following values:

for Sr, $A = 4.5 \times 10^{-2}$, $k = 9.5 \times 10^{-4}$, $b = 2$;
for Cs, $A = 9.8 \times 10^{-2}$, $k = 0.0013$, $b = 34$.

It is possible to compare the results of Aarkrog with the fractional translocations used in models, e.g., that of Boone, Ng, and Palms (1981). The latter give the concentration ratio between the grain of wheat, oats, barley and rye and the whole plant, appropriate for continuous deposition throughout the growing season. Using these ratios, expected values of the fraction in grain at harvest were calculated by multiplying by the observed grain-to-plant mass ratios at harvest. The comparison is probably more apt for spraying within the last few weeks of growth. The comparison shows agreement within a factor of 2 in almost all cases, and is taken to give an indication of consistency in experimental results, on the assumption that the data sources for the model did not include Aarkrog. Variability in Aakrog's data also suggests that a factor of 2 gives a reasonable measure of uncertainty in his model.

Voigt et al. (1991) carried out further studies using only Cs, and also compared their results with those of Middleton and Aarkrog. They described the data for wheat, barley and rye with empirical models of the same form as Aarkrog (1983), showing that the parameter values chosen represent all the data available to them.

The models of Voigt et al. apparently give the fraction of intercepted activity that is translocated to grain, whereas Aarkrog's model provides the fraction of deposited material that translocates. The numerical values are broadly consistent with this distinction and are in reasonable agreement. However, the interspecies differences are greater in Voigt's model than are suggested by the measurements of Aarkrog (1969).

Values and Uncertainties

In addition to variability between species and climatic effects on the rate of crop development and weathering, there must be a substantial effect of the composition of the depositing material. Radionuclides must enter solution before they can be absorbed via the cuticle or stomata. Insoluble particles, such as the fuel debris from Chernobyl, may retain their fission product content for weeks or even years, so the availability for uptake may be much reduced. The long retention times sometimes seen for large particles will be irrelevant if the radionuclides are not available for uptake. The quantity in grain has been estimated by considering the fraction expected to be intercepted, and the fractional translocation.

The results of several investigations, summarized by Voigt et al. (1991), show that individual measurements for a given species differ by up to a factor of about 3 from the median for a given time of deposition before harvest. This variability is taken to represent the effects of weather, different varieties and local conditions. In averaging over a region and over a mix of species, the overall uncertainty due to these causes is taken to be covered by a factor of 3.

In selecting representative values, the variation between species has been treated as follows: Aarkrog (1969) showed that the translocation for barley was somewhat greater than for other common grains produced in Europe. In particular wheat transferred some 6 to 12 times less to grain. Overall, averaging over a mix of barley, wheat, oats and rye, the mean transfer of Sr for grain is likely to be only one half of that for barley alone. For Cs, rye and oats transferred more to grain than barley, while wheat transferred less. It is assumed that the translocation fraction for Cs for barley is appropriate for a mixture of grains without modification. The uncertainty factor mentioned above is thought to be adequate, provided that rice, maize and other grains of markedly different morphology or agricultural management are not important in the mix of grains considered.

Accidents may give rise to largely soluble material, or may lead to emission of chiefly insoluble particles. Chernobyl gave a mixture, with the insoluble large particles dominating deposition at short range, and finer more soluble fume dominant at long range. The median case is assumed to deposit 50% soluble material over the area of interest. The 95 percentile has 100% soluble material, and the 5 percentile case has 90% "insoluble" fuel-like particles. In dry conditions, interception of large particles is reduced, as discussed under Question 4, and additionally translocation of activity from these relatively insoluble particles is suppressed.

Question 8: Concentrations in Root Crops

The general approach used to estimate uptake into the edible parts of root crops was similar to that described for grain in Question 7. There is a wide range of root crops used for human consumption or for animal feed, but only a limited number of species are represented in experiments on foliar uptake and translocation. Whole genera (e.g., onions and leeks) have not been studied. A number of authors have studied uptake by potatoes, and there are more limited studies of carrots, sugar beet and swede.

Moorby and Squire (1963) carried out experiments on Sr in potatoes, and concluded that any uptake occurred after wash-off into soil. Middleton (1958, 1959) and Middleton and Squire (1963) measured uptake of Cs and Sr after spraying onto the leaves of potatoes, swede and sugar beets, and Voigt et al. (1991) report results for potatoes and carrots. The sparse data hint that the uptake is strongly species dependent. For potatoes the time of deposition is also very important, translocation 20 to 60 days before cropping being some 4 times greater than that resulting for 10 days or 70 days. In potatoes, uptake of Cs is greater than that for Sr by 2 orders but for sugar beets the difference was only about a factor of 3 to 10.

Because of the scarcity of information, and the wide range of possible species, it is inevitable that uncertainty will be very large. In addition to the interspecies variability, the possibility of varying quality of deposit, regional changes of species mix and weather all contribute to uncertainty.

For Cs the published studies are generally consistent with a peak of about 0.04 $m^2\ kg^{-1}$. Carrots give similar values for Cs, but sugar beets give values an order of magnitude less. Sr has only of order $1 \times 10^{-4}\ m^2\ kg^{-1}$ for potatoes, but $1 \times 10^{-3}\ m^2\ kg^{-1}$ appears to be representative for carrots. The 95 percentile point takes into account the possibility of generally soluble deposition, well retained by the plant canopy and uncertainty in the sparse information available. (Given the high yield of root crops, uptake factors cannot be much larger.) The 5 percentile is determined by the possible low solubility deposit in poorly intercepted particles, with a combination of weather and mix of species that do not favor uptake.

Question 9: Correlations Between Parameters

Deposition, interception and retention may be affected by the nature and particle size of the contaminant and the weather and season. Consideration of these influences, and data discussed above, lead to the following statements:

1. Increasing initial precipitation strongly increases deposition, strongly decreases interception of anions, decreases interception of cations and particles moderately.

2. In dry conditions, particle size increases deposition, decreases interception, may increase retention, increases resuspension.

3. Soluble particles, being hygroscopic, probably deposit more quickly than insoluble, and, if large, have higher interception and translocation.

4. As a matter of simple logic, conditions which favor resuspension must reduce retention and translocation.

On the basis of the above, the following correlations are expected:

	Deposition	Interception	Resuspension	Retention	Translocation
Deposition		-	(+)		(+)
Interception			-		(+)
Resuspension				-	-
Retention					(+)
Translocation					

Parentheses indicate a weak or uncertain correlation.

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Appendix 1

In constructing the answers to Question 4, values appropriate to wet and dry conditions, and large and small particles have been distinguished.

The uncertainties for some parts of this question reflect uncertainty in dry matter, above-ground, crop yield, B, as well as in the interception parameters. As there was no available data for the B in relation to some of the crops, it is worth listing the values of the different parameters used in estimating the fraction intercepted. If improved information were available for B, it would be straight forward to recalculate the estimate of interception. Assumed parameter values are given in Tables A1 and A2.

The literature on interception is sparse, and is insufficient to establish differences between parameter values due to many of the possible environmental factors which are likely to be significant. The available data limit that the interception of small (≤30 μm diameter) particles is similar to that for wet deposition in moderate or light rainfall. However, the interception of large, dry particles is less, and the interception coefficient for such particles is taken to be a factor of 10 less than that for small particles. Clearly, this division of the size distribution is arbitrary, but the effect of particle size is well supported in the literature. Although wide size distributions are likely to be emitted from many potential accidents, the deposition may be dominated by large particles over important regions.

Interception of some species is reduced in rain events that yield ≥5 or 10 mm of precipitation. Such rain events are sufficiently infrequent to be ignored here.

Table A1. Values used for the Interception Coefficient μ, $m^2\ kg^{-1}$

(i) Conditions: all small particles (<30 μm diameter) in dry or wet deposition also deposition of large particles in rain or to wet surfaces.

Crop	5%	50%	95%
Green vegetables	7	12	17
Grain	0.27	0.4	0.55
Root vegetables*	7/2	12/3	17/5
Grass for hay/silage	2	3	5
Pasture	2	3	5

* Most root vegetables have broad leaves, and the first value applies. Some (e.g., carrots, onions) have narrow or finely divided leaves and the second value is then used. 90% of the root vegetable crop was assumed to have broad leaves.

(ii) Conditions: Dry deposition of large, dry particles (≥30 μm diameter) in dry conditions only.

Crop	5%	50%	95%
Green vegetables	0.7	1.2	1.7
Grain	0.03	0.04	0.06
Root vegetables*	0.7/0.2	1.2/0.3	1.7/0.5
Grass for hay/silage	0.2	0.3	0.5
Pasture	0.2	0.3	0.5

* see footnoote above

Table A2. Values assumed for the dry matter mass of standing crop, *B* $kg\ m^{-2}$,

(used where the dry matter yield was not specified in the question).

Crop	5%	50%	95%
Green vegetables	0.08	0.08	0.08
Grain	1	1.5	2
Root vegetables	0.07	0.1	0.15
Grass for hay/silage	-	-	-
Pasture	0.075	0.1	0.125

Questions 1 through 3 were not addressed.

4. Interception factors

Unknown deposition

Crop	5%	50%	95%
Green vegetables	0.39	0.49	0.60
Grain	0.22	0.35	0.51
Root vegetables	0.37	0.55	0.76
Grass for hay/silage	0.83	0.90	0.96
Pasture	0.13	0.20	0.31

5. Resuspension factor

Resuspension factor

Crop	5%	50%	95%
Surface crop	1E-09	1E-07	0.000008
Pasture grass	2E-09	1E-07	0.000008

6. Retention times

Retention times

Crop	5%	50%	95%
Green vegetables	3	30	50
Grass for silage/hay	2	15	40
Pasture grass without grazing	2	7	40
Pasture grass with grazing			

7. Concentrations in grain at harvest

Strontium

Time before harvest	5%	50%	95%
15 days	0.001	0.01	0.05
30 days	0.0005	0.005	0.03
60 days	0.00005	0.0005	0.003
90 days	3E-07	0.00001	0.0001

Cesium

Time before harvest	5%	50%	95%
15 days	0.0025	0.03	0.2
30 days	0.004	0.05	0.4
60 days	0.003	0.02	0.3
90 days	0.0002	0.001	0.03

8. Concentrations in root crops

Strontium

Time before harvest	5%	50%	95%
15 days	0.000003	0.0001	0.003
30 days	0.000003	0.0001	0.003
60 days	0.00001	0.0003	0.003
90 days	0.00001	0.0003	0.003

Cesium

Time before harvest	5%	50%	95%
15 days	0.000001	0.00007	0.02
30 days	0.00001	0.0007	0.02
60 days	0.0001	0.01	0.1
90 days	0.0001	0.02	0.1

EXPERT D

Question 1. Soil migration

1.1 Chromatography model

There exists an enormous wealth of theories that describe the migration of radionuclides (and other materials) through soils. The most sophisticated ones take into account the movement of the water phase, adsorption and desorption reactions, as well as apparent diffusion effects. Equations result in bell-shaped curves and are similar to the transport equations for radionuclides in air. The application of chromatography equations is very complicated. Details on adsorption, desorption, composition of the soil solution and exchangeable ions of soil particles are required.

1.2 An experimental program

An example of the application of a chromatography model is shown in Figure 1. It was part of an EC program in which the accumulation and migration of about 20 soils in the EC countries were followed for many years. The soils were situated in France, Germany, Italy, Netherlands and United Kingdom. They included sandy soils, clay and loam soils, calcareous soils, organic soils and a red soil. The latter one was in southern Italy so that dry regions were also included. The longest observation period on one soil was about 20 years. For many soils the observation period was too short to draw conclusions on migration (Frissel et al., 1981). Since this study was terminated, many comparable studies have been carried out, usually on a smaller scale and during a shorter period. Results of these studies agree generally with the results of my study. Some exceptions are described below.

1.3 Residence time model

Another model is a so-called residence time model. It does not consider any process and the residence time is the reciprocal value of the migration rate. An example of a residence time model application is shown in Figure 2. Data are also part of the EC program mentioned. An advantage of a residence time model is that information can more easily be transferred from one situation to another.

A related model is the half-life time model, a model favored by radioecologists because they are used on half-life time processes. The relation is: $t = T_{1/2}/0.693$. Numerically the

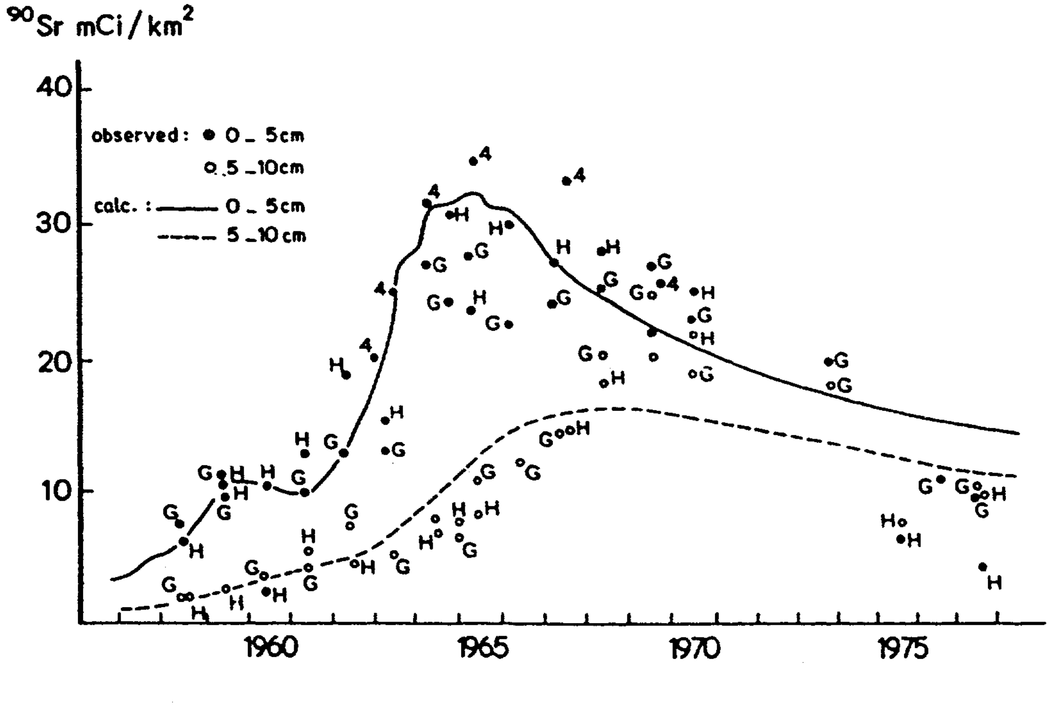

Figure 1. Application of chromatography model on migration of ^{90}Sr. Representative for many soils in north western Europe. H = sandy soil, Hooglanderveen NL; G = peat soil on clay, Groot Ammers, NL; H = poor sandy soil, Heino, NL.

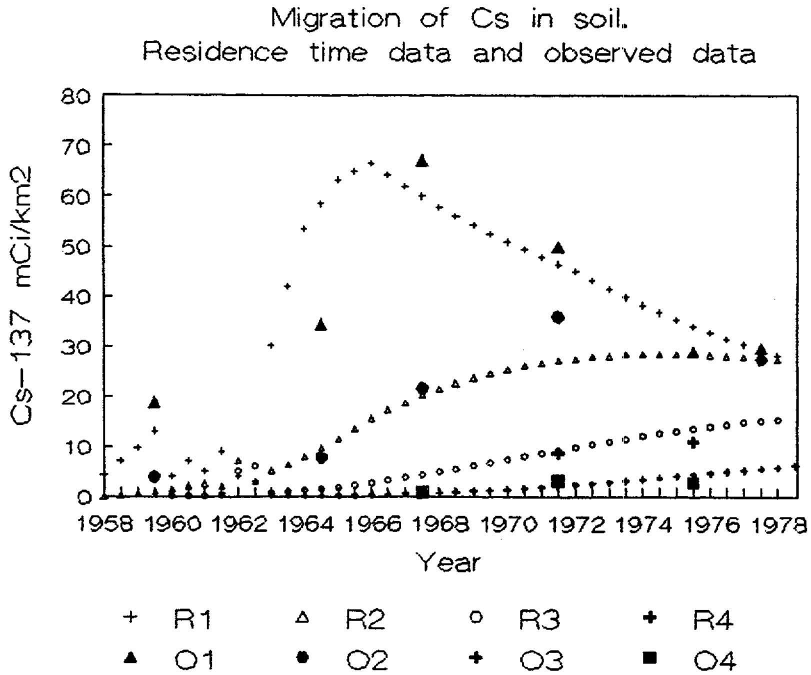

Figure 2. Application of residence time model on migration of ^{137}Cs. Representative for many soils in north western Europe. Clay soil near Alkmaar, NL
R1-R4: Calculated data for layers 0-5, 5-10, 10-15, and 15-20.
O1-O4: Observed data for same layers.

residence time *t* is equal to the decay constant. In fact *t* is the ratio between the holdup in a compartment and the throughput through a compartment (Frissel, 1981). Both residence time and half-life time have in common that the apparent diffusion cannot be taken into account explicitly. Application of a layer thickness implies the introduction of a numeric dispersion. The choice of the layer thickness determines the apparent diffusion. A layer thickness of 1 or 2 cm is a reasonable choice. Many models (including the one I applied) use layers of 5 cm. This choice overestimates the diffusion.

1.4 The K_d-value

A variable which considers more possibilities is the K_d, which is the ratio between radionuclides adsorbed and radionuclides in solution. It serves as a retardation factor but has no possibility to account for apparent diffusion in a system.

The advantage of K_d is that it allows a comparison between different soils. The disadvantage is that K_d in a soil is not constant at all. Recommended values for particular soils vary with a factor 100 to 1000. Recommending a K_d-value is a nuisance; there is always someone to disagree. But that is not all. Every variable which influences adsorption-desorption phenomena influences the K_d, so even for one soil the K_d is not a constant. Variations are caused by variations of the salt content of the soil solution and the redox potential. Both influence the number of exchange sites. It is also often not recognized that the soil is not a physical system, but a biological system. On a normal grazed pasture there is just as much bacteriological and animal biomass below the soil surface as above. The continuous change of the organic mass causes continuous changes of adsorption sites.

1.5 Choice of model for this study

I have therefore based my estimates for migration in soil on residence time models and used the mentioned EC study as a database. In former studies I always tried to obtain an agreement between calculated and observed values. For this study I have also considered at what values of parameters the agreement between observations and calculations disappeared. These values formed the base for the 5% and 95% limits.

1.6 Particle-mediated migration

The study shows some remarkable results. The difference between residence times for Cs and Sr differs by only a factor of two to three. Very probably the reason for this phenomenon is that transport of Cs in soil for an important part occurs via soil particles which are transported through the soil as a result of cracks which form in soil, water flow, and the action of animals. The migration of Pu and Am in the top layer of soils is almost equal to the migration of Cs. Because Pu and Am are not easily soluble in water, the migration via soil particles is the only explanation. At lower depths, e.g., 20 cm and below, transport via the water phase becomes more important. There are no longer cracks in the soil which stimulate mechanical mixing and biological activity is less.

1.7 Chernobyl

I have not considered an observation which was made the first years after Chernobyl. During the first years high migration velocities were reported. I have evaluated a few of these observations by discussing them with the people who took the samples. It is most probable that the migration occurred in the first weeks after deposition. Some soils were flooded during deposition; probably the rain water mixed with the stagnant water before adsorption of Cs occurred. Other soils were rather dry when the Chernobyl-contaminated rain arrived. In such a situation the soil shows large cracks and the water flows immediately downwards to the bottom of the cracks. The radioactivity was transported downwards before it became adsorbed.

1.8 The elicitation questions

Migration experiments with soil columns show that migration is favored by:

- A low exchange capacity, as e.g., in poor sandy soils.
- A high salt concentration (high fertilizer application).
- A high K content in peat soils (high K fertilizer application on peat soils).

The EC study showed, however, that differences of migration in different soils under field conditions are small. I have therefore made no correction for differences of the water surpluses. The elicitation questions refer to a normal sandy soil and a normal peaty soil. Therefore I have assumed that the difference between a sandy soil and the generic European soil will only be noticed below a depth of 15 cm. One may assume that the peat soil will be fertilized with K, and that therefore migration may be higher than in the generic soil. As said, this was not observed in situ. Also, on many Nordic organic upland soils, Cs is not leached downwards. For alpine organic mountain soils, increased leaching was indeed observed. This is the reason I expect the same mean leaching rate in peat soil as in the generic soil. The uncertainty for the migration of Cs in peat soil is, however, higher than for other soils.

1.9 Generic soils, US

European agriculture has a long tradition, it is based on the production of manure by cattle and application of manure on arable land. This tradition is so strong that even citizens of large cities have stored this tradition in their memory and are convinced that organic matter is a precious thing. In the US this tradition is not so strong. Organic matter may easily depleted. Fertilizers are supplied at a lower cost than in northwestern Europe. Thus, organic soils which favor the leaching of Cs may therefore be less common than in Europe. The climate in the greater part of the US is not temperate, as in Europe, but a continental one. This causes more extreme conditions, in particular of rain surplus or transevaporation deficit. There is, however, no reason that the median of US soils in a region which is comparable to Europe will differ significantly from the median for Europe.

1.10 Summary of results

Table 1.

	Time in year					
	Cs			Sr		
	5%	50%	95%	5%	50%	95%
Generic Soil: Migrated						
below 1 cm	1	2	4	0.2	1	2
below 5 cm	4.25	8.5	17	1.7	5.6	11.5
below 15 cm	15.5	33	74	5.2	12.5	30
below 30 cm	31	71	174	14.5	17	40
Sandy Soil: Migrated						
below 1 cm	*	*	*	*	*	*
below 5 cm	*	*	*	*	*	*
below 15 cm	*	*	*	2.5	10	20
below 30 cm	*	*	*	7.5	14	30
Organic Soil: Migrated						
below 1 cm	*	*	*	*	*	*
below 5 cm	2	*	*	*	*	*
below 15 cm	8	*	*	*	*	*
below 30 cm	15	*	*	*	*	*
US generic soil. No difference with European soil.						

Question 2. Fixation of Cs and Sr in soil

Fixation is discussed in Section 3.3: Reduction of availability with time.

Table 2. Tabulated fixation values

	Availability Cs			Availability Sr		
	5%	50%	95%	5%	50%	95%
After 1 year	.90	.75	.70	.99	.97	.95
After 3 year	.73	.45	.34	.97	.91	.86
After 5 year	.59	.33	.20	.95	.86	.79
After 10 year	.53	.24	.11	.94	.80	.72

Question 3. Root uptake concentration factors

3.1 Distribution of concentration factors

The spread of individual root uptake concentration factors (often called transfer factors and denoted by TF) is very large. The distribution is skewed. To investigate effects such as time dependence, pH dependence, etc. usually a log transformation is applied. I have followed this approach to study particular effects. Figures 3 and 4 show the normal and log normal transformed distributions of the uptake of Cs by cereals [Source: Databank on Soil-to-Plant Transfer Factors of the International Union of Radioecologists (IUR)]. I have checked the difference of median values and geometrical mean values. For large data sets this difference is small; for smaller data sets differences of 10% are sometimes observed. Figure 5 shows the distribution of such a set. Some values are exceptionally high; they have to be attributed to adhesion of soil on the crop caused by rain splash. In this case the median value is indeed better; the extreme values have no effect.

3.2 Database

As said, this study is for a greater part based on the IUR database. These data are determined according to a protocol for determining root uptake factors, thus minimizing artifacts and errors in the experimental schemes.

The IUR data bank covers, besides soils of northwestern Europe, some data from temperate regions in North and South America. The spread is therefore large, but the median value of the databank values is very representative.

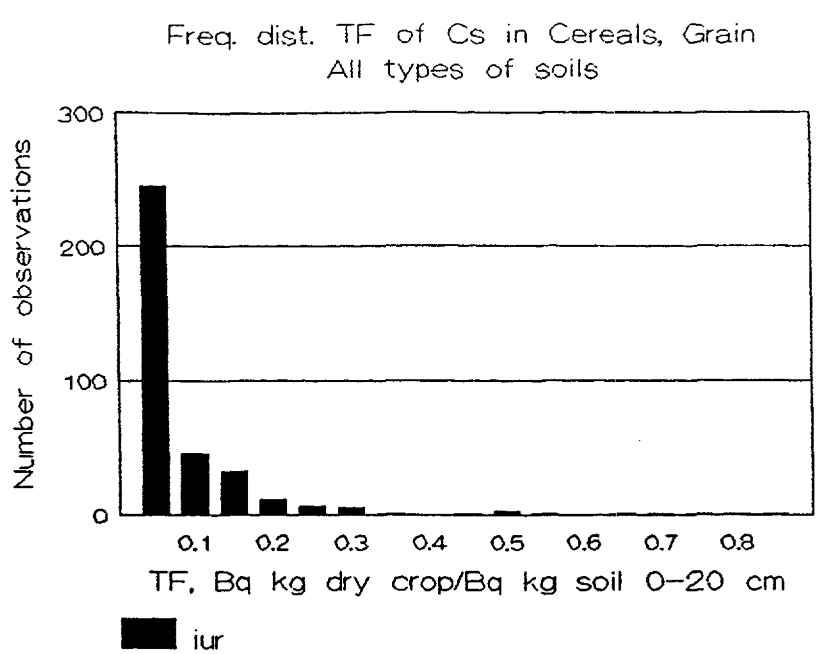

Figure 3. Frequency distribution of concentration ratio of ^{137}Cs in grain and in soil (TF) resulting from root uptake.

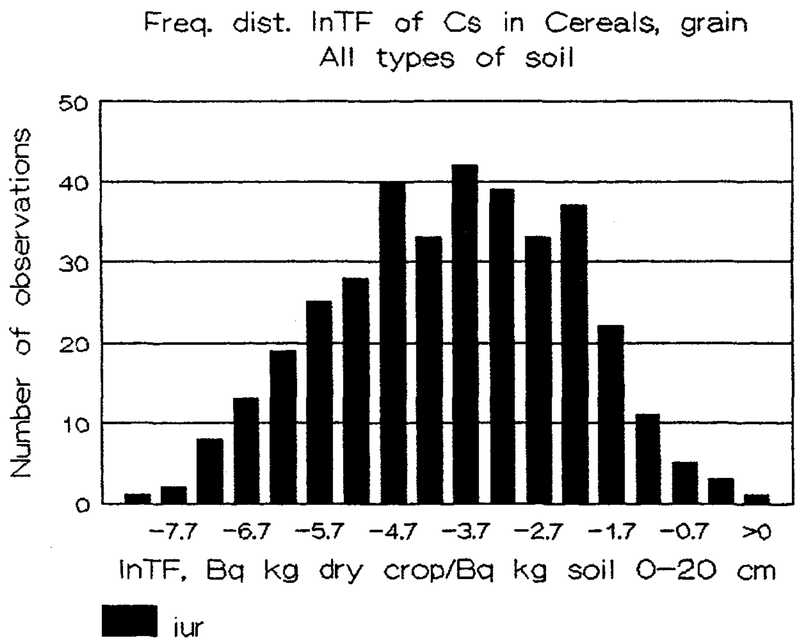

Figure 4. Frequency distribution of logarithm of concentration ratio of ^{137}Cs in grain and in soil (lnTF) resulting from root uptake.

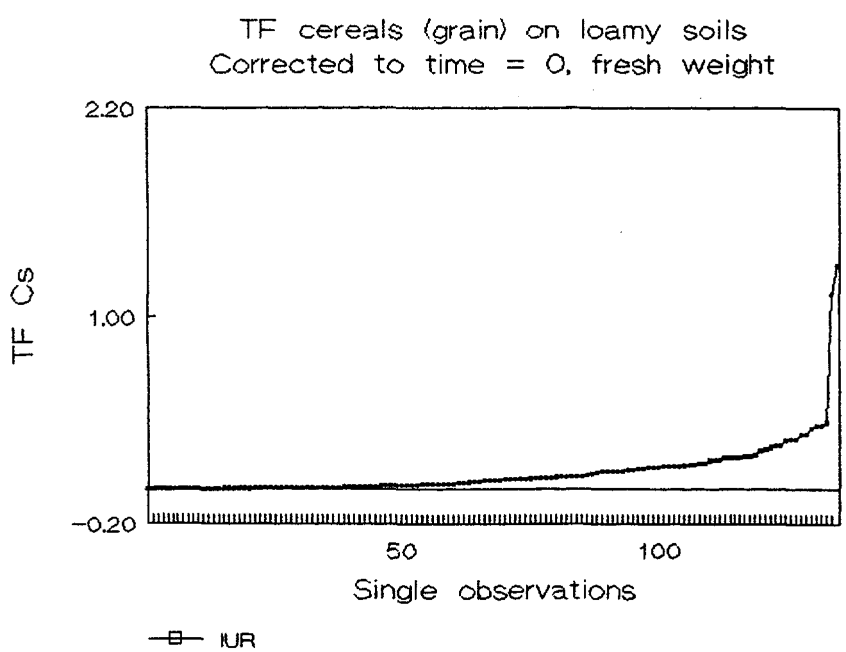

Figure 5. Concentration ratios (TF) for root uptake of ^{137}Cs by cereals.

The number of values is 2000 for Cs and 900 for Sr; the error of the median value is therefore probably low.

Some phenomena are illustrated with figures. All figures show, besides IUR data, data from the former USSR. The latter data are always summary data; I never succeeded in obtaining the original observed values.

In general, the agreement between IUR data and former USSR data is reasonable.

For grass, the USSR data on the uptake of Cs are often higher than the IUR data. This is caused by different management systems. In western Europe pastures are often fertilized; this causes nitrogen fixing plants, e.g., clover and other non-grass species to disappear from the pasture. In some western countries, pastures are even ploughed from time to time; they are replaced by artificial leys, in which no herbs, etc. are admitted. In the former USSR pastures are never fertilized; the fraction of non-grass species is therefore very high. The uptake of Cs by non-grass species is often a factor of 10 higher than the uptake by grass species. This explains the difference between USSR and IUR data. An illustrative example is shown in Figure 6. It shows the Cs uptake data collected by Prister for natural and artificial pastures. Artificial in this context means that the pastures were improved to reduce Cs uptake.

3.3 Reduction of availability with time

The availability for root uptake of radionuclides usually decreases with time. The two main reasons are migration from the root zone and fixation of the radionuclides on soil particles. Cs and Sr migration is important only over very long periods. For Sr, in the first years the reduction is near 3% per year (mean value IUR databank, Frissel, 1992) but the Cs gradually disappeared. An example of the impact with time is shown in Figure 7. The values by Vetrov and Alexakhin are again summary data from the former USSR. Figure 7 shows also an exception observed by Alexakhin outside the Chernobyl 30-km zone. Within the zone the availability of Sr increased for a few years because "heavy" Sr-containing fallout particles dissolved gradually.

The main reason for the Cs fixation is the incorporation of Cs ions in the lattice of illitic clay minerals. This sorption is so strong that even traces of illite are sufficient to cause fixation. It must be assumed that within the area of interest

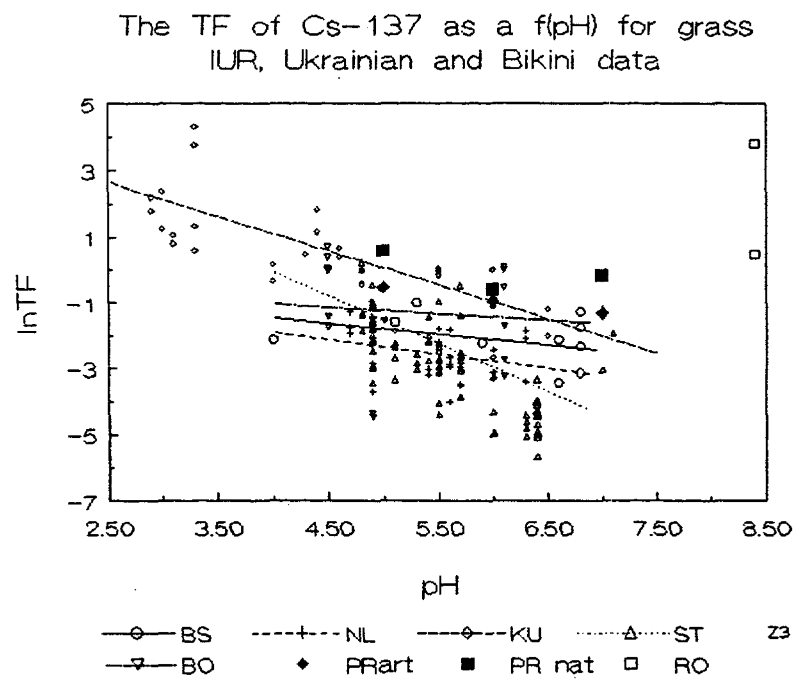

Figure 6. The root uptake of ^{137}Cs by grass as a function of the pH of soils. High values observed by Prister (PR) have to be ascribed to the high abundance of non-grass species in the pastures in the (former) USSR. The IUR investigators are: BS = Belli and Sansone (Italy), NL = Neil (Ireland), KU = Kühn (FRG), ST = Stoutjesdijk (Netherlands), BO = Boikat (FRG).

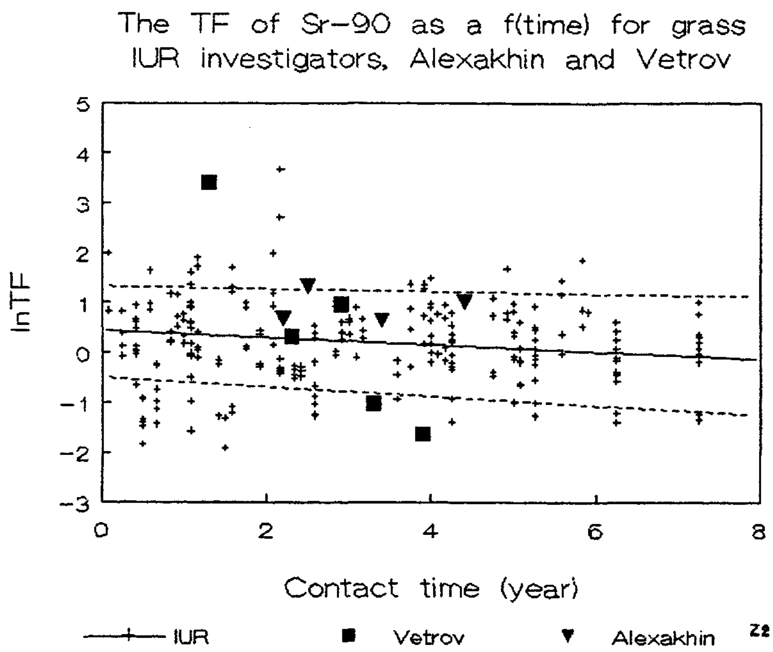

Figure 7. The root uptake of ^{90}Sr by grass as a function of time. Both sets of data of the former USSR are exceptional. The TF values of Vetrov decrease very fast while the ones of Alexakhin increase. The latter effect is caused by "heavy" particles which slowly dissolve.

of this project fixation always occurs. There exist several soils which fix Cs very strongly. There are even soils which fix potassium so strongly that they have to be heavily fertilized each year with potassium fertilizer.

The Cs fixation rate is influenced by the decomposition of organic matter. Usually the organic matter is converted to CO_2, while ammonium ions are formed. In most soils the ammonium is further oxidized to nitrate. In waterlogged soils the oxygen content may be too low to oxidize ammonium ions. In this case the ammonium ions interact with the Cs ions. Cs remains therefore better available and is readily taken up by the vegetation. In the Nordic upland soils the availability of Cs is therefore barely reduced with time.

There are more exceptions, e.g., the calcareous soils on the Marshall Islands, which seem not to fix Cs at all.

Figures 8 and 9 show two examples of the effect of time on the root uptake of Cs. The mean reduction for the IUR values is 15% per year, The values of the former USSR investigators are higher. On various occasions (but not in all cases) the reduction was stronger in the first years after the contamination.

The differences of fixation rate between the former USSR and northwestern Europe is probably the K status of the soil. A well-fertilized soil will fix less Cs than a nonfertilized soil. Fertilizer applications in the USSR are much lower than in western Europe.

Over the long term the reduction is no longer important. The RESRAD code which is used for residual activity on reclaimed sites does not consider fixation.

For answering the elicitation questions I have used reductions of Cs availability of 25, 20, 15, 15, 10, 10, 5, 5, 0, 0% per year for the first 6 years after contamination respectively. Low values are 10% per year for the first 5 years, thereafter going to 0. High values are 30, 30, 30, 15, 15% for the first 5 years, thereafter going to 10%. I have not distinguished between soils, although there are many exceptional soils, I do not think that medians for the different soil types differ. The values are mainly based on the data collected in northwestern Europe. The K status of

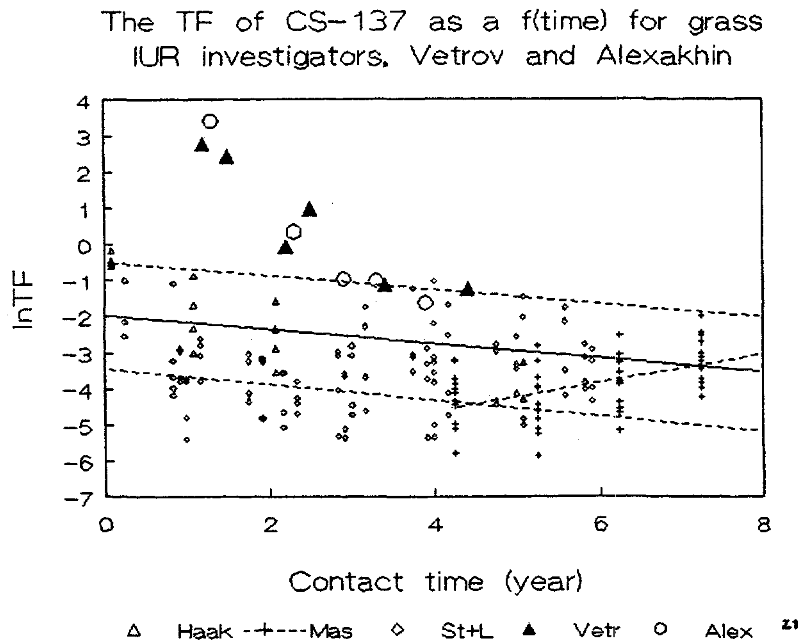

Figure 8. The root uptake of ^{137}Cs by grass as a function of time. IUR investigators: Haak (Sweden), Mas = Masconzoni (Sweden), St+L = Stoujesdijk and Lembrechts (Netherlands). Note the difference between Haak and Masconzoni, both are from the same institute. The difference has to be ascribed to uncontrolled conditions.

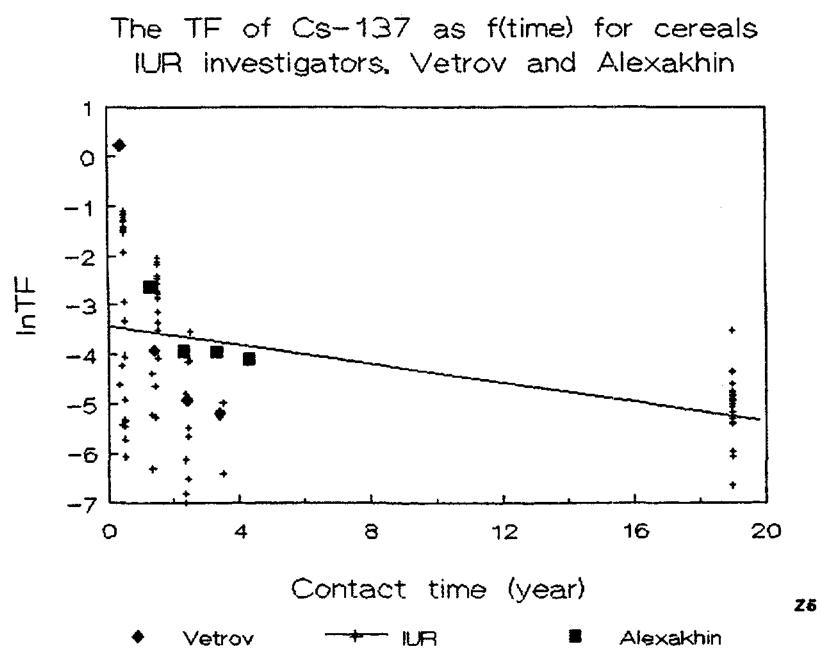

Figure 9. The root uptake of ^{137}Cs by cereals. The IUR data are from many investigators, the data referring to a period of 19 years is from Sweden.

soils in Europe as a whole will be somewhat lower than in northwestern Europe, but certainly considerably higher than in the former USSR.

3.4 Effect of soil type

Almost all investigators who study root uptake take differences between soils into account. Differences exist indeed, but they are for an important part caused by differences of the pH values of soils. For Cs, the uptake increases about 30% per unit decrease of the pH. For Sr this value is 20%. Figure 10 shows an example of the influence of the pH on the uptake of Sr by grass. With the exception of the data by the former USSR investigator Prister, all values are IUR data. There exists a strong correlation between soil type and pH. If root uptake data are limited to the main agricultural areas, it is sufficient to take into account one of these variables, soil type or pH. Extreme pH values are, e.g., found in semi-natural ecosystems. In these systems the pH should always be considered. For answering the elicitation questions only the type of soil is considered; no corrections for pH have been made. (In the IAEA-IUR handbook standardized pH values are used, to do this pH corrections were indeed made).

Figures 6, 8 and 10 show also another phenomenon. The spread of the uptake data per investigator is considerably smaller than the spread for all values. A particular investigator tries to cover the soils and crops for the region under study and does not try to cover an area as large as northwestern Europe.

The IUR databank covers, as said, besides soils of northwestern Europe, also some data from temperate regions in North and South America. The median value is therefore very representative. Application of the median value to a limited part of northwestern Europe, in which of course the natural variation is also limited, may increase the error of the median. To obtain the 5% and 95% limits for a limited part of Europe, dividing or multiplying, respectively, by a factor of 3 will be required. For individual observations (one crop, one field, one year) a factor of 10 must be expected. If no corrections for pH, soil type, and fixation with time are made, the factor can increase to 30.

3.5 The elicitation questions

The answer to the questionnaire is based on: for the generic European soil, all soils; for the organic soil, data for peaty soils; for the sandy soil, data for sandy soils and slightly

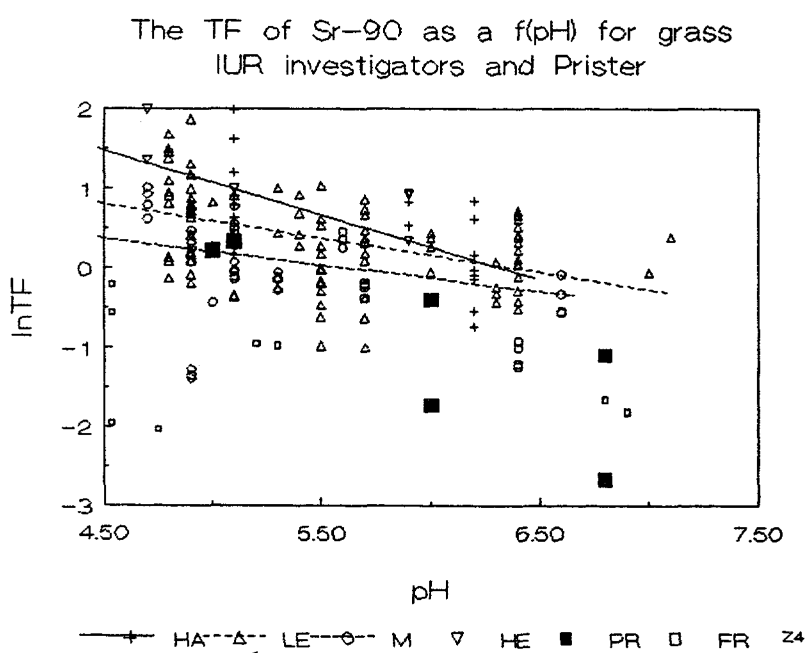

Figure 10. The root uptake of ^{90}Sr by grass as a function of the pH. IUR investigators: Haak (Sweden), LE = Lembrechts (Netherlands), MA = Masconzoni (Sweden), HE = Heine (FRG), FR = Frissel (Netherlands), Former USSER: PR = Prister.

loamy sandy soils. Values for the generic European soil are almost identical to values for sandy soils. High values on peat are compensated by low values on clay. For particular crops the generic European soil may overestimate the uptake. This applies to wheat, part of potatoes, and beets. These crops are mainly produced on loam and clay soils. The uptake from clay and loam soils is slightly lower that from the generic soil. Potatoes from sandy soils are often used in industry and processing removes part of the radioactivity.

The 5% and 95% fractile limits which are used are for Cs; European generic soil ± 20%, sandy soil ± 30%, peat soil ±50%; for Sr; European generic soil ±20%, sandy soil ±20%, peat soil +50%.

I have used the moisture content as provided by NRPB. The value for grass "20% dry matter" is high compared to the value of 10 as used in the IAEA handbook on transfer parameters.

3.6 Generic US soil

As explained, the organic matter content in US soils may be lower than in European soils. Together this might result in slightly higher uptake values. The climate in the greater part of the US is not temperate, as in Europe, but a continental one. This causes more extreme conditions, in particular for root development. As a result, the spread of values will be larger than in Europe.

3.7 Time dependence

It is assumed that migration of Cs and Sr out of the active root layer within a period of 10 years can be neglected. This is also true for removal of Cs and Sr via a harvest. The decrease of the availability is therefore considered to depend only on fixation. Natural variability is, however, also for a part caused by fixation. I have therefore not multiplied both effects, but evaluated which of the two effects is dominating. The dominating effect is selected and used for estimating the 90% interval. An example is shown in Table 3.

3.8 Summary concentration ratios

Summary concentration ratios are presented in Table 4.

Table 3. Selection of the lower limits of the reduction of the root uptake of Cs

Year	Low uptake, medium fixation	Medium uptake, low availability	Selected limit
0.5	0.7	1	0.7
1	.61	.85	.61
3	.31	.34	.31
10	.17	.11	.11

Question 4. Interception factors

Personally I was never involved in interception studies. My main information is derived from the IAEA Handbook on Transfer parameters (IAEA, 1994). The handbook provides for most transfer factors an expected value and uncertainty range. For the interception an expected value is missing; experts could not provide such a value because it is too dependent on the situation (Frissel, 1995). Instead a number of tables and an overview are given. One has to derive default values according to weather conditions.

The total yield for cereals (inclusive straw) is estimated at 12,000 kg/ha (1.2 kg/m^2). The fraction of rootcrops being haulms is estimated at 1/3 of the total crop.

Dry deposition

The most common way to express dry deposition is by the equation:

$$f = e^{(-\mu \cdot B)}$$

where is the interception fraction, B the standing biomass (kg/m^2) and μ is the interception coefficient (m^2/kg). The equation has a theoretical base which might be valid for calm weather conditions. I have based my estimates on those reported values for which it was indicated whether dry or wet crops were considered. A crop is 75% of the time wet because of dew and rain, but an important part of the observations were made during the period that the crop was dry.

Values for cereals and grass differ significantly. I have based my calculations on the lower values for grass, and neglected the high values for cereals.

Table 4. Summary concentration ratios

	Generic European			Sand			Organic		
Sr 0.5 Year	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.11	.13	.16	.14	.18	.21	.008	.017	.025
Root crops	.26	.32	.39	.30	.37	.44	.011	.020	.030
Potato	.04	.05	.06	.04	.06	.07	.004	.007	.011
Gr. Veg.	.41	.51	.61	.55	.69	.83	.026	.052	.078
Grass	.24	.30	.36	.31	.39	.47	.021	.043	.064
Sr 1 year	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.11	.13	.16	.14	.17	.21	.008	.017	.025
Root crops	.25	.32	.38	.29	.36	.44	.010	.020	.030
Potato	.04	.05	.06	.04	.05	.07	.004	.007	.011
Gr. Veg.	.40	.50	.60	.55	.68	.82	.025	.051	.077
Grass	.24	.29	.35	.91	.38	.46	.021	.042	.064
Sr 3 year	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.10	.12	.15	.13	.16	.19	.008	.015	.023
Root crops	.24	.29	.35	.27	.34	.40	.009	.018	.027
Potato	.03	.04	.05	.04	.05	.06	.003	.007	.010
Gr. Veg.	.37	.47	.56	.51	.63	.76	.024	.047	.071
Grass	.22	.27	.33	.28	.35	.42	.020	.039	.059
Sr 10 year	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.09	.11	.13	.11	.14	.17	.007	.013	.020
Root crops	.21	.26	.31	.24	.30	.35	.008	.016	.024
Potato	.03	.04	.04	.04	.04	.05	.003	.006	.009
Gr. Veg.	.33	.41	.49	.44	.55	.67	.021	.041	.062
Grass	.19	.24	.29	.25	.31	.37	.017	.034	.051

Farmland default values	
Cereals	.20
Root crops	.10
Potato	.05
Gr. Veg.	.30
Grass	.05-.20

Comment: I have compared the farmland default values for cereals, root crops and grass with IUR data. Results are shown in Fig. 11-13.

Table 4. Summary concentration ratios (continued)

Cs 0.5 Year	Generic European			Sand			Organic		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.025	.031	.038	.025	.036	.047	.029	.058	.086
Root crops	.008	.010	.012	.010	.014	.018	.010	.020	.030
Potato	.029	.036	.034	.034	.049	.064	.024	.048	.071
Gr. Veg.	.035	.044	.053	.041	.058	.075	.045	.090	.135
Grass	.026	.032	.039	.030	.043	.055	.043	.086	.128
Cs 1 year	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.022	.027	.033	.022	.032	.041	.025	.050	.075
Root crops	.007	.009	.010	.009	.012	.016	.009	.018	.026
Potato	.025	.032	.038	.030	.043	.056	.021	.042	.062
Gr. Veg.	.031	.039	.046	.035	.051	.066	.040	.079	.118
Grass	0.23	.028	.034	.026	.037	.049	.038	.075	.112
Cs 3 year	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.011	.014	.023	.011	.016	.026	.013	.026	.042
Root crops	.003	.004	.007	.004	.006	.010	.005	.009	.015
Potato	.012	.016	.026	.015	.022	.036	.011	.021	.035
Gr. Veg.	.015	.020	.032	.018	.026	.042	.021	.041	.066
Grass	.011	.015	.024	.013	.019	.031	.020	.038	.062
Cs 10 year	5%	50%	95%	5%	50%	95%	5%	50%	95%
Cereals	.003	.008	.017	.004	.009	.019	.006	.014	.030
Root crops	.011	.002	.005	.002	.003	.008	.002	.005	.011
Potato	.004	.009	.019	.005	.012	.026	.005	.011	.025
Gr. Veg.	.005	.011	.023	.006	.014	.031	.010	.022	.048
Grass	.004	.008	.017	.005	.010	.023	.009	.021	.045

Farmland default values		Comment: No disagreement between Farmland default values and IUR values.
Cereals	.010	
Root crops	.005	
Potato	.007	
Gr. Veg.	.007	
Grass	.30 (with fixation)	

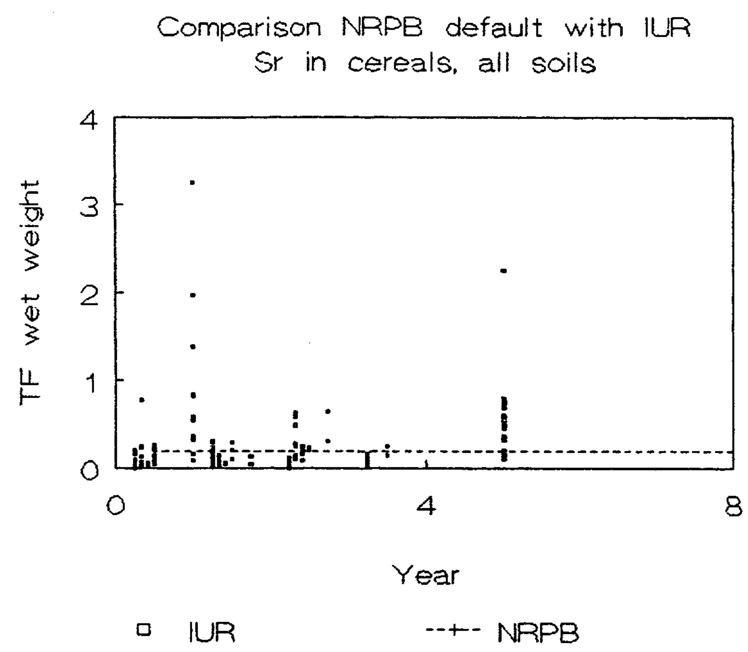

Figure 11. Comparison NRPB Farmland default value for Sr with IUR data. Cereals.

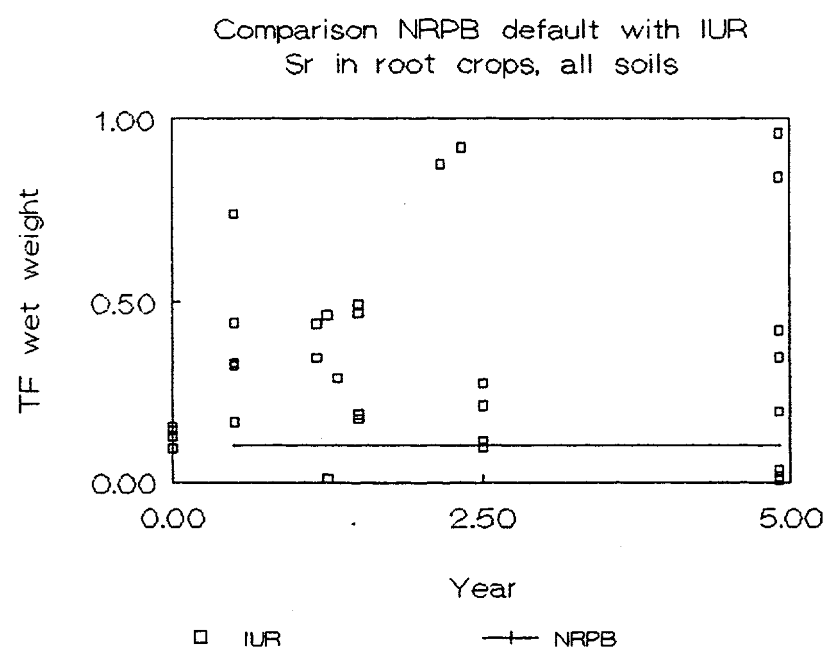

Figure 12. Comparison NRPB Farmland default value for Sr with IUR data. Root crops.

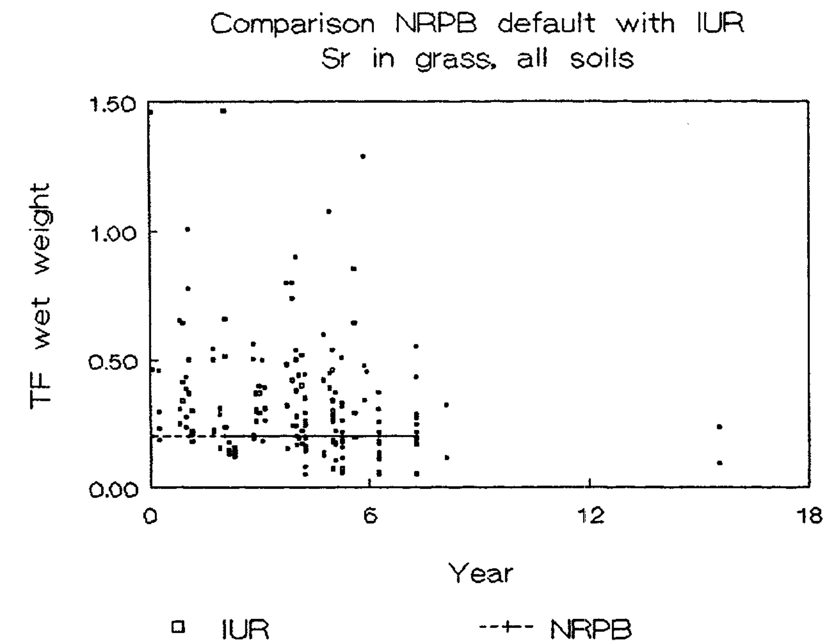

Figure 13. Comparison NRPB Farmland default value for Sr with IUR data. Grass.

I have assumed that the major contribution to the dry deposition results from the period that the crop is wet. The wet period lasts longer and the reported interception coefficients are higher.

The handbook reports values for both μ and σ. I have made various calculations, based on the above equation, for different combinations of B, $\mu \bullet \mu - 2 \bullet \sigma$ and $\mu + 2 \bullet \sigma$.

I have used these results to estimate the median, low and high values of f respectively.

Wet deposition

Wet deposition is less regular than dry deposition. The exponential equation seems therefore not useful. Instead, most values are standardized for the standing biomass, i.e., f/B values are listed in which f is the interception fraction and B is the biomass. There is a dominance of high f/B values. Many of them are 2 or higher. These values refer to very small amount of precipitation, probably they refer to experiments in which investigators tried to get high interception indeed. Values of about 0.4 are reported for rain intensities of 8 and 16 mm.

For cereals, many values are reported ranging from 0.10 to 0.60. A high leaf area index correlates with higher values of f/B. This does not agree with they hypothesis that at higher cities f/B should decrease.

I have considered that at low rain intensities the interception is high (representative f/B 2-4). Rain stems, however, from a rather small layer of the atmosphere. At high rain intensities the interception is low (representative f/B 0.1-0.4), but the rain stems from altitudes going up to 10 km. The share (expressed in Bq's) is therefore probably larger then from low rain intensities.

Literature indicates that differences for particulates and vapor are small. For vapor there are sometimes lower values reported than for particulates.

The estimated values for wet deposition are based on:

Median f/B for ions	=	0.4 (often reported for high rain intensities)
Low f/B for ions	=	0.2 (there are almost no lower values reported)

High f/B for ions = 2 (median value for many investigations – probably with low intensity)

Values for vapor = Lower limit 50% of the limit for ions. Median and high values equal to values for ions.

Question 5. Resuspension factor

I have no experience with resuspension.

Question 6. Retention times

The retention factor seems to be one of the factors on which there is general agreement. It is one of the topics which was only briefly discussed during the preparation of the IAEA-IUR handbook on transfer parameters. An explanation may also be that it is not very important if a crop stays 1 or 2 days longer contaminated with traces of radioactivity. In the literature, retention times are reported as half-life times and residence times. The relation between the residence time t and $T_{1/2}$ is: $t = T_{1/2}/0.693$. Despite this difference, 14 days is recommended for both values. Iodine seems to disappear somewhat faster. My own experience is limited to the Chernobyl period, when I coordinated the measurements in the Netherlands. Both ^{131}I and ^{137}Cs showed the same pattern and disappeared from spinach, lettuce and other vegetables in exactly 14 days, with a $T_{1/2}$ of about 5 or 6 days. In this case growth was included. These vegetables are fast-growing crops and represent therefore the minimum retention time. Without growth, 10 days seems a representative minimum value. Crops which are Ca deficient will take up Sr from the leaf surface. It will not leach off. This is an exceptional situation and is not important for average values. In the elicitation form I have used the values 10, 14 and 21 days.

Question 7. Concentration in grain at harvest

I have no experience in this field.

8. Concentrations in root crops

I have no experience in this field.

9. Correlations between parameters

9.1 Correlation fixation and decrease of root uptake with time

As explained in Section 3.7, I have assumed that the only reason for the decrease of the availability of Cs and Sr with time is caused by fixation.

9.2 Correlation fixation and variation of root uptake

As explained in Section 3.7, the variability of the uptake of radionuclides from soil is partly caused by fixation. I have therefore avoided taking into account the same factor twice. This shown in Table 3.

References

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International Atomic Energy Agency (IAEA). 1994. *Handbook of parameter values for the prediction of radionuclide transfer in temperate environments*, IAEA, Vienna.

1. Soil migration

Generic soil in region of interest within the US

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	1	2	4	0.2	1	2
Below 5 cm	4.2	8.5	17	1.7	4.6	12
Below 15 cm	16	33	74	5.2	13	30
Below 30 cm	31	71	174	14	17	40

Generic soil in region of interest within Europe

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	1	2	4	0.2	1	2
Below 5 cm	4.2	8.5	17	1.7	4.6	12
Below 15 cm	16	33	74	5.2	13	30
Below 30 cm	31	71	174	14	17	40

Sandy soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	1	2	4	0.2	1	2
Below 5 cm	4.2	8.5	17	1.7	4.6	12
Below 15 cm	16	33	74	2.5	10	20
Below 30 cm	31	74	174	7.5	14	30

Highly organic soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	1	2	4	0.2	1	2
Below 5 cm	2	8.5	17	1.7	4.6	12
Below 15 cm	8	33	74	5.2	13	30
Below 30 cm	15	74	174	14	17	40

2. Fixation of Cesium and strontium in soil

Generic soil in regions of interest within the US

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.25	0.3	0.01	0.03	0.05
3 years	0.27	0.55	0.66	0.03	0.09	0.14
5 years	0.41	0.67	0.8	0.05	0.14	0.21
10 years	0.47	0.76	0.89	0.06	0.2	0.28

Sandy soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.25	0.3	0.01	0.03	0.05
3 years	0.27	0.55	0.66	0.03	0.09	0.14
5 years	0.41	0.67	0.8	0.05	0.14	0.21
10 years	0.47	0.76	0.89	0.06	0.2	0.28

Highly organic soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.25	0.3	0.01	0.03	0.05
3 years	0.27	0.55	0.66	0.03	0.09	0.14
5 years	0.41	0.67	0.8	0.05	0.14	0.21
10 years	0.47	0.76	0.89	0.06	0.2	0.28

Generic soil in regions of interest within Europe

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.25	0.3	0.01	0.03	0.05
3 years	0.27	0.55	0.66	0.03	0.09	0.14
5 years	0.41	0.67	0.8	0.05	0.14	0.21
10 years	0.47	0.76	0.89	0.06	0.2	0.28

3. Root uptake concentration factors

6 months after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.035	0.044	0.053	0.41	0.51	0.61
Grain	0.025	0.031	0.038	0.11	0.13	0.16
Root vegetables	0.008	0.01	0.012	0.26	0.32	0.39
Potatoes	0.029	0.036	0.043	0.04	0.05	0.06
Pasture grass	0.026	0.032	0.039	0.24	0.3	0.36

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.041	0.058	0.075	0.55	0.69	0.83
Grain	0.025	0.036	0.047	0.14	0.18	0.21
Root vegetables	0.01	0.014	0.018	0.3	0.37	0.44
Potatoes	0.034	0.049	0.064	0.04	0.06	0.07
Pasture grass	0.03	0.043	0.055	0.31	0.39	0.47

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.045	0.09	0.135	0.26	0.52	0.78
Grain	0.029	0.058	0.086	0.008	0.017	0.025
Root vegetables	0.01	0.02	0.03	0.011	0.02	0.03
Potatoes	0.024	0.048	0.071	0.004	0.007	0.011
Pasture grass	0.043	0.086	0.128	0.021	0.043	0.064

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.035	0.044	0.053	0.41	0.51	0.61
Grain	0.025	0.031	0.038	0.11	0.13	0.16
Root vegetables	0.008	0.01	0.012	0.26	0.32	0.39
Potatoes	0.029	0.036	0.043	0.04	0.05	0.06
Pasture grass	0.026	0.032	0.039	0.24	0.3	0.36

1 year after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.031	0.039	0.046	0.4	0.5	0.6
Grain	0.022	0.027	0.033	0.11	0.13	0.16
Root vegetables	0.007	0.009	0.01	0.25	0.32	0.38
Potatoes	0.025	0.032	0.038	0.037	0.047	0.056
Pasture grass	0.023	0.028	0.034	0.24	0.29	0.35

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.035	0.051	0.066	0.55	0.68	0.82
Grain	0.022	0.032	0.041	0.14	0.17	0.21
Root vegetables	0.009	0.012	0.016	0.29	0.36	0.44
Potatoes	0.03	0.043	0.056	0.04	0.05	0.07
Pasture grass	0.026	0.037	0.049	0.11	0.38	0.46

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.04	0.074	0.118	0.025	0.051	0.077
Grain	0.025	0.05	0.075	0.008	0.017	0.025
Root vegetables	0.009	0.018	0.026	0.01	0.02	0.03
Potatoes	0.021	0.042	0.062	0.004	0.007	0.011
Pasture grass	0.038	0.075	0.12	0.021	0.042	0.064

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.031	0.039	0.046	0.4	0.5	0.6
Grain	0.022	0.027	0.033	0.11	0.13	0.16
Root vegetables	0.007	0.009	0.01	0.25	0.32	0.38
Potatoes	0.025	0.032	0.038	0.037	0.047	0.056
Pasture grass	0.023	0.028	0.034	0.24	0.29	0.35

3 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.015	0.02	0.032	0.37	0.47	0.56
Grain	0.011	0.014	0.023	0.1	0.12	0.15
Root vegetables	0.003	0.004	0.007	0.24	0.29	0.35
Potatoes	0.012	0.016	0.026	0.03	0.04	0.05
Pasture grass	0.011	0.015	0.024	0.22	0.27	0.33

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.018	0.026	0.042	0.51	0.63	0.76
Grain	0.011	0.016	0.026	0.13	0.16	0.19
Root vegetables	0.004	0.006	0.01	0.27	0.34	0.4
Potatoes	0.015	0.022	0.036	0.04	0.05	0.06
Pasture grass	0.013	0.019	0.031	0.28	0.35	0.42

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.021	0.041	0.066	0.024	0.047	0.071
Grain	0.013	0.026	0.042	0.008	0.015	0.023
Root vegetables	0.005	0.009	0.015	0.009	0.018	0.027
Potatoes	0.011	0.021	0.035	0.003	0.007	0.01
Pasture grass	0.02	0.038	0.062	0.02	0.039	0.059

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.015	0.02	0.032	0.37	0.47	0.56
Grain	0.011	0.014	0.023	0.1	0.12	0.15
Root vegetables	0.003	0.004	0.007	0.24	0.29	0.35
Potatoes	0.012	0.016	0.026	0.03	0.04	0.05
Pasture grass	0.011	0.015	0.024	0.22	0.27	0.33

10 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.005	0.011	0.023	0.33	0.41	0.49
Grain	0.003	0.008	0.017	0.09	0.11	0.13
Root vegetables	0.001	0.002	0.005	0.21	0.26	0.31
Potatoes	0.004	0.009	0.019	0.03	0.037	0.045
Pasture grass	0.004	0.008	0.017	0.19	0.24	0.29

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.006	0.014	0.031	0.44	0.55	0.67
Grain	0.004	0.009	0.019	0.11	0.14	0.17
Root vegetables	0.002	0.003	0.008	0.24	0.3	0.35
Potatoes	0.005	0.012	0.026	0.035	0.044	0.053
Pasture grass	0.005	0.01	0.023	0.25	0.31	0.37

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.01	0.022	0.048	0.021	0.041	0.062
Grain	0.006	0.014	0.03	0.007	0.013	0.02
Root vegetables	0.002	0.005	0.011	0.008	0.016	0.024
Potatoes	0.005	0.011	0.025	0.003	0.006	0.009
Pasture grass	0.009	0.021	0.045	0.017	0.034	0.051

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.005	0.011	0.023	0.33	0.41	0.49
Grain	0.003	0.008	0.017	0.09	0.11	0.13
Root vegetables	0.001	0.002	0.005	0.21	0.26	0.31
Potatoes	0.004	0.009	0.019	0.03	0.037	0.045
Pasture grass	0.004	0.008	0.017	0.19	0.24	0.29

4. Interception factors

Unknown deposition

Crop	5%	50%	95%
Green vegetables	0.11	0.45	0.75
Grain	0.08	0.3	0.5
Root vegetables	0.06	0.24	0.4
Grass for hay/silage	0.19	0.75	0.9
Pasture	0.08	0.3	0.5

Particulates and vapor – dry deposition

Crop	5%	50%	95%
Green vegetables	0.20	0.50	0.90
Grain	0.25	0.65	0.95
Root vegetables	0.20	0.50	0.90
Grass for hay/silage	0.25	0.65	0.95
Pasture, grazed	0.10	0.30	0.80

Particulates – wet deposition

Crop	5%	50%	95%
Green vegetables	0.2	0.4	0.9
Grain	0.25	0.5	0.9
Root vegetables	0.2	0.4	0.9
Grass for hay/silage	0.1	0.2	0.8
Pasture, grazed	0.3	0.5	0.95

Vapor – wet deposition

Crop	5%	50%	95%
Green vegetables	0.1	0.4	0.9
Grain	0.1	0.5	0.95
Root vegetables	0.1	0.4	0.9
Grass for hay/silage	0.1	0.2	0.8
Pasture, grazed	0.2	0.5	0.95

5. **Interception factors** — not addressed.

6. **Retention times**

Retention times

Crop	5%	50%	95%
Green vegetables	10	14	21
Grass for silage/hay	10	14	21
Pasture grass without grazing	10	14	21
Pasture grass with grazing			

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Question 1. Soil migration

For estimation of the cesium migration in soil, the migration velocities determined e.g., by Bunzl et al. (1994, 1995) and Bachhuber et al. (1982), for weapons and for the Chernobyl fallout are used. It was observed that the Chernobyl fallout migrates faster by a factor of 2 to 7.

For sandy soils, the residence half-times are assumed to be slightly less (Bunzl et al, 1992).

For cesium in highly organic soils, the same values are assumed as for sandy soil.

Strontium migrates faster in the soil. It is assumed that the migration is a factor of 1.5 to 3 more efficient than for cesium. On organic soils, the same migration velocity is assumed as for cesium, since Sr interacts very effectively with the organic matter.

Bachhuber, H., Bunzl, K., Schimmack, W., and Gans, I. 1982. The migration of Cs-137 and Sr-90 in multi-layered soils: results from batch, column, and fallout investigations; *Radioactive Waste Management* 59, 291-301.

Bunzl, K., Kracke, W., and Schimmack, W. 1992. Vertical migration of Pu-239/240, Am-241 and Cs-137 fallout in a forest soil under spruce, *Analyst* 117, 469-474.

Bunzl, K., Förster H., Kracke, W., and Schimmack, W. 1994. Residence times of fallout Pu-239/240, Am-241, and Cs-137 in the upper horizons of an undisturbed grassland soil, *J. Environm. Radioactivity* 22, 11-27.

Bunzl, K., Kofuji, H., Schimmack, W., Tsumura, A., Ueno, K., and Yamamoto, M. 1995. Residence times of global weapons' testing fallout Np-237 in a grassland soil compared to Pu-239/240, Am-241 and Cs-137; *Health Physics* 68, 89-93.

Question 2. Fixation of cesium and strontium in soil

The estimation for the generic soil is based on the analysis of the UIR data bank (Frissel, 1992). This analysis shows that cesium declines in plants according to a half-life of approximately 4 to 10 years with a mean of 7 years. These values have been used to estimate the fixation process.

The fixation process for strontium is much less important. According to Frissel (1992), the fixation is equivalent to a half-time of 15 to 25 years with a mean of about 20 years.

No distinction is made for the generic soil in Europe and the US.

For sandy soils, the fixation process is probably less pronounced. However, the fixation depends not only on the amount of clay in the soil, but also on the contribution of specific clay minerals in the soil. Therefore, similar fixations can be observed on sandy soils.

In the contaminated areas of Russia, Belarus, and the Ukraine, a lot of sandy soils were affected. In the first four or five years after the accident, a rapid decrease could be observed at many sites. However, this decrease was very likely influenced by the application of countermeasures such as the enhanced use of fertilizer. Since the beginning of the 90's, the decrease is much less pronounced; it is now on the order of the values derived from the UIR data bank. Therefore, the same values are recommended as for the generic soil.

On organic soils, the fixation process is much less pronounced. The variation is wider, since most organic soils have a more or less large fraction of an organic matter which is sufficient to fix the very small amounts of cesium. On some soils, (Colgan et al., 1993; Sanzharova et al., 1994), the fixation seems to be very low or no fixation seems to be observable at all. Therefore, for organic soil, a fixation half-life is recommended of 15 years with a range of 10-25 years.

The fixation for Sr does not seem to be affected by the organic matter content. Therefore the same values are recommended for the organic soils as for the generic soil.

Colgan, P.A., McCann, P., McGee, E.J., and McAulay, I.R. 1993. Short- and long-term losses of Cs-137 from peatland soils; *Irish Journal of Agricultural and Food Research* 32, 37-46.

Frissel, M.J. 1992. An update of recommended soil-to-plant transfer factors of Sr-90, Cs-137, and transuranes, Meeting of the UIR-working group on soil-to-plant transfer factors, Madrid, 1-3 June 1992.

Sanzharova, N.I., Fesenko, S.V., Alexakhin, R.M., Anisimov, V.S., Kutznetsov, V.K., and Chernyayeva, L.G. 1994. Changes in the forms of Cs-137 and its availability for plants as dependent on properties of fallout after the

Chernobyl nuclear power plant accident; *The Science of the Total Environment* 154, 9-22, 1994.

Question 3. Root uptake concentration factors

a) The estimate is based on the analysis of the UIR data bank (Frissel, 1992) which was introduced in the IAEA parameter handbook (1994).

The distribution for the generic soil was derived from the values given for clay/loam and sandy soil. For sandy soils, the values for sand are used and for highly organic soils, the values for peat are used.

For the uncertainty in Frissel (1992), in most cases a factor of 10 is applied. However, this value represents the whole range of uncertainty for a value on a single field at a specific time. The uncertainty of the mean value is smaller than a factor of 10. For estimation, a factor of 3 is applied which is thought to be appropriate for the question asked here.

For the generic soil in the US, the same values are assumed as for the European region, since the soil conditions and the farming practices are similar in the context of this question.

b) If it is meant that the pasture has not been cultivated (no fertilizer, etc.) and not been used for grazing prior to the deposition, I would expect higher concentration ratios. The pH value might be lower than for cultivated pasture and the levels of potassium and calcium are also probably lower.

The difference is hard to estimate; I would expect higher values of approximately a factor of 2. However, this difference would probably disappear within 2 or 3 years after a "normal" cultivation and use of the land has started.

Frissel, M.J. 1992. An update of recommended soil-to-plant transfer factors of Sr-90, Cs-137, and transuranes, Meeting of the UIR-working group on soil-to-plant transfer factors, Madrid, 1-3 June 1992.

IAEA (International Atomic Energy Agency). 1994. *Handbook of parameter values for the prediction of radionuclide transfer in temperate environments*; Technical Report Series No. 364.

Question 4. Interception factors

The interception fraction for all chemical forms and weather situations is a nonlinear problem and it should not be mixed as it is done in this question. These nonlinearities will probably lead to a bimodal distribution, one peak for weather conditions with rain, and another representing dry situations. Furthermore, the interception fraction of wet deposition depends also on the element (Hoffman et al., 1992; Pröhl and Hoffman, 1993).

Therefore, higher uncertainty than necessary will be associated with the answer to the questions as it is asked. The uncertainty could be reduced if the question asked for differentiating according to the element and according to dry and wet deposition.

For dry deposition, for estimation of the interception fraction, it is assumed that the deposit is split in proportion to the area of the leaves and the area of the soil. The leaf area is estimated from Müller and Pröhl (1993) for the yield given above. For grain and root vegetables (including potatoes), the time of the maximum development of foliage is considered, which is in June for grain and in July for potatoes.

Table 4-1. Estimated interception fractions for dry deposition

Plant	Leaf area	Soil area	Total area	Estimated interception fraction*	Estimated interception for I_2
Green veg.	2-3	1	3-4	0.7-0.8	0.8-0.9
Grain	5-7	1	6-8	0.8-0.9	0.85-0.95
Root veg.	4-6	1	5-7	0.8-0.9	0.85-0.95
Pasture grass	2-3.5	1	3-4.5	0.7-0.8	0.8-0.9
Grass for silage	4.5-6.5	1	5.5-7.5	0.8-0.9	0.85-0.95

* Estimated as the ratio of leaf area to total area.

However, it is assumed that for elemental iodine, the interception fractions are larger, since the elemental iodine is actively taken up by the leaves, but not by the soil.

For dry deposition, the uncertainty bounds are derived, assuming that the mid value for the interception in Table 4-1 represents the 50% value. However, in Table 4-1 other factors influencing the interception such as the wind speed and the particle size are not taken into account. Therefore, the estimations for the 5% and the 95% value are wider than in Table 4-1.

The interception for wet deposited activity is estimated according to the approach given in Müller and Pröhl (1993). A key factor for the interception is the amount of rainfall during which the deposition occurs. Therefore, two cases are considered: in the first case, it is assumed that the deposition occurs during a shower of 1 mm rain; in the second case, 10 mm are assumed. This is not the maximum, but showers above that value are very infrequent.

The distribution is derived weighting the element dependence with the dependence on the amount of rainfall. The distribution bounds would be less if an element-dependent approach were used.

It is thought that the interception of cesium during a shower of 3 mm represents the 50% value, because this combination is intermediate with respect to rainfall and the elemental characteristic. The lower bound is thought to be well represented by the interception of iodine during a 10 mm shower, the upper bound is given by the interception of Sr during a shower of 1 mm.

During 10% of the time, there is rainfall in Middle Europe (Nielsen, 1981). No information could be found about the variability of this value; it is thought that it varies between 5 and 15%.

Hoffman, F.O., Thiessen, K.M., Frank, M.L., and Blaylock, B.G. 1992. Quantification of the interception and initial retention of radioactive contaminants; *Atmospheric Environment* 26A, 3313-3321.

Müller, H., and Pröhl, G. 1993. ECOSYS-87 - a dynamic model for assessing radiological con-sequences of nuclear accidents, *Health Physics* 64, 232-252.

Nielsen, O.J. 1981. *A literature review on radioactivity transfer to plants and soil*; Risö-Report-R-450.

Pröhl, G., and Hoffman, F.O. 1993. *The interception, initial retention and post-deposition retention by vegetation of wet and dry deposited radionuclides*, Review paper of the VAMP Terrestrial Working Group (draft), International Atomic Energy Agency.

Question 5. Resuspension factor

According to IAEA (1992), initial resuspension factors were measured at considerable number of sites in Middle Europe after the Chernobyl accident. The values found were in the range of 5E-9 to 5E-8 m^{-1} with an average value of 1.5E-8 m^{-1}. The measured air concentrations decreased with a half-life of approximately 1 y with a range of 0.5-2 y.

It is assumed that the resuspension depends on the characteristic of the surface (Nicholson, 1988; Sehmel, 1980). It is thought that resuspension on arable land is higher than on pasture since the pasture canopy protects the soil against resuspension. To account for this effect, it is assumed that the resuspension on arable land is factor of 2 higher than on pasture land.

Therefore, for the median value, it is assumed that the initial resuspension factor is 2E-8 m^{-1} for arable soil and 1E-8 m^{-1} for pasture. Assuming a half-life of 1 y, this gives resuspension factors after 6 months of 1.5E-8 m^{-1} and 8E-9 m^{-1} for arable land and pasture respectively. The 5% and 95% values are estimated under the following assumptions:

> The uncertainty of the initial resuspension factor due to influences of wind speed, weather conditions, and soil management is assumed to be a factor of 3. Furthermore there is an uncertainty on the time-dependence which accounts for another factor of 2 for the 5% value. The 95% value is less affected by the uncertainty of the time-dependence. Therefore the distribution is slightly skewed.

International Atomic Energy Agency (IAEA). 1992. *Modeling of resuspension, seasonality and losses during food processing*; IAEA-TECDOC-647.

Nicholson, K. 1988. *A review of particle resuspension; Atmospheric Environment* 22, 2639- 2651.

Sehmel, G.A. 1980. Particle resuspension - a review, *Environment International* 4, 107-127.

Question 6. Retention times

After the Chernobyl accident, many measurements showed half-times for a decrease of activity concentration of approximately 10 d including growth dilution (e.g., Kirchner, 1994). At that time, the growth dilution was very intensive. According to Müller and Pröhl (1993) and Ruhr-Stickstoff (1985), the increase of biomass in early summer under good growth conditions (sufficient water and nutrient supply) is equivalent to a half-life of 20 d. The half-life per unit ground of 20 d and that for growth dilution of 20 d gives the half-life of 10 d which was observed after the Chernobyl accident.

The value for pasture grass has been derived assuming a daily growth of 4 (2-6) g/m^2 d (dry matter), which corresponds to a half-life of approximately 24 d (12 to 35 d).

Table 4.2. Estimated interception fractions for wet depositions

Plant	Leaf area	Interception fraction					
		I		Cs		Sr	
		1 mm	10 mm	1 mm	10 mm	1 mm	10 mm
Green veg.	2-3	0.2-0.4	0.03-0.05	0.3-0.5	0.06-0.09	0.35-0.6	0.1-0.2
Grain	5-7	0.4-0.7	0.05-0.08	0.6-0.95	0.1-0.15	0.8-0.95	0.2-0.3
Root veg.	4-6	0.4-0.7	0.07-0.12	0.6-0.95	0.15-0.25	0.75-0.95	0.3-0.5
Pasture grass	2-3.5	0.17-0.35	0.02-0.04	0.3-0.5	0.04-0.07	0.35-0.6	0.07-0.15
Grass for silage	4.5-6.5	0.40-0.60	0.05-0.07	0.6-0.85	0.09-0.13	0.75-0.95	0.15-0.3

The 50% value for pasture grass is derived by combining from the 50% value for weathering without growth dilution and the mean half-life due to growth. The 5%- and the 95%-value is derived accordingly.

Kirchner, G. 1994. Transport of iodine and cesium via the grass-cow-milk pathway after the Chernobyl accident; *Health Physics* 66, 653-665.

Müller, H., and Pröhl, G. 1993. ECOSYS-87 - a dynamic model for assessing radiological consequences of nuclear accidents, *Health Physics* 64, 232-252.

Pröhl, G., and Hoffman, F.O. 1993. *The interception, initial retention and post-deposition retention by vegetation of wet and dry deposited radionuclides, Review paper of the VAMP Terrestrial Working Group (draft)*, International Atomic Energy Agency.

Ruhr-Stickstoff. 1985. Faustzahlen der Landwirtschaft; Landwirtschaftsverlag Münster-Hiltrup.

Question 7. Concentrations in grain at harvest

The results given in the table are a result of the uncertainty of the interception and the translocation. As shown in Question 4, the uncertainties for interception are large due to the influence of the weather.

First, the concentration in grain is estimated for a unit deposition on the leaves. The 50%-values are estimated from Voigt et al. (1991) and from the data of Aarkrog (1969, 1972, 1975), Ludwieg (1962) and Middleton, (1959). From the experiments, it is obvious that the variations are considerable. The uncertainty is higher with longer the time between deposition and harvest, since additional uncertainty is introduced due to variation of the physiological development during the vegetation period.

The interception for grain is estimated for the different times before harvest.

The interception depends not only on the weather conditions but also on the stage of development of the plant. During the 90 days, the variations in the development of the plants are considerable. The leaf area indices during the time period considered vary from 1.5 to 7 which is reflected in the uncertainties of the interception factors.

Aarkrog, A. 1969. The direct contamination of rye, barley, wheat, and oats with Sr-85, Cs-134, Mn-54 and Ce-141; *Rad. Botany* 9, 357-366.

Aarkrog, A. 1972. *Direct contamination of barley with Be-7, Na-22, Cd-115, Cs-134, and Ba-133*; Risö-Report-256, 163-175.

Aarkrog, A. 1975. Radionuclide levels in mature grain related to radiostrontium content and time of direct contamination; *Health Physics* 28, 557-562.

Ludwieg, F. 1962. Die Aufnahme von Cs-137 durch Kartoffelblätter; Zeitschrift Pflanzenernährung, *Düngung und Bodenkunde* 99, 190-194.

Middleton, L.J. 1959. Radioactive Sr and Cs in the edible parts of crops after foliar contamination, *Int. J. Radiat. Biol.* 4, 387-402.

Voigt, G., Pröhl, G., and Müller, H. 1991. Experiments on the seasonality of the cesium translocation in cereals, potatoes and vegetables, *Radiat. Environm. Biophysics* 30, 295-303.

Question 8. Concentrations in root crops

For cesium, the estimate is based on the results given in Voigt et al. (1991), Ludwieg (1963) and Middleton (1959).

There is no measurable translocation of strontium from the leaves to the roots (Moorby and Squire, 1963). This is consistent with the observations in the period of weapons fallout where the strontium levels in potatoes were not affected by the foliar deposition of strontium.

Ludwieg, F. 1962. Die Aufnahme von Cs-137 durch Kartoffelblätter; Zeitschrift Pflanzenernährung, *Düngung und Bodenkunde* 99, 190-194.

Middleton, L.J. 1959. Radioactive Sr and Cs in the edible parts of crops after foliar contamination, *Int. J. Radiat. Biol.* 4, 387-402.

Moorby, J., Squire, H.M. 1963. The entry of strontium into potato tubers after foliar contamination; *Radiation Botany* 3, 95-98.

Voigt, G., Pröhl, G., and Müller, H. 1991. Experiments on the seasonality of the cesium translocation in cereals, potatoes and vegetables, *Radiat. Environm. Biophysics* 30, 295-303.

Question 9. Correlations between parameters

Correlation between processes:

Process 1	Process 2	Strength of correlation
Interception	rainfall	- - -
TF soil-plant, Cs	Cs-uptake of other plants	++
TF soil-plant, Sr	Sr-uptake of other plants	++
Wind-driven resuspension	rainfall	- - -
Retention half-time	amount of rainfall	- -
TF soil-plant, Cs	Cs-retention in soil	-
TF soil-plant, Sr	Sr-retention in soil	-

+++ strong, positive
++ moderate, positive
+ weak, positive
- weak negative
- - moderate, negative
- - - strong, negative

Additional Elicitation Questions

1. Soil Migration

a)

The rainfall in summer is typical for middle Europe. The high content of clay and organic matter indicate a strong sorption of Cs in the soil. The pH value is relatively high considering the organic matter content of approximately 10% (on a dry weight basis). On this soil, the cesium should migrate very slowly with migration velocities of about 0.5 cm, which corresponds to residence half-times in a 1 cm thick layer of approximately 2.5 years. The range of the residence half-times is assumed to be 1.5 to 3.5 years for a 1-cm layer.

1. Soil migration

Generic soil in region of interest within the US

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.3	2.5	3.5	0.12	0.97	2.18
Below 5 cm	12	18	25	4.03	8.13	16.2
Below 15 cm	40	60	80	13.7	26.7	53.3
Below 30 cm	80	120	160	26.7	53.3	106.2

Generic soil in region of interest within Europe

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.3	2.5	3.5	0.12	0.97	2.18
Below 5 cm	12	18	25	4.03	8.13	16.2
Below 15 cm	40	60	80	13.7	26.7	53.3
Below 30 cm	80	120	160	26.7	53.3	106.2

Sandy soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.2	1.7	2.3	0.09	0.69	1.46
Below 5 cm	8	12	17	2.64	5.43	11.3
Below 15 cm	25	40	55	8.65	17.8	35.0
Below 30 cm	50	80	110	16.8	35.6	73.3

Highly organic soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.2	1.7	2.3	0.2	1.2	2.3
Below 5 cm	8	12	17	8	12	17
Below 15 cm	25	40	55	25	40	55
Below 30 cm	50	80	110	50	80	110

2. Fixation of cesium and strontium in soil

Generic soil in regions of interest within the US

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.06	0.1	0.16	0.027	0.034	0.045
3 years	0.19	0.26	0.41	0.08	0.1	0.13
5 years	0.29	0.39	0.58	0.13	0.16	0.21
10 years	0.5	0.63	0.82	0.24	0.3	0.37

Sandy soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.06	0.1	0.16	0.027	0.034	0.045
3 years	0.19	0.26	0.41	0.08	0.1	0.13
5 years	0.29	0.39	0.58	0.13	0.16	0.21
10 years	0.5	0.63	0.82	0.24	0.3	0.37

Highly organic soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.027	0.045	0.06	0.027	0.034	0.045
3 years	0.08	0.13	0.19	0.08	0.1	0.13
5 years	0.13	0.21	0.29	0.13	0.16	0.21
10 years	0.24	0.37	0.5	0.24	0.3	0.37

Generic soil in regions of interest within Europe

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.06	0.1	0.16	0.027	0.034	0.045
3 years	0.19	0.26	0.41	0.08	0.1	0.13
5 years	0.29	0.39	0.58	0.13	0.16	0.21
10 years	0.5	0.63	0.82	0.24	0.3	0.37

3. Root uptake concentration factors

6 months after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.03	0.08	0.2	0.2	0.7	2.0
Grain	0.009	0.025	0.06	0.08	0.2	0.5
Root vegetables	0.01	0.03	0.2	0.1	0.3	0.8
Potatoes	0.01	0.03	0.08	0.02	0.05	0.14
Pasture grass	0.02	0.05	0.13	0.1	0.3	0.8

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.03	0.1	0.3	0.2	0.6	2
Grain	0.01	0.03	0.1	0.08	0.25	0.8
Root vegetables	0.008	0.025	0.08	0.1	0.3	1
Potatoes	0.012	0.04	0.12	0.02	0.06	0.2
Pasture grass	0.02	0.06	0.2	0.1	0.35	1

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.015	0.05	0.15	0.015	0.05	0.15
Grain	0.025	0.08	0.25	0.006	0.02	0.06
Root vegetables	0.06	0.2	0.6	0.0012	0.004	0.012
Potatoes	0.015	0.05	0.15	0.0012	0.004	0.012
Pasture grass	0.03	0.1	0.3	0.02	0.07	0.2

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.03	0.08	0.2	0.2	0.7	2.0
Grain	0.009	0.025	0.06	0.08	0.2	0.5
Root vegetables	0.01	0.03	0.2	0.1	0.3	0.8
Potatoes	0.01	0.03	0.08	0.02	0.05	0.14
Pasture grass	0.02	0.05	0.13	0.1	0.3	0.8

1 year after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.03	0.08	0.2	0.25	0.75	2.0
Grain	0.008	0.02	0.06	0.07	0.2	0.5
Root vegetables	0.002	0.006	0.02	0.1	0.3	0.7
Potatoes	0.01	0.03	0.08	0.016	0.05	0.11
Pasture grass	0.02	0.05	0.13	0.1	0.3	0.75

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.03	0.1	0.3	0.2	0.6	2
Grain	0.01	0.03	0.1	0.06	0.2	0.6
Root vegetables	0.0008	0.0025	0.008	0.1	0.3	1
Potatoes	0.012	0.04	0.12	0.015	0.05	0.15
Pasture grass	0.02	0.06	0.2	0.1	0.35	1

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.015	0.05	0.15	0.015	0.05	0.15
Grain	0.025	0.08	0.25	0.006	0.02	0.06
Root vegetables	0.06	0.2	0.6	0.0012	0.004	0.012
Potatoes	0.015	0.05	0.15	0.0012	0.004	0.012
Pasture grass	0.03	0.1	0.3	0.02	0.07	0.2

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.03	0.08	0.2	0.25	0.75	2.0
Grain	0.008	0.02	0.06	0.07	0.2	0.5
Root vegetables	0.002	0.006	0.02	0.1	0.3	0.7
Potatoes	0.01	0.03	0.08	0.016	0.05	0.11
Pasture grass	0.02	0.05	0.13	0.1	0.3	0.75

3 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.06	0.2	0.2	0.6	1.6
Grain	0.007	0.02	0.05	0.06	0.17	0.4
Root vegetables	0.0015	0.005	0.012	0.1	0.3	0.7
Potatoes	0.01	0.03	0.07	0.016	0.05	0.13
Pasture grass	0.01	0.03	0.09	0.1	0.3	0.7

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.025	0.08	0.25	0.2	0.6	2
Grain	0.008	0.025	0.08	0.06	0.1	0.6
Root vegetables	0.0006	0.002	0.006	0.1	0.3	1
Potatoes	0.01	0.03	0.1	0.015	0.05	0.15
Pasture grass	0.013	0.04	0.13	0.1	0.3	1

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.015	0.05	0.15	0.015	0.05	0.15
Grain	0.025	0.08	0.25	0.006	0.02	0.06
Root vegetables	0.06	0.2	0.6	0.0012	0.004	0.012
Potatoes	0.015	0.05	0.15	0.0012	0.004	0.012
Pasture grass	0.03	0.1	0.3	0.02	0.07	0.2

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.02	0.06	0.2	0.2	0.6	1.6
Grain	0.007	0.02	0.05	0.06	0.17	0.4
Root vegetables	0.0015	0.005	0.012	0.1	0.3	0.7
Potatoes	0.01	0.03	0.07	0.016	0.05	0.13
Pasture grass	0.01	0.03	0.09	0.1	0.3	0.7

10 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.01	0.03	0.08	0.16	0.5	1.1
Grain	0.01	0.03	0.0899	0.05	0.13	0.3
Root vegetables	0.0009	0.003	0.007	0.07	0.2	0.5
Potatoes	0.005	0.015	0.035	0.012	0.03	0.08
Pasture grass	0.006	0.02	0.04	0.05	0.14	0.4

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.012	0.04	0.12	0.12	0.4	1.2
Grain	0.004	0.012	0.04	0.05	0.15	0.5
Root vegetables	0.0003	0.001	0.003	0.06	0.2	0.6
Potatoes	0.005	0.015	0.05	0.012	0.04	0.12
Pasture grass	0.006	0.02	0.06	0.06	0.27	1.24

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.002	0.02	0.2	0.015	0.05	0.15
Grain	0.003	0.03	0.3	0.006	0.02	0.06
Root vegetables	0.05	0.15	0.5	0.0012	0.004	0.012
Potatoes	0.012	0.04	0.12	0.0012	0.004	0.012
Pasture grass	0.004	0.045	0.43	0.02	0.07	0.2

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.01	0.03	0.08	0.16	0.5	1.1
Grain	0.01	0.03	0.0899	0.05	0.13	0.3
Root vegetables	0.0009	0.003	0.007	0.07	0.2	0.5
Potatoes	0.005	0.015	0.035	0.012	0.03	0.08
Pasture grass	0.006	0.02	0.04	0.05	0.14	0.4

4. Interception factors

Unknown deposition

Crop	5%	50%	95%
Green vegetables	0.55	0.7	0.87
Grain	0.69	0.8	0.99
Root vegetables	0.69	0.8	0.99
Grass for hay/silage	0.69	0.8	0.95
Pasture	0.55	0.7	0.87

5. Resuspension factor

Resuspension factor

Crop	5%	50%	95%
Surface crop	3E-09	1.5E-08	6E-08
Pasture grass	1.5E-09	8E-09	3E-08

6. Retention times

Retention times

Crop	5%	50%	95%
Green vegetables	15	20	25
Grass for silage/hay	15	20	25
Pasture grass without grazing	8	11	15
Pasture grass with grazing			

7. Concentrations in grain at harvest

Strontium

Time before harvest	5%	50%	95%
15 days	0.006	0.02	0.07
30 days	0.0007	0.007	0.02
60 days	0.00015	0.0016	0.0085
90 days	6.7E-07	7.0E-06	7.4E-05

Cesium

Time before harvest	5%	50%	95%
15 days	0.014	0.05	0.18
30 days	0.02	0.07	0.2
60 days	0.02	0.08	0.25
90 days	0.0002	0.002	0.02

8. Concentrations in root crops

Cesium

Time before harvest	5%	50%	95%
15 days	0.015	0.05	0.15
30 days	0.015	0.05	0.15
60 days	0.015	0.05	0.15
90 days	0.01	0.03	0.1

EXPERT F

General Introduction

1. Choice of generic soil

In the frame of this study, it has been assumed, as requested in the General Conditions of the Elicitations Questions, that the regions of interest (ROI) were restricted to those typical of warm temperate climates (but only for Europe!), and that Mediterranean countries, arid areas, and areas subject to arctic conditions were excluded. Notice that the climatic criteria "warm temperate climates" excludes two huge agricultural surfaces in the US, so that it was not considered for US.

In a first step, an overview of the soil types of the ROI was released for Europe and US, according to the cartographic units defined for the FAO/UNESCO Soil Classification of the Soil Map of the world (1/5,000,000). For this classification, the relevant properties of the soil were selected according to the agreed principles for the formation of soils, so that correlations could be made with as many as possible other characteristics. These properties are combined in "diagnostic horizons," that were adopted for the establishment of the definitions.

In Europe, the map shows that in the ROI, agricultural areas are mainly covered by:

- Dystric cambisols,
- Orthic luvisols,
- Eutric cambisols.

All these soils present similarities from a pedogenetic point of view. In particular, their formation was governed by the successive depositions of loess during the Quaternary glaciations. As a consequence, the granulometry of the soils formed from that loessic material is about the same (importance of the silty fraction), although some differences of natural origin can be observed from a radioecological point of view, i.e., on the soil parameters influencing the mobility of radionuclides in the soil and in the soil-plant systems (presence of lime interfering with the pH, organic matter formed in some climatic conditions, etc.).

As a result, the generic soil selected for agricultural disturbed soils is the Orthic luvisol which can be considered as typical because of its abundance, its representativity and the mean values observed for their relevant pedochemical parameters.

In undisturbed pasture grass ecosystems, Dystric cambisols and Eutric luvisols were identified as generic soils.

In the US, the identification of representative soils required the superposition of the land use maps and of the climatic map, which allowed us to eliminate the southern part of the US. It led to the selection of the following soil types:

- Dystric cambisols,
- Orthic luvisols,
- Phaeozems which constitute generic agricultural soil.

In undisturbed pasture grass ecosystems, Dystric cambisols and Eutric luvisols were identified as generic soils.

In Europe, as in the US, chernozems, although well represented from a surfacic point of view and being not so different from the generic soil than podzols or peat soils, were not considered as representative, because of the nature of the climate (continental) under which they are formed.

2. Statistical method used

In order to make our expert judgements applicable for uncertainty analysis, the data were provided, as far as possible, relative to the degree of confidence, based on the use of a cumulative probability distribution.

Most of the time, the following procedure was used:

- Once the data were found in the literature, they were ranked and their frequency of occurrence was calculated. The cumulative probability of the data was afterwards drawn on probability paper.

This probability paper was used in order to:

- determine graphically the 5%, 50% and 95% quantiles of the distributions,
- check the normality or log normality of the distribution of the data.

Indeed, on such papers, the linearity of the distributions obtained can be regarded as a sign of normality or log normality, according to the type of scale (linear/logarithmic) of the x axis. Note also that such papers may also help in the estimation of medians, means and standard deviations.

Question 1: Soil Migration

A) General considerations

- Prior to the Chernobyl accident, rapid developments in modeling had not been accompanied by a similar expansion in data. Chernobyl provided an opportunity to test and further develop many of the models but the timescale of some soil processes implies that it could be several years before adequate data can be acquired for validation purpose.

- Chernobyl highlighted two aspects of radionuclide behavior in soil which require careful consideration. These are:

  The rapid penetration of radionuclides in some depth in soil profiles at early times after deposition, particularly in conditions of wet deposition.

  The problems of dealing with material that enters the soil as discrete particles often of low solubility.

  The latter is more difficult to treat without detailed knowledge of the initial chemical behavior within soil.

- For Chernobyl, simple exponential models or those based on diffusion alone have not provided an adequate description of the behavior of radiocesium in soils other than in the first few months following the accident.

B) Assumptions made for answers and references used

Few data are available on the time evolution of the migration of the radiocesium and radiostrontium in the profiles of different soil types. The only source available of data was provided by a paper of Romanov (EC, 1990), concerning the Chelyabinsk region, after the Kyshtym accident. These data were given for a soddy-podzolic soil and a Chernozem which exceptionally was considered as the generic soil, by lack of other data.

References

EC (Commission of the European Communities). 1990. *Proceedings of Seminar on Comparative assessment of the environmental impact of radionuclides released during three major nuclear accidents: Kyshtym, Windscale, Chernobyl., Luxembourg, 1-5 October 1990*, Report EUR 13574, 421-436.

Question 2: Fixation of Cs and Sr in soil

Introduction

The approach for the determination of the data related to the fixation of radionuclides in soil was based on the observation of the time evolution of radiocesium and radiostrontium concentrations after deposition in pasture grass. Even if during the first year after deposition the grass contamination is achieved by translocation, mainly from the shoot bases and not via the soil, the beginning of the radionuclide fixation in the soil was considered as the moment of the deposition (see also the discussion).

Discussion

Huge difficulties were met in answering this question because it was not well formulated.

The first problem comes from the use of the term "in soil." At point zero after deposition on grassland, only a small fraction of the contamination has reached the soil, most of it being concentrated either on aerial parts of the leaves or at the plant base (direct contamination).

The problem is thus the evaluation of the portion which has reached the soil just after deposition.

Moreover, the second problem consists in the calculation of the unavailable fraction which appears as something impossible, unless some hypotheses are made.

The reason is first that the available fraction is not necessarily the fraction taken up by plants. The latter may only be a part of the available fraction!

Nevertheless, the only way to calculate the unavailable fraction for grass was to consider the available fraction as 100% of the grass contamination just after deposition and to consider as unavailable, by calculation, the difference of radionuclide accumulation in grass between the moment of the contamination and the considered time.

As the decrease of the grass-soil concentration ratios is rapid in the first months after contamination, the fraction supposed to be unavailable rapidly becomes high.

If the estimation had been made, taking the starting point one year after deposition when indirect transfer (from the soil) really becomes effective, the fraction becoming unavailable would have been estimated as much less important.

For this question the working hypotheses are thus of prime importance.

Data were obtained from different sources:

- UIR-report (Kirchmann, 1991) for the generic soil. This report presented numerous data from Grebenschikova (1 to 3 years after accident). Uncertainty ranges were also provided by Grebenschikova. The data to 3 years were extrapolated to 5 and 10 years, knowing that fixation process is greatly attenuated after that period.

- Vandecasteele et al. (1988) for the time evolution of radiocesium concentration in grass grown on a podzolic soil.

- For organic soils, some data could be drawn from results presented by Klas Rosen during the UIR meeting of the Working group soil-to-plant transfer factors, held in 1991 at Uppsala (UIR VII, 1990).

References

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UIR. 1990. VII Report of the Working group Soil-to-Plant transfer, RIVM.

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Question 3: Root Uptake

A) General considerations

- The main soil characteristics affecting the soil-to-plant transfer factor are:

  pH; cation exchange capacity; organic matter content and composition; and clay content and composition.

- Extensive data exist in the literature for a range of plant and soil combinations, and climate and growth conditions. Unfortunately, many of the available data are difficult to interpret without supporting data for the state of growth and biomass distribution of the plant concerned, relevant physical and chemical characteristics of the soil, and details on depth distribution of the radioisotope.

- To overcome these difficulties, a working group of UIR defined standard conditions for experimental studies and evaluated data from these experiments in relation to measured soil parameters. The main difficulty in the derivation, understanding, and application of TF is that it is defined on the basis of total concentration of a radionuclide in soil. For many radionuclides the total concentration in soil bears little or no resemblance to subsequent plant uptake. Additionally, TF (like K_d) is defined for equilibrium conditions.

B) Rationale

Introduction

The determination of the requested values for question 3a was done using the transfer values proposed by Frissel (IAEA, 1994), including uncertainty ranges. Frissel's recommended values (drawn from UIR data bank) are based on a time lag of 2 years. They were corrected for the present exercise using a correction factor for time residence in the soil, furnished by the same author (UIR VI, 1989).

For providing the root uptake values for grass grown on a well mixed soil (not considered as a permanent pasture but as a culture), data by different authors were found (UIR VI, 1990; Jouve, 1990; Priester, 1990; Ohlenschlaeger, 1991; and Alexakhin, 1991).

Discussion

For some data, in general presented by people from the CIS, some calculations were done in order to express the soil contamination in Bq/kg instead of Ci/km^2 or kBq/km^2. The transformation led us to consider a contaminated soil layer of 20 cm.

Data were found in a table providing soil-to-plant transfer factors, based on Bq per dry weight crop/Bq per dry weight soil. Corrective factors were applied to the expected value and the values of the confidence interval:

- to express the data on a fresh weight basis for the crop,
- to take into account the fixation by the soil (for Cs and Sr).

Plant species also play an important role in the transfer values.

C) *References*

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Ohlenschlaeger, M. 1991. (RISO National Laboratory - Denmark), "Root absorption factors for varieties of crop species," in *Improvement of practical countermeasures: The agricultural environment, Post - Chernobyl action*, Report EUR 12554 EN, EC, Radiation Protection, pp. 68-79.

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Question 4: Interception

A) *General considerations*

- Fraction reaching the ground: $1 - f - e^{-\mu B}$ where
  f = fraction retained on vegetation
  B = biomass (dry weight), kg/m^2
  μ = interception coeff., m^2/kg

- Degree of retention of particles by plant leaves under damp conditions (more than 90% RH) is ~2 times the retention under dry conditions.

- Results of Aarkrog (1969) and Voigt (1991) show that values of *f* and *f/b* decrease as crop matures. Also values of *f* decrease if amount of simulated rain increases.

- Values of *f/B* of wet deposited activity are element dependent.

- During intermittent rain, *f/B* remains constant.

- For prolonged deposition to vegetation (as occurred during weapons tests) Chamberlain and Garland (1991) applied the normalized specific activity concept:

$$NSA = \frac{\text{Bq/kg dry weight (foliage)}}{\text{Bq/m}^2\text{/d (rate deposition on the ground)}}$$

  Example:

  40 m^2 d/kg is a value appropriate for herbage in good growing conditions; a much higher NSA is observed in poor growing conditions and for native vegetation.

- μ is higher for wet than for dry material deposited during day time.

- According to Chamberlain, the data are particularly sparse for dry deposition of particles smaller than 30 μm diameter. In addition there is no information on interception at the moderate rate of rainfall common in Britain and little is known of the differences between various species of plants.

But interspecies differences are small (factor of 4) in comparison to an order of magnitude variation with the chemical form.

B) References

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Voigt, G., Pröhl, G., and Müller, H. 1991. "Experiments on the seasonality of the cesium translocation in cereals, potatoes and vegetables," *J. Environ. Biophys.* 30, 395.

Question 5: Resuspension

A) General considerations

Resuspension of radionuclides attached to soil particles provides a mechanism for loss from the system by water- or wind-mediated erosion, and for contamination surfaces. Resuspension has generally been treated by means of an empirical resuspension factor defined as the ratio of a radionuclide concentration in air (Bq/m^3) to the ground surface content (Bq/m^2).

Despite many measurements, the prediction of resuspension remains uncertain. Many factors influence resuspension (12 factors listed!), one being "time since deposition." Soon after deposition K is on the order of 10^{-6} to 10^{-4} m^{-1} but over a period of years, K declines to ~10^{-9} m^{-1}.

- Arid and semidesert areas predominate in high K values.
- Strong dependence on wind speed is apparent.
- Few investigations of resuspension in humid climate of Europe. But the Chernobyl accident provided a unique opportunity to observe resuspension from a brief event which caused widespread contamination in Europe.
- Variation of K with deposit has been observed as generally different mechanisms operated for large and small deposits, large being caused by wet deposition in heavy rain and small being caused mainly by dry deposition.

There is a greater availability for material for resuspension of material deposited dry than for wet deposited material.

One must also consider that the long-range transport can increase the value of K observed in areas of low deposit but decrease the K values in areas of high deposit.

Another explanation is also plausible: the fallout from the stratosphere reservoir (where a part of the Chernobyl debris could have been injected): the effect of this fallout is more visible where the initial deposit was lower.

B) References

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Question 6: Retention

A) General considerations

- Weathering half-lives in the range of 12 to 17 days are commonly encountered in the literature. Such values are probably appropriate to initial retention of fission products after weapons testing for which losses occur as a result of re-entrainment of carrier particles, sloughing of leaf surface waxes, and leaching by rainfall. Much longer half-lives or more complex patterns in retention can be associated with radionuclides applied in solution, submicron particles, and gaseous or volatile radionuclides such as those of sulfur and iodine.

- The "non removable" particles on foliage would always be available for ingestion by animals and human beings. For most vegetables and grasses, those constitute from 2 to 10 percent of the initial deposit.

- Miller (1967) observed that the weathering data indicated a more rapid removal of the particles from foliage with time after contamination due to wind effect than can be accounted by a weathering half-life of 10 to 14 days.

The wind-weathering factor is given by the function:

$$e^{-K_w V_w t}$$

t = time after contamination
V_w = average surface wind speed over the time interval t
K_w = coeff. value is function of humidity conditions during and after the contamination.

These values could vary for the same type of plant by a factor of 1000.

B) References used

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Question 9: References

Miller, C.F. 1967. "The retention by foliage of silicate particles ejected from the volcano Irazu in Costa Rica," *Proc. Radioecological Concentration Processes* (Aberg, B. Hungate, F.P., eds), Pergamon.

1. Soil migration

Generic soil in region of interest within the US

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.33	1	1.33	0.166	0.5	0.666
Below 5 cm	9	30	40	6	18	22
Below 15 cm	40	120	160	20	28	36
Below 30 cm	60	200	250	25	35	45

Generic soil in region of interest within Europe

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.33	1	1.33	0.166	0.5	0.666
Below 5 cm	9	30	40	6	18	22
Below 15 cm	40	120	160	20	28	36
Below 30 cm	60	200	250	25	35	45

Sandy soil

Element	Cesium			Strontium		
Soil Depth	5%	50%	95%	5%	50%	95%
Below 1 cm	0.083	0.33	0.5	0.083	0.33	0.666
Below 5 cm	3	10	14	11	15	19
Below 15 cm	12	40	56	16	22	30
Below 30 cm	16	60	90	20	30	40

2. Fixation of cesium and strontium in soil

Generic soil in regions of interest within the US

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.4	0.6	0.01	0.04	0.05
3 years	0.95	0.97	0.99	0.05	0.15	0.25
5 years	0.95	0.98	0.99	0.2	0.36	0.5
10 years	0.95	0.99	0.999	0.6	0.8	0.95

Sandy soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.6	0.86	0.9	0.01	0.03	0.05
3 years	0.8	0.9	0.99	0.02	0.04	0.05
5 years	0.9	0.95	0.99	0.05	0.09	0.15
10 years	0.95	0.99	0.999	0.1	0.25	0.3

Highly organic soil

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.5	0.65	0.8	NR	NR	NR
3 years	0.75	0.85	0.95	NR	NR	NR
5 years	0.8	0.9	0.98	NR	NR	NR
10 years	0.85	0.95	0.99	NR	NR	NR

Generic soil in regions of interest within Europe

Element	Cesium			Strontium		
Time	5%	50%	95%	5%	50%	95%
1 year	0.1	0.4	0.6	0.01	0.04	0.05
3 years	0.95	0.97	0.99	0.05	0.15	0.25
5 years	0.95	0.98	0.99	0.2	0.36	0.5
10 years	0.95	0.99	0.999	0.6	0.8	0.95

3. Root uptake concentration factors

6 months after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.005	0.05	0.43	0.162	0.572	2.115
Grain	0.001	0.014	0.14	0.022	0.119	0.626
Root vegetables	0.001	0.014	0.1	0.022	0.237	2.331
Potatoes	0.001	0.014	0.18	0.004	0.032	0.27
Pasture grass	0.003	0.025	0.28	0.086	0.237	0.615

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.01	0.11	1.12	0.065	0.637	6.345
Grain	0.004	0.04	0.36	0.032	0.205	1.327
Root vegetables	0.0003	0.003	0.03	0.032	0.291	2.957
Potatoes	0.004	0.04	0.43	0.011	0.054	0.291
Pasture grass	0.006	0.06	0.59	0.075	0.356	1.651

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.007	0.07	0.7	0.01	0.05	0.56
Grain	0.01	0.12	1.3	0.002	0.022	0.19
Root vegetables	NR	NR	NR	NR	NR	NR
Potatoes	0.01	0.07	0.74	0.0004	0.0043	0.043
Pasture grass	0.01	0.15	1.46	0.011	0.076	0.68

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.005	0.05	0.43	0.162	0.572	2.115
Grain	0.001	0.014	0.14	0.022	0.119	0.626
Root vegetables	0.001	0.014	0.1	0.022	0.237	2.331
Potatoes	0.001	0.0014	0.18	0.004	0.032	0.27
Pasture grass	0.003	0.025	0.28	0.086	0.237	0.615

1 year after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.004	0.04	0.39	0.15	0.56	2.06
Grain	0.001	0.01	0.1	0.02	0.11	0.61
Root vegetables	0.001	0.01	0.09	0.02	0.23	2.27
Potatoes	0.002	0.02	0.16	0.004	0.03	0.27
Pasture grass	0.003	0.03	0.25	0.08	0.23	0.6

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.01	0.1	1.02	0.06	0.62	6.19
Grain	0.003	0.03	0.27	0.03	0.19	1.3
Root vegetables	0.0003	0.003	0.03	0.03	0.29	2.89
Potatoes	0.004	0.04	0.39	0.01	0.05	0.29
Pasture grass	0.01	0.05	0.55	0.07	0.35	1.61

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.006	0.06	0.6	0.01	0.05	0.54
Grain	0.009	0.09	0.9	0.002	0.02	0.19
Root vegetables	NR	NR	NR	NR	NR	NR
Potatoes	0.01	0.06	0.61	0.0004	0.004	0.04
Pasture grass	0.01	0.12	1.2	0.01	0.07	0.7

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.004	0.04	0.39	0.15	0.56	2.06
Grain	0.001	0.01	0.1	0.02	0.11	0.61
Root vegetables	0.001	0.01	0.09	0.02	0.23	2.27
Potatoes	0.002	0.02	0.16	0.004	0.03	0.27
Pasture grass	0.003	0.03	0.25	0.08	0.23	0.6

3 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.01	0.31	0.15	0.53	1.96
Grain	0.001	0.01	0.1	0.02	0.11	0.58
Root vegetables	0.001	0.01	0.07	0.02	0.22	2.16
Potatoes	0.001	0.01	0.13	0.004	0.03	0.25
Pasture grass	0.002	0.02	0.2	0.08	0.22	0.57

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.01	0.08	0.81	0.06	0.59	5.88
Grain	0.003	0.3	0.26	0.03	0.19	1.23
Root vegetables	0.0002	0.002	0.02	0.03	0.27	2.74
Potatoes	0.003	0.03	0.31	0.01	0.05	0.27
Pasture grass	0.004	0.04	0.43	0.07	0.33	1.53

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.004	0.04	0.4	0.01	0.05	0.52
Grain	0.006	0.06	0.6	0.002	0.02	0.18
Root vegetables	NR	NR	NR	NR	NR	NR
Potatoes	0.01	0.05	0.54	0.0004	0.004	0.04
Pasture grass	0.01	0.11	1.06	0.01	0.07	0.63

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.003	0.01	0.31	0.15	0.53	1.96
Grain	0.001	0.01	0.1	0.02	0.11	0.58
Root vegetables	0.001	0.01	0.07	0.02	0.22	2.16
Potatoes	0.001	0.01	0.13	0.004	0.03	0.25
Pasture grass	0.002	0.02	0.2	0.08	0.22	0.57

10 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.004	0.127	0.12	0.43	1.58
Grain	0.0004	0.004	0.04	0.02	0.09	0.47
Root vegetables	0.0004	0.004	0.029	0.02	0.18	1.75
Potatoes	0.0004	0.004	0.053	0.003	0.02	0.2
Pasture grass	0.001	0.008	0.082	0.06	0.18	0.46

Sandy soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.004	0.033	0.331	0.05	0.48	4.75
Grain	0.001	0.012	0.106	0.02	0.15	0.99
Root vegetables	0.0001	0.001	0.008	0.02	0.22	2.21
Potatoes	0.001	0.012	0.127	0.01	0.04	0.22
Pasture grass	0.002	0.016	0.176	0.06	0.27	1.24

Highly organic soil

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.002	0.02	0.2	0.01	0.04	0.42
Grain	0.003	0.03	0.3	0.002	0.02	0.15
Root vegetables	NR	NR	NR	NR	NR	NR
Potatoes	0.004	0.02	0.221	0.0003	0.003	0.03
Pasture grass	0.004	0.045	0.43	0.01	0.06	0.51

Generic soil in regions of interest in Europe

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	0.001	0.004	0.127	0.12	0.43	1.58
Grain	0.0004	0.004	0.04	0.02	0.09	0.47
Root vegetables	0.0004	0.004	0.029	0.02	0.18	1.75
Potatoes	0.0004	0.004	0.053	0.003	0.02	0.2
Pasture grass	0.001	0.008	0.082	0.06	0.18	0.46

4. Interception factors

Unknown deposition

Crop	5%	50%	95%
Green vegetables	0.0037	0.17	0.26
Grain	0.21	0.9	0.999
Root vegetables	0.23	0.37	0.6
Grass for hay/silage	0.066	0.13	0.31
Pasture	0.009	0.058	0.28

5. Resuspension factor

Resuspension factor

Crop	5%	50%	95%
Surface crop	1.1E-08	5E-08	0.00006
Pasture grass	1E-08	5E-08	0.00006

6. Retention times

Retention times

Crop	5%	50%	95%
Green vegetables	NR	NR	NR
Grass for silage/hay	0.13	17.5	44
Pasture grass without grazing	3.7	19	62
Pasture grass with grazing			

7. Concentrations in grain at harvest

Strontium

Time before harvest	5%	50%	95%
15 days	0.0008	0.034	0.041
30 days	0.013	0.021	0.042
60 days	0.000041	0.002	0.0052
90 days	4.5E-07	0.000014	0.00011

Cesium

Time before harvest	5%	50%	95%
15 days	0.012	0.076	0.13
30 days	0.09	0.1	0.21
60 days	0.023	0.09	0.14
90 days	0.00017	0.014	0.026

8. Concentrations in root crops

Strontium

Time before harvest	5%	50%	95%
15 days	9.5E-07	0.000004	5.1E-06
30 days	1.9E-06	0.000008	0.00001
60 days	0.000007	0.00003	0.000038
90 days	0.000026	0.00011	0.00014

Cesium

Time before harvest	5%	50%	95%
15 days	0.0061	0.0085	0.0106
30 days	0.0078	0.011	0.014
60 days	0.012	0.017	0.021
90 days	0.02	0.028	0.035

EXPERT G

General Comments

I have worked with the evaluation of uncertainties in food chain transfer models for more than 20 years, yet I consider myself to have only a limited base of personal knowledge for many of the parameters for which information is requested in this expert elicitation. The parameters for which I am most confident in submitting a subjective estimate of uncertainty are those for which I have spent either a dedicated effort reviewing original research papers or on which I have conducted specific experiments. These parameters are:

- the fraction of material deposited with wet and dry deposition that is initially retained onto the surfaces of vegetation (Hoffman et al., 1982; Bondietti et al., 1984; Hoffman et al., 1992; IAEA, 1995a);
- the post-deposition retention of deposited materials onto pasture vegetation (Miller and Hoffman, 1983; IAEA, 1995a); and
- the milk transfer coefficients for cow's and goat's milk for radioactive iodine (Hoffman, 1978).

For all other parameters, my base of knowledge is limited to a less extensive survey of the literature, reviews by other scientists, and personal experience with validation studies designed to test the predictions of exposure assessment models (Ng and Hoffman, 1987; Richmond et al., 1988; Hoffman et al., 1988; Köhler et al., 1991; IAEA, 1995b, c). The source of much of the data that I will use in forming these judgments will be from previous uncertainty analyses that I have performed (Hoffman and Baes, 1979; O'Neill et al., 1981; Schwarz and Hoffman, 1981; Hoffman and Miller, 1983; Hoffman et al., 1984; Shevenell and Hoffman, 1993) and from experience gained while working on projects with the IAEA (1982, 1994) and NCRP (1989, 1995). Much of my knowledge about the potential uncertainty in model parameters was developed from 1978 through 1988 while collaborating with the late Dr. Yook C. Ng of Lawrence Livermore National Laboratory. Dr. Ng dedicated almost one quarter of a century to the evaluation of original references and the derivation of element specific transfer coefficients.

Although I have been invited to participate in the expert panel on animals, I have some limited expertise with some of the questions elicited for the panel on soil and plants. I am therefore submitting my subjective estimates of parameter values for portions of questions 3, 4, and 6. Of these, I am most confident in the values that are submitted for the interception fraction and retention times.

Soil and Plants

Question 3. Root uptake concentration factors

Generic soils in regions of interest in the US

The uncertainty associated with transfer coefficients to be used to estimate the collective dose over a large region such as the eastern US will be less related to the variability of reported data than to the relevancy of these data for estimating a regional average at the time of an accidental release. For this reason, I have chosen to use ranges markedly less than those given in previous reviews and uncertainty analyses that have been oriented towards assessing the dose to specific or reference individuals. I feel justified in using smaller ranges of uncertainty given the extent to which these parameters have been reviewed in the literature for a large variety of conditions. Nevertheless, I believe that the ranges that I have selected should encompass the true but unknown regional average value with a subjective level of confidence of 90%.

The primary references that I have consulted are the IAEA Handbook (1994), Ng et al. (1982a), Baes et al. (1984), and Frissel (1992). In the elicitation table, much of the uncertainty in pasture grass will be due to the time of the year and temperature at the time of the accident which should affect the wet to dry weight ratio (given that the questionnaire has asked for us to make estimates based on the fresh weight of vegetation and the fact that most measured values of soil-to-plant uptake have been made on a dry weight basis). The values in the table are relevant for soil-to-plant concentration ratios that should be relevant at between one to three years post deposition.

According to IAEA (1994) "... the bioavailability of cesium and strontium decreases in most agricultural areas with time due to aging effects (i.e., irreversible adsorption and incorporation of nuclides in the soil mineral lattice). For ^{90}Sr this decrease will be around 3% per year and for ^{137}Cs around 15% per year during the first two years after contamination. Thereafter, the rate of decrease seems to become less." I personally have no experience estimating the decrease of the root uptake of these elements with time after deposition so I will have to rely on the recommendations made by others.

Question 4. Interception factors

This is a parameter for which I conducted experimental field research (Hoffman et al., 1982, 1989, 1992, 1995) as well as reviews of original references (Hoffman and Baes, 1979; IAEA, 1995a; Pröhl et al., 1995). My research, however, has been restricted to estimates of the interception of wet deposited materials by pasture grasses, old field vegetation, and leaves of deciduous and coniferous trees. Major differences have been observed between radionuclides deposited in rain as anions and cations, with insoluble particles exhibiting a behavior somewhat similar to cations. The primary reason for this difference is that the surface of the leaf exhibits a predominantly negative charge.

For anions like iodide, iodate, and periodate in rain, the concentration in rain will be approximately constant with respect to the concentration on vegetation. On a dry wt. basis, this constant relationship will be about 2 to 3 L/kg regardless of the amount of rain. For a rainfall of 1 mm and a standing biomass of pasture grass of 300 g m^{-2}, the interception fraction for anions in rain would be about 0.50 for grass cut from a height of about 5 cm above the soil surface. I expect that the uncertainty bounds on this value could range from 0.3 to 0.8. Values approaching 1.0, however, could occur if rain is in the form of a light mist.

The values I am presenting for this elicitation are averages for discrete precipitation events. For increasing amounts of rain above 1 mm, the interception fraction determined for a rainfall of 1 mm should be simply divided by the amount of rain. Thus, for a continuous rainfall of 20 mm, the interception fraction for anions should be $0.5 \div 20 = 0.025$. Higher interception fractions would occur if deposition occurs with intermittent rain events. In this case, the material deposited in the initial rain event is not efficiently removed by subsequent rain. For intermittent rain exceeding 10 mm, the interception fraction for anions could range from 0.05 to 0.10 for a standing biomass of pasture vegetation of 300 g m^{-2}.

For cations in rain, like soluble forms of cesium, the interception fraction can be much higher than for anions and the rain that leaves the vegetation surfaces will be less contaminated than the rain prior to interception by vegetation. At 1 mm of rain and a standing crop biomass of 300 g m^{-2} the interception fraction for cesium will approach 1.0. For cations, our experimental work has shown that increasing amounts of rain only has a slight effect on decreasing the interception fraction. The ranges given below are smaller than ranges found in the literature due to the fact that the question asks for a regional average value.

Interception during dry deposition.

Typically, for leafy vegetation a value of α ($m^2\,kg^{-1}$) in Chamberlain's equation (int. factor = $1 - e^{-\alpha B}$) should be about 3.0 $m^2\,kg^{-1}$ for all materials (with a 90% range of 2 to 6 $m^2\,kg^{-1}$) under conditions of dry deposition. For large particles (>40 μm) that are inefficiently retained by vegetation, this value should be decreased by about one order of magnitude. In addition, there is some evidence suggesting that if the vegetation surfaces are wet or moist prior to the arrival of dry deposition, the values of μ will be increased by a factor of 2 to 3 over the values that would normally have been observed when the surface of the plant were dry (IAEA, 1994).

A major difficulty with dry deposition estimates will be proper estimation of the rate of deposition to the plant surface. This estimate requires that the deposition velocity be determined for the total flux of material deposited to the surface of the vegetation canopy. I have had limited experience in determining interception factors for other crops and for dry deposition so I will not attempt to provide results for these conditions in this elicitation.

Question 6. Retention

In all my investigations of this parameter, including both field research and reviews of the literature (Hoffman et al., 1982a, 1992; Miller and Hoffman, 1983; IAEA, 1995a; Pröhl et al., 1995), the postdeposition weathering for all particulate radionuclides on pasture and old field vegetation can be reasonably described by a 10 to 15-day environmental half-life. During periods of rapid vegetation growth, this parameter may be as low as 6 days. For vegetation that is nearly dormant, values approaching 40 days may occur. This range should be appropriate for both iodine and cesium when vegetation is standing in the field.

The large uncertainty reflects the unknown time of the year in which an accidental release of radionuclides may occur and the prevailing stage of growth of pasture vegetation at that time. The values provided in the table below are for the first 30 days postdeposition. At longer time periods, activity losses from vegetation surfaces may be offset by uptake from roots and contamination from soil resuspension.

I do not have a good feel for the potential effect of grazing in reducing the observed field retention times. I also have limited experience with loss rates of other types of vegetation. From what I have read in the literature, retention times are unlikely to exceed 45 days for leafy vegetation, including the leaves of deciduous trees. For vegetation that is harvested and stored, such as for hay and silage, the retention times will be nearly infinite.

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Soil and Plant

3. Root uptake concentration

1 to 3 years after deposition

Generic soil in regions of interest in the US

Crop	Cesium			Strontium		
	5%	50%	95%	5%	50%	95%
Green vegetables	6E-3	2E-2	6E-2	1E-1	3E-1	1.0
Grain	4E-3	9E-3	2E-2	5E-2	1.3E-1	3E-1
Root vegetables	1E-3	4E-3	2E-2	2E-2	1E-1	5E-1
Potatoes	3E-3	1E-2	3E-2	2E-2	5E-2	1E-1
Pasture grass	6E-3	5E-2	2E-1	1E-2	2E-1	1.0

4. Interception factors

Interception during wet deposition

Pasture veg.	Interception fractions		
	5%	50%	95%
iodine at 1mm rain	0.3	0.5	0.8
iodine at 10mm rain	0.03	0.05	0.08
cesium at 1mm rain	0.6	0.8	1.0
cesium at 10 mm rain	0.4	0.6	0.8

6. Retention times

Retention times

Crop	5%	50%	95%
Green vegetables			
Grass for silage/hay			
Pasture grass without grazing	6	10	40
Pasture grass with grazing			

APPENDIX D

Structure Document and Elicitation Questionnaire for the Expert Panel on Animal Transfer and Behavior

ELICITATION QUESTIONS

Expert Panel on Animals

EC/USNRC Joint Project on
Uncertainty Analysis of Consequence Assessment Programs

J. Brown and J.A. Jones
NRPB, UK

General Conditions

The results of the analysis will be used to make estimates of the uncertainty associated with the collective dose from ingestion and the consequences of banning food that are representative of the majority of reactors within Europe and the US. Inevitably, given the diversity of siting land for reactors within Europe and the US, the results cannot be universally applicable. In this study the regions of interest are restricted to those typical of warm temperate climates, for example northwestern Europe, and northeastern/southeastern US. Mediterranean countries, arid areas of the US and areas subject to arctic conditions are not included. The estimates of uncertainty made by the experts should be applicable to the main agricultural production areas in these regions. Areas such as semi-natural environments should only be considered in so far as they contribute to the food production for the regions of interest in this study.

In general, the questions are asked for the generic case and the expert is asked to define the assumptions he or she has made in determining a generic value. In some cases, more detailed information is asked for, such as a parameter value as a function of soil type. The uncertainty considered in answering the elicitation questions should include the effects of typical variations of weather conditions (e.g., amounts and frequencies of rain) and soil type (where appropriate). In general, the ranges provided should include the uncertainty resulting from the possible range of values for all conditions which are not specified in the information given with the question. For each question a list of conditions are given which are not specified in the question. This list is not exhaustive and does not preclude the experts considering other factors which they believe are important in contributing to the uncertainty.

The quantity used in the models is the best estimate of the value for the various parameters. The uncertainty ranges specified must correspond to this. In this context, the quantity required is the uncertainty on the average value for the region described above. For example, this means that where a parameter refers to the behavior of material in animals, the ranges given must describe the uncertainty on that quantity averaged over a group or groups of animals in the region of interest, rather than the variability between animals in these groups. Where a parameter refers to behavior in crops, then it must reflect the average over different crop growing areas and different stages of the growing season, and not the variability between areas or times of the year.

Some questions refer to transfer from "average" or "generic" soils to crops. In these cases, the experts must consider which types of soil are likely to support the crop under consideration in the region described above and take into account the relative amounts of these in deriving the generic value.

Unless otherwise stated the effect of radioactive decay should not be taken into account.

For the crops considered in COSYMA and FARMLAND the generic terms green vegetables, grain and root vegetables are used. Green vegetables include all leafy green vegetables and brassicas, e.g., cauliflower and cabbages. Grain is representative of cereals grown for human consumption which are dominated by wheat. Root vegetables include potatoes and other vegetables such as carrots and onions. The consumption of root vegetables is typically dominated by potatoes and this should be taken into account in answering the questions relating to root vegetables.

Some additional questions were asked of the experts to perform additional research on the merits of alternative weighting schemes. The quantitative assessments are not included in the rationales, but qualitative information in response to the questions is included for the reader's benefit. A similar approach is taken for dependency information which was requested from the experts. Quantitative information will be provided in follow-up documentation dealing specifically with alternative weighting techniques and dependencies.

1. Animals' consumption rates

(a) What are the daily consumption rates of feedstuffs, for dairy cows, beef cattle, sheep, pigs and poultry?

The answers should be given in kg per day, dry weight. Please provide values for outdoor and indoor feeding for as many of the feedstuffs listed that you believe are appropriate for each animal. You should assume that the animal consumes 100% of each feedstuff and not combinations of feedstuffs, i.e., the consumption of different feedstuffs is not related. These parameters are used to determine the intake of radioactive material; you should not increase these consumption rates to allow for any additional uncontaminated supplementary feed if you feel that this would be used during the periods considered. You should assume that there is sufficient feed for the animals to eat what they require.

Not specified: *animal weight*
milk yields / stage of lactation
quality of feed

Dairy Cows

Feedstuff	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Silage/hay						
Cereals						

Beef Cattle

Feedstuff	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Silage/hay						
Cereals						

Sheep

Feedstuff	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Silage/hay						
Cereals						

Pigs

Feedstuff	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Silage/hay						
Cereals						

Poultry

Feedstuff	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Silage/hay						
Cereals						

Change to elicitation question for US experts

Question reworded. Revised question given below.

1. Animals' consumption rates

(a) What are the annual average daily consumption rates of feedstuffs, for dairy cows, beef cattle, pigs and poultry?

The answers should be given in kg per day, dry weight. For each animal please provide values for as many of the feedstuffs listed that you believe are appropriate. Similarly, please provide values for the feeding practices, i.e., indoors[1] (not grazing) and/or outdoors (grazing) that you believe are appropriate for each animal. It is emphasized that these parameters are used to determine the intake of radioactive material; you should not increase these consumption rates to allow for any additional uncontaminated supplementary feed if you feel that this would be used during the periods considered. You should assume that there is sufficient feed for the animals to eat what they require.

You should provide values that are appropriate for animals used for food production and you should take into account the different intake rates over the fattening period of the animal where appropriate.

If you believe that the categories in the below tables are not appropriate, do not provide distributions (for example, if in your experience, pigs never graze on pasture grass, leave the allocated slots blank).

Not specified: *animal weight / age of animal*
milk yields / stage of lactation
quality of feed
fattening period

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Hay						
Cereals (concentrate)						
Other (e.g., maize silage)						

1. The indoor/outdoor nomenclature was established for the European experts. It was decided in the US meeting that the nomenclature grazing/not grazing would work better for the US situation.

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Hay						
Cereals (concentrate)						
Other (e.g., maize silage)						

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Hay						
Cereals (concentrate)						
Other (e.g., maize silage)						

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass						
Hay						
Cereals (concentrate)						
Other (e.g., maize silage)						

(b) What is the daily consumption of soil by cattle, sheep, pigs and poultry?

The answers should be given in kg per day, dry weight. It should be assumed that the animals are outdoors on an inland site. The feeding practice assumed should be continuous grazing of pasture grass for cattle and sheep and the consumption of cereals and cereals/grass for pigs and poultry, respectively.

Not specified: *animal weight*
consumption rate of grass
weather conditions
time of year
stocking density
quality of pasture

Soil consumption rate

Animal	5%	50%	95%
Cattle			
Sheep			
Pigs			
Poultry			

Change to elicitation question for US experts

Question reworded but essentially the same. Revised question given below.

(b) What is the annual average daily consumption of soil by cattle, pigs and poultry?

The answers should be given in <u>kg per day, dry weight</u>. The feeding practice assumed should be consistent with those given in part a). Please indicate what is the major source of soil ingestion, e.g., associated with feedstuff, housing conditions etc.

If you believe the soil consumption of beef and dairy cattle is different, please provide values for both types of cattle in addition to an average value for cattle.

Not specified: *animal weight*
consumption rate of feedstuff
weather conditions
time of year
stocking density
quality of feedstuff

Soil consumption rate

Animal	5%	50%	95%
Cattle			
Pigs			
Poultry			

2. Availability of ingested feed

What fraction of the activity associated with consumed pasture grass would you expect to be available for transfer across the gut? Please provide values for radioactive material freshly deposited onto grass and for radioactive material biologically incorporated into grass. Would you expect the availability of soil associated activity to be the same? If not, what is the difference?

The feeding practice assumed should be continuous grazing of pasture grass.

Not specified: *animal species*
soil type
type of deposit

Element	Pasture grass: activity freshly deposited			Pasture grass: activity biologically incorporated		
	5%	50%	95%	5%	50%	95%
Strontium						
Caesium						
Iodine						

Element	Soil		
	5%	50%	95%
Strontium			
Cesium			
Iodine			

Change to elicitation question for US experts

Case omitted and combine with Cases C - E as described below.

3. Transfer to meat

(a) Consider an animal which is continuously fed Sr or Cs at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, F_f to the meat of the animal for each element? The quantity should be expressed as the fraction of the daily intake which is in each kg of the animal's meat, once an equilibrium situation has been reached, units d kg^{-1}. Please provide values for dairy cows, beef cattle, sheep, pigs and poultry.

Values should be for the edible meat of animals at slaughtering age, i.e., for beef, lamb, pork and chicken. The field conditions assumed should that animals are outdoors either continuously grazing pasture grass or consuming cereals.

Would your answer be different if the animals are being fed indoors? If so, what would the difference be?

Not specified: *animal weight*
milk yield / stage of lactation

Dairy Cows

Element	5%	50%	95%
Strontium			
Cesium			

Beef Cattle

Element	5%	50%	95%
Strontium			
Cesium			

Sheep

Element	5%	50%	95%
Strontium			
Cesium			

Pigs

Element	5%	50%	95%
Strontium			
Cesium			

Poultry

Element	5%	50%	95%
Strontium			
Cesium			

Change to elicitation question for US experts

The availability of the ingested intake for transfer across the gut (Case B) was combined with the elicitation questions in Case C as follows.

(a) Consider an animal which is continuously fed Sr or Cs at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, Ff to the meat of the animal for each element? The quantity should be expressed as the fraction of the daily intake which is in each kg of the animal's meat, once an equilibrium situation has been reached, units d kg^{-1}. Please provide values for dairy cows, beef cattle, sheep, pigs and poultry as a function of available form (activity freshly deposited on feedstuff, activity biologically incorporated in feedstuff, and activity associated with soil.

Values should be for the edible meat of animals at slaughtering age, i.e., for beef, lamb, pork and chicken. The field conditions assumed should that animals are outdoors either continuously grazing pasture grass or consuming cereals.

Would your answer be different if the animals are being fed indoors? If so, what would the difference be?

If you believe that equilibrium will not be reached during the lifetime of the animal please provide values appropriate for the animals lifetime. Please indicate if values are not for equilibrium in the tables and document your assumptions in the rationale.

Not specified: *animal weight*
milk yield / stage of lactation

Dairy cows, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Beef cattle, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Sheep, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Pigs, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Poultry, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Dairy cows, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Beef cattle, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Sheep, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Pigs, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Poultry, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			

Dairy cows, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			

Beef cattle, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			

Sheep, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			

Pigs, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			

Poultry, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			

4. Transfer to eggs

(a) Consider a laying hen which is continuously fed Sr, I or Cs at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, F_f to an egg for each element? The quantity should be expressed as the fraction of the daily intake which is in each kg of the edible fraction of the egg, once an equilibrium situation has been reached, units d kg^{-1}.

The field conditions assumed should be that animals are outdoors either continuously grazing pasture grass or consuming cereals.

Would your answer be different if the chicken is being fed indoors? If so, what would the difference be?

Not specified: *animal weight*
egg production rate

Chicken Eggs

Element	5%	50%	95%
Strontium			
Iodine			
Cesium			

Change to elicitation question for US experts

The availability of the ingested intake for transfer across the gut (Case B) was combined with the elicitation questions in Case D as follows.

(a) Consider a laying hen which is continuously fed Sr, I or Cs at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, Ff to an egg for each element? The quantity should be expressed as the fraction of the daily intake which is in each kg of the edible fraction of the egg, once an equilibrium situation has been reached, units d kg^{-1}.

The field conditions assumed should that animals are outdoors either continuously grazing pasture grass or consuming cereals. If as in the US, the animals are exclusively grain fed, and your distributions reflect this, please state so in the rationale.

Would your answer be different if the chicken is being fed indoors? If so, what would the difference be?

If you believe that equilibrium will not be reached during the lifetime of the animal please provide values appropriate for the animal's lifetime. Please indicate if values are not for equilibrium in the tables and document your assumptions in the rationale.

Not specified: *animal weight*
egg production rate

Chicken eggs, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium			
Iodine			
Cesium			

Chicken eggs, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Iodine			
Cesium			

Chicken eggs, activity associated with soil

Element	5%	50%	95%
Strontium			
Iodine			
Cesium			

5. Transfer to milk

(a) Consider an animal which is continuously fed Sr, Cs or I at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, F_m *to the milk of the animal for each element? The quantity should be expressed as the fraction of the daily intake which is in each litre of the animal's milk, once an equilibrium situation has been reached, units* $d\,l^{-1}$*. Please provide values for dairy cows, sheep and goats.*

The field conditions assumed should be the agricultural practices assumed should be continuous grazing of pasture.

Would your answer be different if animals are being fed indoors? If so, what would the difference be?

Not specified: *animal weight*
milk yield / stage of lactation

Dairy Cows

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Sheep

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Goats

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Change to elicitation question for US experts

The availability of the ingested intake for transfer across the gut (Case B) was combined with the elicitation questions in Case E as follows:

(a) Consider an animal which is continuously fed Sr, Cs or I at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, Fm to the milk of the animal for each element? The quantity should be expressed as the fraction of the daily intake which is in each litre of the animal's milk, once an equilibrium situation has been reached, units $d\ l^{-1}$. *Please provide values for dairy cows, sheep and goats.*

The field conditions assumed should be the agricultural practices assumed should be continuous grazing of pasture.

Would your answer be different if animals are being fed indoors? If so, what would the difference be?

If you believe that equilibrium will not be reached during the lifetime of the animal please provide values appropriate for the animals lifetime. Please indicate if values are not for equilibrium in the tables and document your assumptions in the rationale.

Not specified: *animal weight*
milk yield / stage of lactation

Dairy cows, activity freshly deposited on feed stuff

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Sheep, activity freshly deposited on feed stuff

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Goats, activity freshly deposited on feed stuff

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Dairy cows, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Sheep, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Goats, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Dairy cows, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Sheep, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Goats, activity associated with soil

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

6. Biological half-life in animals

(a) If an animal has been fed Sr, Cs or I at a constant rate for some period of time under field conditions and equilibrium within the animal's body has been reached, what is the weighted average residence time of the activity in the meat of the animal? Please provide values for dairy cows, beef cattle, sheep, pigs and poultry.

The required quantity is the weighted average residence time. The retention function of material within the animal tissues is likely to have several components with different residence times. The required quantity is the weighted average of these residence times.

Not specified: *animal weight*

Dairy Cows

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Beef Cattle

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Sheep

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Pigs

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

Poultry

Element	5%	50%	95%
Strontium			
Cesium			
Iodine			

7. Correlations between parameters

Some of the quantities for which ranges of values have been obtained are likely to be correlated. The final set of questions relates to the degree of correlation between these parameters.

Please indicate if you believe there are correlations between any of the parameters addressed in the previous questions, including those between different elements for the same parameter. Please indicate, if you believe there is a correlation, whether it is strong or weak and positive or negative.

Additional Elicitation Questions

1. Transfer to meat (d/kg)

(a) A lactating cow fed on hay and food concentrate pellets is administered cesium-134 orally at a constant rate of activity for 4 months. What is the transfer factor for muscle at the end of the period?

Not specified: *animal weight*
milk yield/stage of lactation

	5%	50%	95%
Transfer factor for muscle ($d\ kg^{-1}$)			

(b) Adult sheep, both lactating and non-lactating are fed on green kale pellets contaminated with cesium-134 at a constant rate of 16 kBq per day for 34 days. What is the activity concentration in muscle at the end of the period in both lactating and non-lactating animals?

Not specified: *animal weight*
milk yield/stage of lactation

Activity concentration in muscle ($Bq\ kg^{-1}$)	5% ($Bq\ kg^{-1}$)	50% ($Bq\ kg^{-1}$)	95% ($Bq\ kg^{-1}$)
Lactating animal			
Non-lactating animal			

2. Transfer to milk (d/l)

(a) A lactating cow fed on hay and food concentrate pellets is administered cesium-134 orally at a constant rate of activity for 4 months. What is the radiocesium equilibrium transfer factor for milk F_m?

Not specified: *animal weight*
milk yield/stage of lactation

	5%	50%	95%
F_m for cows milk ($d\ l^{-1}$)			

3. Biological half-life in animals (days)

(a) An adult sheep has been fed equal amounts of wheat and dried grass harvested under field conditions which is contaminated with cesium-137 at constant rate for a period of 60 days. It is then returned to a contamination-free diet. What are the concentrations of cesium-137 in sheep muscle at 5 days, 10 days, 30 days and 60 days following removal from the contamination diet?

Not specified: *animal weight*

Time	5%	50%	95%
5 days			
10 days			
30 days			
60 days			

Correlations Among Random Variables in the Food Chain

Experiment

Univariate uncertain quantities *X* and *Y* have smooth distributions. The marginal distributions of *X* and *Y* are assumed to be known or already assessed. Consider an experiment for assessing the (rank) correlation between *X* and *Y*. In all possibilities, *X* and *Y* realize specific values. The (rank) correlation summarizes how the realized values of *X* and *Y* appear together. If *X* and *Y* are positively (rank) correlated, then, roughly, large values of *X* appear together with large values *Y*, and small values of *X* appear together with small values of *Y*. If *X* and *Y* are negatively correlated then the reverse holds; large values of *X* appear together with small values of *Y*, etc.

Imagine now that many realizations are examined, and that the values for *X* and *Y* in each realization are recorded on a slip of paper and the paper slips deposited in a large urn. We will draw, say, 1000 slips of paper from this urn (without replacement). We now discard all slips for which the *X* value is less than the median *X* value. We now have roughly 500 slips of paper, since the probability of *X* being less than its median is (by definition) 1/2. Suppose we have exactly 500 slips left on which *X* is greater than its median value. We now ask: on how many of these slips will *Y* be greater than the median *Y* value?

If the answer is "250," then the probability is 1/2 that *Y* is bigger than its median, given that *X* is bigger than its median. This would be the case if *X* and *Y* were independent.

If the answer is "more than 250," then there is a tendency for large *X*'s and large *Y*'s to appear together, and this would be the case if *X* and *Y* were positively rank correlated.

If the answer is "less than 250," then there is a tendency for large *X*'s and small *Y*'s to appear together, and this would be the case if *X* and *Y* were negatively correlated.

The expert is asked to describe his/her feeling for correlation by a number *N* between 0 and 500. This number is substituted into the following equation.

$$Pr\,(Y > \text{median} \mid X > \text{median}) = N/500$$

An appropriate joint distribution will then be selected which

- has the assessed marginal distributions
- satisfies the above equation
- has minimal information among all distributions satisfying the above.

Example

The following conditional probability

Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value)

should read as follows: Given that the median value of the daily intake of pasture grass is for a certain animal above its median value, what would the probability be that for the same experiments the daily intake of silage/hay of the same animal is also above its median value?

Animal: Possible Correlations

Question 1a: Daily Consumption of Various Feedstuffs

Dairy Cows

- Outdoors
  Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value | D.I. of Silage/Hay above its median value) =

- Indoors:
  Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value | D.I. of Silage/Hay above its median value) =

- Cereals or Silage/Hay:
  Pr (D.I. of Cereals (indoors) above its median value | D.I. of Cereals (outdoors) above its median value) =

Beef Cattle

- Outdoors
  Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value | D.I. of Silage/Hay above its median value) =

- Indoors:
  Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value | D.I. of Silage/Hay above its median value) =

- Cereals or Silage/Hay:
  Pr (D.I. of Cereals (indoors) above its median value | D.I. of Cereals (outdoors) above its median value) =

Sheep

- Outdoors
  Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value | D.I. of Silage/Hay above its median value) =

- Indoors:
  Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value | D.I. of Silage/Hay above its median value) =

- Cereals or Silage/Hay:
  Pr (D.I. of Cereals (indoors) above its median value | D.I. of Cereals (outdoors) above its median value) =

Pigs

- Outdoors
  Pr (D.I. of Silage/Hay above its median value | D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value | D.I. of Silage/Hay above its median value) =

- Indoors:
  Pr (D.I. of Silage/Hay above its median value I D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value I D.I. of Silage/Hay above its median value) =

- Cereals or Silage/Hay:
  Pr (D.I. of Cereals (indoors) above its median value I D.I. of Cereals (outdoors) above its median value) =

Poultry

- Outdoors
  Pr (D.I. of Silage/Hay above its median value I D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value I D.I. of Silage/Hay above its median value) =

- Indoors:
  Pr (D.I. of Silage/Hay above its median value I D.I. of Pasture grass above its median value) =
  Pr (D.I. of Cereals above its median value I D.I. of Silage/Hay above its median value) =

- Cereals or Silage/Hay:
  Pr (D.I. of Cereals (indoors) above its median value I D.I. of Cereals (outdoors) above its median value) =

Among Animals

- Pr (D.I. of pasture grass for beef cattle above its median value I D.I. of pasture grass of dairy cows above its median value) =
- Pr (D.I. of pasture grass for sheep above its median value I D.I. of pasture grass of beef cattle above its median value) =
- Pr (D.I. of pasture grass for pigs above its median value I D.I. of pasture grass of beef cattle above its median value) =
- Pr (D.I. of pasture grass for poultry above its median value I D.I. of pasture grass of pigs above its median value) =

Question 1b: Daily Consumption of Soil.

- Pr (D.I. of soil of sheep above its median value I D.I. of soil of cattle above its median value) =
- Pr (D.I. of soil of pigs above its median value I D.I. of soil of sheep above its median value) =
- Pr (D.I. of soil of poultry above its median value I D.I. of soil of pigs above its median value) =

Question 2: Availability of Ingested Feed.

Activity freshly deposited on the pasture grass:

- Pr (Availability of cesium above its median value I Availability of strontium above its median value) =
- Pr (Availability of iodine above its median value I Availability of cesium above its median value) =

Activity biologically incorporated in the pasture grass:

- Pr (Availability of cesium above its median value I Availability of strontium above its median value) =
- Pr (Availability of iodine above its median value I Availability of cesium above its median value) =

Between activity Freshly Deposited (F.D.) and Biologically Incorporated (B.I.):

- Pr (Availability of strontium above its median value for F.D. | Availability of strontium above its median value for B.I.) =

Soil:

- Pr (Availability of cesium above its median value for F.D. | Availability of strontium above its median value) =
- Pr (Availability of iodine above its median value for F.D. | Availability of cesium above its median value) =

Between activity Biologically Incorporated (B.I.) and Soil Associated (S.A.) activity:

- Pr (Availability of strontium above its median value for S.A. | Availability of strontium above its median value for B.I.) =

Question 3: Transfer to Meat of Cesium and Strontium:

For each animal:

- Pr (Transfer to meat of cesium above its median value | Transfer to meat of strontium above its median value) =

Among animal:

- Pr (Transfer to meat of beef cattle above its median value | Transfer to meat of dairy cow above its median value) =
- Pr (Transfer to meat of pigs above its median value | Transfer to meat of beef cattle above its median value) =
- Pr (Transfer to meat of sheep above its median value | Transfer to meat of pigs above its median value) =
- Pr (Transfer to meat of poultry above its median value | Transfer to meat of sheep above its median value) =

Question 4: Transfer to Eggs

- Pr (Transfer to eggs of iodine above its median value | Transfer to eggs of strontium above its median value) =
- Pr (Transfer to eggs of cesium above its median value | Transfer to eggs of iodine above its median value) =

Question 5: Transfer to Milk of Cesium, Strontium and Iodine:

Dairy Cow:

- Pr (Transfer to milk of cesium above its median value | Transfer to milk of strontium above its median value) =
- Pr (Transfer to milk of iodine above its median value | Transfer to milk of cesium above its median value) =

Sheep:

- Pr (Transfer to milk of cesium above its median value | Transfer to milk of strontium above its median value) =
- Pr (Transfer to milk of iodine above its median value | Transfer to milk of cesium above its median value) =

Goats:

- Pr (Transfer to milk of cesium above its median value | Transfer to milk of strontium above its median value) =
- Pr (Transfer to milk of iodine above its median value | Transfer to milk of cesium above its median value) =

Among Animals:

- Pr (Transfer to milk of sheep above its median value | Transfer to milk of diary cow above its median value) =
- Pr (Transfer to milk of goats above its median value | Transfer to milk of sheep above its median value) =

Question 6: Biological Half-Life in Animal:

Dairy Cow:

- Pr (Biological half-life of cesium above its median value | Biological half-life of strontium above its median value) =
- Pr (Biological half-life of iodine above its median value | Biological half-life of cesium above its median value) =

Beef Cattle:

- Pr (Biological half-life of cesium above its median value | Biological half-life of strontium above its median value) =
- Pr (Biological half-life of iodine above its median value | Biological half-life of cesium above its median value) =

Sheep:

- Pr (Biological half-life of cesium above its median value | Biological half-life of strontium above its median value) =
- Pr (Biological half-life of iodine above its median value | Biological half-life of cesium above its median value) =

Pigs:

- Pr (Biological half-life of cesium above its median value | Biological half-life of strontium above its median value) =
- Pr (Biological half-life of iodine above its median value | Biological half-life of cesium above its median value) =

Poultry:

- Pr (Biological half-life of cesium above its median value | Biological half-life of strontium above its median value) =
- Pr (Biological half-life of iodine above its median value | Biological half-life of cesium above its median value) =

Among Animals:

- Pr (Biological half-life of cesium of beef cattle above its median value | Biological half-life of cesium of dairy cow above its median value) =

- Pr (Biological half-life of cesium of sheep above its median value | Biological half-life of cesium of beef cattle above its median value) =
- Pr (Biological half-life of cesium of pigs above its median value | Biological half-life of cesium of sheep above its median value) =
- Pr (Biological half-life of cesium of poultry above its median value | Biological half-life of cesium of pigs above its median value) =

Question 7: Correlations Among Questions:

For dairy cows (Question 1a and Question 1b):

- Pr (D.I. of soil of cattle above its median value | D.I. of pasture grass of cattle above its median value) =

For dairy cows (Question 1b and Question 2):

- Pr (D.I. of cesium in soil above its median value | Absorption of cesium in soil above its median value) =

For dairy cows (Question 1a and Question 3):

- Pr (Transfer to meat of strontium above its median value | D.I. of pasture grass of dairy cow above its median value) =

For dairy cows (Question 3 and Question 6):

- Pr (Transfer to meat of cesium above its median value | Biological half-life of cesium above its median value) =

For the poultry (Question 4 and Question 6):

- Pr (Transfer to eggs of cesium above its median value | Transfer to meat of cesium above its median value) =

For dairy cows (Question 3 and Question 5):

- Pr (Transfer to milk of cesium above its median value | Transfer to meat of cesium above its median value) =

APPENDIX E

Rationales and Responses of the Expert Panel on Animal Transfer and Behavior

Rationales and Responses of the Expert Panel on Animal Transfer and Behavior

EXPERT H

Transfer of artificial radionuclides through the food chain to humans has been studied extensively. In particular there have been exhaustive studies of radionuclide transfer following the period of atmospheric nuclear weapons testing, and following the Chernobyl accident. Consequently a substantial body of published literature exists, and reviews of published data can usefully be consulted to arrive at median estimates of transfer for a given parameter. A number of primary sources have been consulted (Ng, 1982; Coughtrey, 1990; IAEA/IUR, 1994). National statistics have also been consulted where appropriate.

Parameters derived from experimental studies of transfer are incorporated into predictive models for application in the event of future releases. Such models inevitably take a cautious approach, and simple assignation of a transfer parameter based on a median assessment of transfer may inaccurately represent a radionuclide's behavior in circumstances different from those under which it was measured. This is compounded by the requirement that models have broad relevance across wide geographical areas. In assessing confidence parameters for the current study, a number of factors have therefore been considered which will affect the breadth of uncertainty.

Responses have been derived on the basis of the geophysical, environmental, and agricultural conditions found in northern Europe but excluding the Mediterranean area. Across this area the treatment of farm animals will vary, with indoor feeding dominating in the nordic countries for long periods of the year, while in more temperate climes such as the UK or northern France, many animals remain outside all the year round. This in itself has implications for such pathways as soil ingestion which can be maximized under the poor quality grazing conditions encountered in late winter and spring. Furthermore, across the area under consideration the nature of the production system will affect radionuclide transfer. Experience following Chernobyl has shown that in less intensive production systems radionuclide transfer is higher.

A further significant factor in assigning values to parameters is the quantity and quality of available data. Uncertainties are greater when available data is scarce. Similarly, data derived under laboratory based studies may not ideally be representative of transfer in the field.

When presented with sufficient data on a given parameter it is therefore relatively simple to derive a value for the median transfer across an area the size of northern Europe. However, accurate assessment of transfer at the 5% and 95% level of the dataset requires detailed knowledge of environmental and production systems across the area under review, and knowledge of radionuclide behavior in a wide range of soil, plant and animal systems. The values of the 5% and 95% level of confidence offered do not necessarily therefore reflect real values but a hypothetical range of possibilities.

Question 1. Animals' consumption rates

National statistics were the primary source of data, but also important were the personal communications of people working in the field. In assessing consumption rates it is very important to take account of varying production systems, particularly with respect to variations in feeding practices at different times of year.

It is important to remember that animals are rarely maintained on a single dietary source. Often even when outside, animals are fed supplementary feed, especially in winter when hay and root crops may be offered. It seems unrealistic to make an assumption that the consumption of different feedstuffs is unrelated when clearly they are related. Estimates of consumption rates are therefore based around realistic assumptions about production systems.

Dairy cattle eat more feed than beef cattle, and are also more likely to receive dietary supplements, especially during milking. On average the daily dry matter intake of dairy and beef cattle will be around 15 and 10 kg, respectively. This will obviously vary according to such factors as animal size and feed quality. When grazing outdoors the bulk of intake will be pasture grass and it is likely that at least 5% of beef cattle will not be fed any supplement.

Sheep consume around 1 kg of food daily. Again, at least 5% of sheep grazing outdoors will probably receive no feed supplement.

Pigs do not eat grass and have only been considered when fed indoors. Estimates of feed consumption by poultry are based on the assumption that they eat a similar quantity of cereal outside or inside.

Daily consumption of soil

Estimates of soil ingestion by cattle and sheep have been based on a review of available literature. It is apparent that under normal circumstances, ingestion of soil is typically 1-2% of dry matter intake. However, under extreme conditions, for instance well stocked pastures in winter months, this can rise substantially. The mode of grazing is a factor in intake of soil by grazing animals; sheep graze very close to the soil surface and will usually ingest a greater proportion of soil; however when grazing on particularly loose sandy soils cattle have been observed to often pull up fodder plants by the roots, which would result in increased soil intake.

Values for soil consumption by pigs and poultry are very much estimates as no data were found on soil ingestion by these animals. It would certainly be likely that pigs would ingest some soil after licking snouts, and that the foraging behavior of free range chickens would also give rise to ingestion of small quantities of soil.

Question 2. Availability of ingested feed

Experimental data obtained since Chernobyl have added much to the understanding of the importance of relative bioavailability of radiocesium to absorption by animals. Several studies reported that pasture grass contaminated with freshly deposited radiocesium was less available for transfer than when it had been biologically incorporated. However, it is also important to remember that the form of the Chernobyl deposit may not be repeated in a future event and that such a deposit might be more or less available. For strontium, a similar pattern is emerging showing that strontium deposited in particulate form may become increasingly available as time passes and the particles weather. When biologically incorporated, strontium is also believed to be almost completely available for absorption. These factors have therefore been reflected in the wide range of uncertainty for both cesium and strontium when freshly deposited, less so when biologically incorporated.

It is also important to note that although cesium is generally assumed to be in a completely available form when biologically incorporated, the gut absorption factor is generally around 0.85 when measured by the true absorption method (the value of 0.6 sometimes recommended is a result of measurement of apparent absorption). It seems advisable to make a distinction between "available for transfer" and actual "transfer". The recommendations here are based on the former parameter.

Iodine associated with vegetation is almost completely available for uptake, and this is reflected in the values given.

Activity associated with soil is not as available as that associated with vegetation. For radiocesium the availability is probably related to the immobilization capacity of the soil. The results of in-vitro and in-vivo experiments suggest that availability factors of soil-associated activity vary between about 3% for soils with high immobilization capacity and about 20% for soils with low immobilization capacity (Cooke et al., in press). Therefore, soil-associated radiocesium is up to about 20% as available as that which is biologically incorporated into vegetation. There are few data regarding the availability of soil-associated strontium or iodine but it is likely that it would be higher than for radiocesium, although its importance would be reduced because of the greater availability of those nuclides for root/shoot uptake. The paucity of available data is reflected in the greater uncertainties proposed for these nuclides.

Question 3. Transfer to meat

Equilibrium transfer of cesium to meat has been well established under controlled experimental conditions, and this is reflected in the comparatively small uncertainties regarding this parameter. However, the transfer rate will be affected by the bioavailability of the radionuclide associated with the vegetation. It would be expected that transfer from a recent deposit could be lower than from a deposit that had been biologically incorporated. Consequently the 5% confidence interval is set much lower than the median value, whereas the 95% value is little greater than the median, as biologically incorporated radiocesium is almost completely absorbed. For strontium the meat pathway is less important than transfer to milk (qv) and therefore data are relatively scarce.

Question 4. Transfer to eggs

Estimates of radionuclide transfer to eggs are made on the basis of available literature.

Question 5. Transfer to milk

Transfer to milk is a significant pathway in the event of a release and has therefore been the subject of many in-vivo studies. The values cited are fairly well established and based on review of available literature. The same comments apply as stated for transfer to meat regarding the form of the radiocesium in/on the vegetation and impact on the distribution of transfer values.

Question 6. Biological half-life in animals

The biological half-life of a radionuclide in animals may be the product of two or more separate retention functions. This leads to comparatively great uncertainties in calculation of a weighted mean and this is reflected in the uncertainties given. Estimates of the 5% confidence interval are dominated by the short-term retention and the 95% confidence interval is based upon maximum importance of long-term retention function. This is the case for cesium where several retention components are operative in producing a weighted half-life.

For strontium uncertainties are further compounded because the metabolic behavior of the radionuclide is strongly influenced by the calcium status of the animal. Consequently literature estimates of Sr biological half-life are few and vary considerably.

For iodine-131 the biological half-life is dominated by the short physical half-life and this is reflected in the comparatively small uncertainty.

Data for sheep and cattle are readily available although subject to some variability. Data for pigs are available for radiocesium.

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1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	6	12	20	NR	NR	NR
Silage	0.1	1	4	4	8	12
Cereals (concentrate)	0.1	2	19	0.5	5	12

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	5	7.5	11	NR	NR	NR
Silage	0.000001	1	3	5	8	11
Cereals (concentrate)	0.000001	0.5	2	0.000001	1	4

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.5	1	2	NR	NR	NR
Silage	0.000001	0.2	0.5	0.5	0.8	2
Cereals (concentrate)	0.000001	0.1	0.5	0.1	0.3	0.8

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.05	0.07	0.15	0.05	0.07	0.15

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.01	0.2	0.7
Sheep	0.02	0.1	0.3
Pigs	0.001	0.01	0.1
Poultry	0.001	0.002	0.005

2. Availability of ingested feed

Activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	0.2	0.7	0.98
Cesium	0.2	0.4	0.98
Iodine	0.8	0.9	0.99

Activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	0.9	0.95	0.99
Cesium	0.8	0.95	0.98
Iodine	0.9	0.95	0.99

Activity associated with soil

Element	5%	50%	95%
Strontium	0.1	0.5	0.8
Cesium	0.001	0.05	0.2
Iodine	0.2	0.5	0.9

3. Transfer to meat (d/kg)

Dairy cows

Element	5%	50%	95%
Strontium	0.001	0.007	0.008
Cesium	0.008	0.02	0.04

Beef cattle

Element	5%	50%	95%
Strontium	0.001	0.008	0.009
Cesium	0.008	0.05	0.07

Sheep

Element	5%	50%	95%
Strontium	0.003	0.04	0.05
Cesium	0.04	0.4	1.3

Pigs

Element	5%	50%	95%
Strontium	0.02	0.04	0.05
Cesium	0.03	0.3	1.2

Poultry

Element	5%	50%	95%
Strontium	0.01	0.08	4
Cesium	0.3	2	10

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.1	0.2	0.6
Iodine	2	3	4
Cesium	0.06	0.4	2

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.001	0.003	0.005
Cesium	0.002	0.007	0.02
Iodine	0.001	0.01	0.04

Sheep

Element	5%	50%	95%
Strontium	0.001	0.04	0.08
Cesium	0.006	0.06	0.1
Iodine	0.08	0.5	0.9

Goats

Element	5%	50%	95%
Strontium	0.006	0.03	0.04
Cesium	0.009	0.1	0.5
Iodine	0.06	0.4	0.7

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	8	20	35
Cesium	8	25	35
Iodine	4	7.5	8

Beef cattle

Element	5%	50%	95%
Strontium	8	20	35
Cesium	8	25	35
Iodine	4	7.5	8

Sheep

Element	5%	50%	95%
Strontium	9	20	40
Cesium	9	23	40
Iodine	4	7.5	8

EXPERT I

Question 1. Animals' consumption rates

According to the recommendations of the Bavarian Animal Breeding Institute (Bayerische Landesanstalt für Tierzucht [BLT]) in general cows and beef are rather insensitive to different feed, and may be fed with different combinations of feed in order to reach the requested dry matter intake given in the tables. Therefore an additional table for a standard feed combination used in Bavaria during the winter season is given below for dairy cows and beef cattle based on feeding recommendations (BLT, Röhrmoser and Propstmeier, pers. com.; Kirchgessner, 1987; Kolb and Gürtler, 1971).

In general, the consumption of fresh pasture grass depends very much on the season when a different quality and quantity of fresh grass is available. Therefore, different supplementations with maize silage/hay and cereals will be applied according to the season and the individual milk yield (recommended value of concentrate is 0.5 kg/d per additional liter of milk exceeding 10 l/d, maximum will be 3 kg/d). For indoors, in this case, it is assumed that this corresponds to animals kept indoors only (also during the grazing season), and fresh cut pasture grass is provided. For beef cattle fattening in Germany, animals are normally kept indoors during the whole season and do not graze outdoors; in addition, they get the same feed or feed combination throughout the whole year. As mentioned above, in general cattle have to be fed with a dry matter intake as given in the tables, no matter which feed intake is taken as 100%; however, animals would refuse to stay on cereals only (minimum this needs to be supplemented by protein feed, additionally it would be too expensive for the farmers!). The 5% values given in the table refer to the minimum intake of dry matter, the 50% values refer to a "normal" median intake, and the value for 95% is a maximum which will not be exceeded under normal conditions.

Dairy Cows

Feed combination*	5%	50%	95%
Maize silage	5	7.5	10
Fresh pasture grass	5	7.5	10
Cereals	0.5	1.0	1.5
Total	10.5	16.0	21.5
* values are given in kg/d dry weight, additionally concentrate is supplied according to milk yield (see text)			

Beef Cattle

Feed combination*	5%	50%	95%
Maize silage	5	7.5	10
Cereals	0.5	1.0	1.5
Total	5.5	8.5	11.5
* values are given in kg/d dry weight			

Concerning commercial pig fattening in Germany, the animals are practically kept only indoors (exception are private farms). They do not consume fresh pasture grass or hay/silage; the main fattening feed is whey (≈15 kg/d f.w.), potatoes (≈10 kg/d f.w.), or cereals. Therefore only data for cereals are given in the table. The assumptions for the values given is a fattened pig with a liveweight of 120 to 150 kg, considered to be the slaughtering weight for pork meat production. However it has to be taken into account that these are growing animals starting from a 25 to 30 kg liveweight; therefore an additional table for intakes according to weight increase is given (BAYWA; Voigt et al., 1986; Beresford and Howard, 1991) for a mixture of different cereals (commercial feed). On average, the weight increase is 1.0 ± 0.2 kg/d due to this fattening method covering a period of about 90 d (Voigt et al., 1986).

Pigs

Weight of pigs liveweight (kg)	5%	50%	95%
30 - 40	5	6	7
40 - 60	6	7.3	8.5
60 - 70	7.5	9.0	10.5
80 - 90	8.0	9.5	11.0
90 -100	9.0	10.3	12.0
≥100	11.0	13.0	15.0
values are given in kg/d dry weight of cereal mixture = commercial product (BAYWA)			

For sheep the values are derived from literature (Kirchgessner, 1987; Kolb and Gürtler, 1971) and BLT recommendations (BLT, Röhrmoser and Propstmeier, pers. com.). The data given in the table refer to milking sheep; for grazing lambs a factor of about 2 less can be assumed. For indoors, somewhat lower values are assumed since animals do not need to graze large areas; therefore energy requirements are less.

Keeping animals indoors also applies for commercial poultry farming. However, it again becomes practice to especially leave egg-laying hens free-ranging (more in private farms). The intake of fresh pasture grass will be insignificant and can be neglected. Values given in the tables refer to recommendations given by BLT (Röhrmoser and Propstmeier, pers. com.).

Soil intake

Soil intake varies considerably depending on many factors such as season of the year, soil adhesion on plants, grazing management, stocking density, condition of pastures etc. (Pfeiffer et al., 1984). For the 5% value, soil adhesion due to resuspension on herbage has been taken into account (Hinton, 1992), an average value over the season for the 50% value, and for the 95% value the highest reported values. For sheep generally higher values are assumed for they normally graze on semi-natural environments or unimproved land where coverage of pasture may not be that dense. Also, soil intake by hens/poultry may be high when they are free-ranging. Recent experiments in Goiania, Brazil (Amaral et al., 1996) have shown that a considerable amount of radioactivity via soil intake reaching a value of about 30 g soil per d is taken up by hens; therefore the 95% value refers to these experiments. Grazing cows seem to avoid uptake of soil (Bavarian farmers' comments). Additionally, due to rotational grazing regimes (moving animals to ungrazed pastures every day) and good vegetation growth conditions in Germany (and Northern Europe) they are provided with sufficiently high and dense pasture grass with less soil adhering to the upper plant parts. Therefore, in general lower values are given than for sheep. The very low values (5% values) for pigs and poultry are assumed for indoor housing only, and being fed with commercial feed where no soil contamination may be expected.

Question 2. Availability

The values for Sr and Cs given are derived mainly from true absorption measurements and some in vitro techniques to determine bioavailability. There are many experiments [published and partly unpublished results from experiments of the CEC/FARM animal group, and Salbu et al. (1992), Singleton et al. (1992), and Voigt et al. (1993a)] showing clearly that there exist different availabilities of radionuclides for different sources (ionic, biologically incorporated, different plant species, soil). Additionally, radiocesium from the Chernobyl accident has shown a different bioavailability due to its physico-chemical form and "aging" effects (see increasing transfer coefficients in dependence of time after the accident (Voigt et al., 1993a; Ward et al., 1989; Solheim-Hansen and Hove, 1991; Voigt et al., 1996; Belli et al., 1993)). Availability of Cs in soil is further dependent on the soil characteristics (clay content, organic/mineral soil). Sr availability is mainly dependent on the Sr/Ca ratio in the different sources. These are the factors taken into account for giving the values provided in the tables: the 5% value refers to the lowest availability measured, the 50% value to the mean i.e., "normal" conditions, and the 95% value to a high availability. Iodine in general is supposed to show little difference in its bioavailability (recent experimental results of the CEC/ FARM animal group) and in most cases is available to almost 100%.

Question 3. Transfer to meat

Here, for Sr and Cs, experimental data were considered only (including own experiments, review articles [Coughtrey, 1990; Müller-Brunnecker, 1982; Pröhl, 1990; Voigt et al., 1993b], and results of the CEC/FARM animal group). The transfer coefficient (F_m) depends on many factors such as lactation stage, age, weight, and muscle types etc., as given also in the introduction to this chapter. The 5% values refer to results of lowest measured F_m, 50% to the most frequent ones, and 95% to the highest value measured in order to cover the whole range of possibilities which might occur after accidental releases of radionuclides. Between cows and sheep/goats, in addition to literature data, a scaling factor of 10 has been considered. In the tables for sheep, the values for lamb are taken as representative for it will be the meat generally consumed; for adult sheep, values a factor of 10 lower can be assumed.

In dairy cows and beef cattle, F_ms for Sr are regarded to be the same (Pröhl and Müller, 1993). Concerning transfer of Sr to meat, it might be considered that due to a long retention in the bone, equilibrium in some experiments has not been reached. This has to be taken into account when determining F_m for long-lived strontium radioisotopes. By applying model calculations, Coughtrey (1990) has suggested the following equilibrium transfer coefficients to meat:

Beef cattle	0.008	pig	0.04
Dairy cow	0.005	sheep	0.04
calf	0.11	lamb	0.33
goat	0.04	chicken	0.08.

However due to fattening practices (normally covering a time period of maximum 90 d for young animals), these higher F_ms may be an overestimate since animals are slaughtered before reaching equilibrium conditions.

Concerning radiocesium, F_ms are given according to that mentioned above. Also the physico-chemical form and the bioavailability play an important role for transfer through the gut and subsequent transfer to meat and has been taken into account. Ionic or aged radiocesium generally tends to give higher values compared to freshly deposited or bioincorporated radiocesium (Müller-Brunnecker, 1982; Ward et al., 1989; Solheim-Hansen and Hove, 1991; Voigt et al., 1996). There will be no difference between indoor and outdoor feeding.

Question 4. Transfer to eggs

Here the total consumable egg is taken as representative (literature review [Coughtrey, 1990; Müller-Brunnecker, 1982; Pröhl, 1990; Pröhl and Müller, 1993] and own experiments [Voigt et al., 1993b]). However it has to be considered that there exist differences in transfer to egg white and yolk (including the biological half-lives). The egg weight as well as egg laying period of hens and the breed have to be considered. Iodine values are based mainly on stable iodine considerations with a wide variation range, the low value referring to experimental data (Okonski et al., 1971).

Question 5. Milk transfer coefficients

The same as stated for the transfer to meat is valid and considered for milk transfer of radionuclides. The behavior of radionuclides in sheep and goats is assumed to be similar; therefore identical values are given (Pröhl, 1990; Pröhl and Müller, 1993).

Iodine transfer depends strongly on the supply of stable iodine in feed, physiological state of the animal, temperature, and many other factors. In cows there is a great variation in reported milk transfer coefficients (Müller-Brunnecker, 1982; Pröhl, 1990; Pröhl and Müller, 1993; Voigt et al, 1994); the 50% value refers to conditions which are likely to occur after accidental releases (e.g., Chernobyl experience [Voigt et al., 1989b]).

Question 6. Biological half-lives

According to literature for Sr the following T_{biol} are taken as to be representative:

- 5% confidence interval: only the short term retention is considered with a value of 0.5 d;
- 50%: (Coughtrey, 1990) 0.3 d (0.93), 19.8 d (0.009), 693 (0.011) resulting in an equivalent value of 8 d;
- 95%: (Pröhl and Müller, 1993) 0.5 d (0.89), 20 d (0.05), 690 (0.06) resulting in an equivalent value of 43 d.

For all animals except poultry the same values seem to be appropriate (Coughtrey, 1990; Pröhl and Müller, 1993). For hens the retention equation of Coughtrey (1990) is considered as the representative median with 0.5 d (0.86), 4.3 d (0.019), 33 d (0.065), and 141 d (0.0014) giving an equivalent T_{biol} of 3 d; the 5% value is taken as the short component of the retention function only, and the 95% value is taken without the long term component of 141 d.

For iodine there is a lack of experimental animal data. However, it is clear that the T_{biol} depends on the stable iodine saturation of the thyroid. As an upper limit for the muscle half-life, the thyroid half-life (turnover rate) of 16 d for cows, 14 d for sheep/lamb and 30 d for pigs (corresponding to their similarity with humans) is taken into account.

For Cs measured experimental data are taken from the literature and own investigations (Coughtrey, 1990; Pröhl, 1990; Pröhl and Müller, 1993; Voigt et al., 1989a). For poultry a different T_{biol} exists for breast and leg muscles; therefore the values cover this including a high value of 25 d for intake of radiocesium with grass cobs (unusual feed) (Voigt et al., 1993b).

Answers to additional elicitation questions

It is assumed that these are the values determined by Assimakopoulos et al. (CEC/FARM animal group) with higher Cs milk transfer coefficients than normally expected, presumably due to the physico-chemical form of ^{134}Cs (ionic). For fallout conditions, I would expect median values to be lower (by a factor of about 10 according to own experiments with one cow given ^{137}Cs bioincorporated over a period of more than 5 months (Voigt et al., 1986), and Chernobyl experience (Voigt et al., 1996; Voigt et al., 1989b). This is also true for the median milk transfer coefficient, however not to that same extent (factor of 2 to 3 [Voigt et al., 1996]).

In general for non-lactating or late lactating animals a factor of 2 higher meat transfer can be assumed according to Assimakopoulos et al. results; this has been taken into account by considering the sheep meat transfer to have an equilibrium value of 0.34 ± 0.07 d/kg.

The biological half-lives and corresponding activity concentrations (i.e., % of retained activities) were calculated as follows: For the 5% confidence values an average half-life of 12 d is assumed (Crout SHEEP model/CEC/FARM animal group), for the 50% a value of 18 d (Coughtrey, 1990), and for 95% the value of 25 d referring to lambs (Pröhl and Müller, 1993).

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1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	10	16	25	10	16	25
Silage	NR	NR	NR	10	16	25
Cereals (concentrate)	8	12	16	8	12	16

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	7	9	12	7	9	12
Silage	7	9	12	7	9	12
Cereals (concentrate)	6	8	10	6	8	10

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.7	2	2.5	0.5	1	2
Silage	0.7	2	2.5	0.5	1	2
Cereals (concentrate)	0.5	1	2	0.5	1	2

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	NR	NR	NR	11	13	15

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.07	0.1	0.15	0.07	0.1	0.15

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.01	0.1	0.2
Sheep	0.03	0.15	0.35
Pigs	0.0001	0.01	0.03
Poultry	0.0001	0.005	0.03

2. Availability of ingested feed

Activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	0.05	0.15	0.3
Cesium	0.1	0.4	0.999
Iodine	0.8	0.99	0.999

Activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	0.1	0.2	0.3
Cesium	0.6	0.8	0.999
Iodine	0.9	0.99	0.999

Activity associated with soil

Element	5%	50%	95%
Strontium	0.01	0.15	0.5
Cesium	0.01	0.6	0.999
Iodine	0.9	0.99	0.999

3. Transfer to meat (d/kg)

Dairy cows

Element	5%	50%	95%
Strontium	0.0001	0.0003	0.0008
Cesium	0.001	0.01	0.015

Beef cattle

Element	5%	50%	95%
Strontium	0.0001	0.0003	0.0008
Cesium	0.01	0.04	0.1

Sheep

Element	5%	50%	95%
Strontium	0.001	0.003	0.004
Cesium	0.1	0.5	1.6

Pigs

Element	5%	50%	95%
Strontium	0.0001	0.002	0.05
Cesium	0.03	0.4	1.1

Poultry

Element	5%	50%	95%
Strontium	0.001	0.03	0.3
Cesium	1.4	4.5	10

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.002	0.3	8.6
Iodine	0.004	3	10
Cesium	0.2	0.5	1.4

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.0004	0.002	0.005
Cesium	0.001	0.003	0.015
Iodine	0.001	0.007	0.03

Sheep

Element	5%	50%	95%
Strontium	0.004	0.01	0.04
Cesium	0.006	0.06	0.09
Iodine	0.1	0.5	1

Goats

Element	5%	50%	95%
Strontium	0.004	0.01	0.02
Cesium	0.006	0.06	0.1
Iodine	0.1	0.5	1

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	0.5	8	43
Cesium	20	30	50
Iodine	4	8	16

Beef cattle

Element	5%	50%	95%
Strontium	0.5	8	43
Cesium	30	40	60
Iodine	4	8	16

Sheep

Element	5%	50%	95%
Strontium	0.5	8	43
Cesium	20	30	40
Iodine	1	7	14

Pigs

Element	5%	50%	95%
Strontium	0.5	8	43
Cesium	20	30	40
Iodine	1	8	30

Poultry

Element	5%	50%	95%
Strontium	0.5	3	20
Cesium	8	15	25
Iodine	1	7.5	20

EXPERT J

General Approach:

This effort involved a combination of reviewing published and some unpublished data, indirect calculations in some cases, general experience with field data and observations, and model testing exercises. With regard to the published literature, my focus was on review/synthesis articles that embodied more extensive reviews of individual papers. Several such reviews have been carried out in recent years and it was deemed more efficient to work with these rather than to attempt a comprehensive search of the primary literature. The latter would require considerably more time than was available. Where appropriate, these reviews as well as primary papers are cited in this report. A limited amount of unpublished data with which the author was involved in gathering was used to form judgments in some cases where published data were not located. It is also true that some judgment was based on a general familiarity with many papers read over the years but which were not specifically located and cited for this elicitation. Much of the experience called upon in this task was the development and testing of the foodchain transport model PATHWAY (Whicker and Kirchner, 1987). Of great importance was the performance of this model against sets of independent data (Kirchner and Whicker, 1984). Although this model was originally parameterized for conditions pertinent to the western US, it has been extensively compared with data sets from locations elsewhere in the US and Europe. The latter was accomplished through the international model testing program called BIOMOVS (Nielsen, Kohler, and Peterson, 1990). A certain degree of confidence has evolved in this model, as well as the basic parameters embodied in it. The actual parameter distributions selected in this study made allowances for the goal of achieving data relevant to the eastern US where most reactors are located, although the uncertainty ranges include conditions relevant to the entire continental US (Alaska and Hawaii excluded). My experience, and therefore the rationale used, varied for the specific questions.

Questions on Animals:

Question 1. (a) Consumption Rates – Feed.

I do not profess any expertise on this topic, however we developed dietary estimates for the model PATHWAY (Whicker and Kirchner, 1987; Whicker et al., 1990; Ward and Whicker, 1990), so some literature and rationale are available. Most of this effort was tailored to the western US for the 1950s period, so it requires adjustment to the present and for the eastern US. Some data on total dry matter intakes (and ranges) are provided in IAEA (1994).

Question 1. (b) Consumption Rates – Soil.

Insoluble tracers, such as titanium, have been measured in animal feces to estimate soil ingestion rates. This is not normally an important pathway, but there are times and places where it can be. Some of the principal historical studies on this topic were conducted by Mayland et al. (1975), Healy (1967, 1968), and Field and Purves (1964). Recent papers include Belli, et al. (1993) and Assimakopoulos et al. (1993). My estimates are based on the older literature.

Question 2. Availability of Ingested Feed.

I did not attempt this question because this implicitly included in the range of transfer coefficients to animal products. Clearly not all the material on plants is soluble. There is a tendency for material that is biologically incorporated to be more soluble than that which is not. This has been demonstrated in particular for Cs. The Cs which may not be available is usually that material which has been fixed in the lattice structure of micaceous clays, or material that is fixed in insoluble fuel particles, such as the case for close-in Chernobyl fallout.

Question 3. Transfer to Meat.

A relatively large body of literature is available for this parameter. Coughtrey (1990) conducted an extensive review of the topic and integrated much of the information using allometric relationships and models. I used his estimates for central tendency and ranges for my 50% and 5%/95% quantiles, respectively, making sure that these ranges covered our values used in the PATHWAY model, in which there is a reasonable degree of confidence. Much of the experimental data were based on soluble tracers, but the ranges are expected to cover cases where fallout is less soluble. Some of the higher range values account for younger animals, which tend to have higher transfer coefficients. Coughtrey attempted to correct data to equilibrium conditions, so this should not be an issue.

Question 4. Transfer to Eggs.

In this case the review of IAEA (1994) was used, which in turn relied on primary literature for I by Ennis et al. (1988) and Coughtrey (1990) for Cs and Sr. These references provided ranges which were used for the 5% and 95%

quantiles. Another review consulted was Ikenberry (1982), which provided parameters for the PATHWAY model.

Question 5. Transfer to Milk.

Again, the IAEA (1994) review was consulted, which in turn cites primary work on cows for I by Hoffman (1978) and for Cs/Sr by Coughtrey (1990). Other literature is cited in IAEA (1994) for sheep and goats. The question of equilibrium should not be a problem for I or Cs, but could be for Sr, due to its long-term buildup in bone. It is not clear without further investigation whether the 50% values need adjustment for equilibrium. The main differences between indoor vs. outdoor feeding would likely be for Cs, if a reasonable fraction of the intake was surficial material fixed to clay minerals. In that case, transfer coefficients might be reduced for outdoor feeding.

Question 6. Biological Half-life in Animals.

A comprehensive analysis of the biological half-lives of Cs in various farm animals was developed by Coughtrey and Thorne (1983), in which body weight was found to be a strong predictor of this parameter. For cows, sheep, and pigs, the predictive equation is $TB = 5.18\ M^{0.3}$, where TB is the biological half-life in days, and M is the body mass in kg. For poultry, $TB = 22.3\ M^{0.325}$. The expected body masses assumed were 600 kg for dairy cows, 330 kg for beef cattle, 50 kg for sheep, 110 kg for pigs, and 0.27 kg for poultry. The distribution quantiles are unsupported assumptions based on the variables such as mass, temperature, diet, etc. that can modify metabolic rates and elemental turnover.

This question was not attempted for Sr or I. A cursory search did not reveal much information. I have information on captive mule deer, however.

Additional Questions – Animals

Question 1. (a) Transfer to Meat (Lactating Cow).

For this question, it was assumed that the lactating cow was somewhat larger than the beef cow, and that milk production competes somewhat with muscle for the Cs. I started with the estimates for the beef cow, then modified those for the lactating condition and larger body size based on intuition. Literature to support this was not located. Equilibrium was assumed since with an estimated TBiol, $1\text{-}e^{-\lambda t}$ should be ~0.9.

Question 1. (b) Transfer to Meat (Sheep).

In this case, data for the nonlactating animal was taken from the same source as in question 3, but adjusted for the lack of equilibrium by $1\text{-}e^{-\lambda t}$, where $\lambda = \ln 2/17$ days, and t = 34 days. Values for the lactating animal were reduced slightly from the nonlactating animal.

Question 2. Transfer to Milk.

The same values and rationale as in question 5 were used.

Question 3. Biological Half-life in Animals.

This question relied on the estimates and rationale for the biological half-life of Cs in sheep from question 6, and the assumption that the loss strictly follows first order kinetics.

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1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	3	10	20	NR	NR	NR
Silage	1	4	15	10	14	20
Cereals (concentrate)	1	3	5	1	3	6

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	5	9	12	0	0	0
Silage	0	0	0	2	4	7
Cereals (concentrate)	0	1	2	2	5	7

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.6	1.2	2.4	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	NR	NR	NR	NR	NR	NR

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.001	0.005	0.01	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.05	0.09	0.12	0.07	0.1	0.15

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.05	0.5	1.0
Sheep	0.01	0.1	0.4
Pigs	NR	NR	NR
Poultry	0.001	0.01	0.05

3. Transfer to meat (d/kg)

Beef cattle

Element	5%	50%	95%
Strontium	0.0003	0.008	0.1
Cesium	0.01	0.05	0.07

Sheep

Element	5%	50%	95%
Strontium	0.003	0.04	0.4
Cesium	0.04	0.17	1.6

Pigs

Element	5%	50%	95%
Strontium	0.002	0.04	0.06
Cesium	0.03	0.24	1.1

Poultry

Element	5%	50%	95%
Strontium	0.01	0.08	4
Cesium	0.3	10	12

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.1	0.2	0.6
Iodine	2	3	5
Cesium	0.06	0.4	2

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.001	0.002	0.003
Cesium	0.001	0.008	0.03
Iodine	0.001	0.01	0.04

Sheep

Element	5%	50%	95%
Strontium	0.01	0.06	0.1
Cesium	0.006	0.06	0.1
Iodine	0.08	0.5	0.9

Goats

Element	5%	50%	95%
Strontium	0.006	0.03	0.04
Cesium	0.009	0.1	0.5
Iodine	0.06	0.4	0.7

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	20	35	45
Iodine	NR	NR	NR

Beef cattle

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	10	30	40
Iodine	NR	NR	NR

Sheep

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	10	17	25
Iodine	NR	NR	NR

Pigs

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	12	21	30
Iodine	NR	NR	NR

Poultry

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	5	15	20
Iodine	NR	NR	NR

EXPERT K

General approach

Values have been given for the type and age of animal which is providing the relevant foodstuff. For example, for milk the lactating adult is used, whereas for meat the animal age/ weight which is most common at time of slaughter is assumed for beef, pork and lamb. Table headings and subdivisions have been changed accordingly.

Upper and lower ranges have been determined as follows: the 5% value gives a low value below which a value would be expected to occur only 1 in 20 times, and the 95% value gives a high value above which a value would occur only 1 on 20 times. For some of the parameters there is a large amount of data and these values can be well defined from available literature. In contrast, for some radionuclide/ parameter/animal combinations, there are few published data and the 5% and 95% values have been deliberately lowered or increased to reflect the lack of data. In addition, the 5% and 95% values also take into account the wide range in liveweights, and hence intake rates, of different ruminant breeds, which include comparatively small and large breeds. In some cases the quoted range is wide, even though there are a wide range of reported data. This is because of the conditions attached to each question, which necessitate a wide range to accommodate the expected variability.

Question 1. Animals' consumption rates

a) Daily consumption rates

The assumption is stated that each feedstuff constitutes 100% of the diet, and that the animal is not eating combinations of feedstuffs. However, eating combinations of feedstuffs is common, especially for some housed animals. Therefore, the requested assumption is unrealistic and contrary to normal farming practice for some of the animals/situations considered. The main exception to this would be for some ruminants grazing outdoors during the summer period. The assumption of 100% of herbage intake from pasture grass is realistic for some animals in this case. Throughout, I have assumed that cereals refers to a concentrate mixture. The assumption of 100% cereals intake by ruminants is inadvisable, since it would need to be supplemented with protein, would be expensive and would lead to gastric problems if maintained for long periods.

The values given are based on two types of source: agricultural literature on nutrient requirements of livestock (e.g., Agricultural Research Council, 1980) and recommendations of intake used in the radioecological literature (e.g., Coughtrey, 1990; IAEA, 1994). I am not an expert on intake of animals, and, with the exception of sheep and goats, I have little direct experience of measuring intake.

<u>Dairy cows, beef cattle and sheep</u>

I have assumed that indoor and outdoor feeding refers to a complete year. The most recent feed intake models used in practical feed planning increase the feed intake by 15% for loose housing or outdoor grazing compared with tethered or indoor cows. This is because of the increased maintenance requirement due to motion (Ingvartsen, 1994). I have therefore allowed for this in the intake estimates. For the outdoor period I have assumed that animals are maintained permanently outdoors. For indoors, I have assumed that animals are provided with recently cut pasture grass when housed. However, while this practice may be carried out in some parts of continental Europe, it would not be a valid assumption for the majority of animals in countries such the UK and Ireland. I have assumed that there would be no difference between pasture grass and silage/hay feedstuff intake.

The values given for cereals alone are unrealistic. Usually giving up to 80% of the energy as concentrate is acceptable. After this level, the rapid digestion of concentrate increases the rate of acid production in the rumen, thereby decreasing the acidity of the celluolytic bacteria. Also, persistent low pH in the rumen will disturb the general rumen function. Therefore, normally it is not advisable to feed concentrate (or grains or beets) alone.

Intake depends on liveweight, and feeding levels also take into account the stage of lactation. Lactating cows are generally thought to eat 35-50% more than nonlactating animals of the same liveweight on the same diet.

If I allow for combinations of feedstuffs under more realistic feeding conditions, with outdoors referring to April-September and indoors referring to October-March, and intake of one feedstuff taking account of the other components of the diet, then the values would be:

	Dairy Cows					
	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass	9	17	23	0.0001	0.3	1.5
Silage/ hay	0.0001	0.5	2.5	9	17	23
Cereals	0.3	1.3	2.5	0.5	1.5	3
	Beef cattle					
	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass	6	8.5	11.5	0.0001	0.2	1
Silage/ hay	0.0001	0.3	2	6	8.5	11.5
Cereals	0.05	0.8	2	0.3	1	2.3

The ranges given reflect the differences in liveweight that occur, particularly in dairy cows, for instance at the higher 95% range of intake will be a dairy cow giving a maximum milk output whilst at the lower 5% range will be small specialist breeds of dairy cows, such as a Jersey cow where output of milk will be much lower.

Throughout the questions, values for lamb are given for animals ready for slaughter, and not for adult sheep apart from the values for transfer to milk. It is unlikely that sheep grazing outdoors will be fed entirely on hay/silage, and often they get very little, if any, concentrate throughout the grazing season. Therefore more reasonable estimates, as defined above, are as follows:

	Lamb					
	Outdoors			Indoors		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.7	1.1	2.2	0.0001	0.1	0.5
Silage/ hay	0.0001	0.1	0.5	0.5	1.1	2.2
Cereals	0.0001	0.1	0.3	0.1	0.3	0.7

Fewer sheep than cattle would be kept indoors during the October - March period.

Pigs

Pigs do not eat pasture grass or silage/hay as a sole component of the diet, and therefore I did not complete this part of the form. A more realistic diet would include concentrate, potatoes and whey. Total daily intake of fattening pigs would vary with liveweight, and would increase over the fattening period. Values have been given for an animal at a suitable slaughter liveweight of about 115-145 kg. There may be some intake of pasture grass or silage/hay by animals which are kept in less intensive conditions and which have access to pasture. In these conditions, and allowing for cereal intake, estimated intake of grass/silage or hay would be:

5%: 0.001 50%: 0.7 95%: 3

Poultry

Intake of pasture grass or silage/hay alone is unrealistic and has not been attempted. Therefore, only values for concentrates have been included. The same values have been given for both indoors and outdoors. However, a more realistic mixed diet may include concentrate and bone meal. In addition, green forage may be consumed by free-ranging poultry.

b) Daily consumption of soil

Seasonal variation in soil consumption is considerable, with much higher soil consumption rates when there is low vegetation biomass (e.g., winter) and high stocking density. It has been assumed that cows and sheep are grazing solely on pasture grass. The values for ruminants are rather higher than might actually occur because the assumption has been made that the animals are outdoors all year round. Compared to liveweight, values for sheep are higher than those for cattle to reflect the grazing conditions and habits of the two species. For lamb, the values quoted are low compared with that expected for ewes since many of the lambs are only present for the spring/summer/early autumn period and therefore high winter soil intakes are not relevant, since the animals are already slaughtered.

Soil intake rates for poultry will vary considerably depending on whether (and to what extent) the animals are free-ranging. The wide range for poultry also reflects the paucity of data for soil ingestion by such birds.

Question 2. Availability of ingested feed

The values given are true absorption coefficients, i.e., the fraction of ingested radionuclide which passes the gut wall into the plasma, as defined in Beresford et al. (1992) and Mayes et al. (1992). The approach is summarized in Mayes et al. (1996). The values are generally based on ruminant data, and for radiocesium, are based mainly on measurements with sheep. Currently, there is little evidence to suggest that gut absorption for cattle differs from that for sheep (Howard, 1994).

Availability of radionuclides for absorption across the gut wall is highly dependent on the physicochemical form. There are data to show reduced availability for absorption of freshly deposited radiocesium after the Chernobyl accident. It is, however, difficult to use these values to predict the availability of radionuclides emitted by a future accident where the bioavailability of emitted radionuclides may be different. The high uncertainty values given for freshly deposited radionuclides reflect the uncertainty concerning the chemical form. The 5% values assume a low-availability source such as a fuel-particle associated deposit, for which there are few data. The 95% values assume that the freshly deposited radionuclide has the same availability as that when it is plant-incorporated.

Gut absorption of radiostrontium will be most heavily influenced by the Ca status and intake of the animal. The values given take account of recent studies with goats for radiostrontium by the EC Animal group (Howard, 1994). For radiocesium, gut absorption has been measured and summarized recently, and the 50% value used here is that recommended by Beresford et al. (1995). The lower value reflects possible lower availability for absorption for radiocesium in plants with a lower digestibility than pasture grass, such as heather. Gut absorption for radioiodine is generally considered to be complete, and recent unpublished studies by the EC Animal group show little evidence of reduced availability for different physicochemical sources of radioiodine.

While there have been recent measurements of the availability of soil-associated radiocesium for gut absorption or transfer to milk, there are few equivalent data for radiostrontium or radioiodine. For radiocesium, the extent of gut absorption is determined by the type of soil, and seems to be correlated with that for soil-to-plant transfer; the 95% values for radiocesium assume that the ingested soil is a pure peat with a low radiocesium fixation potential; those for the 5% value assume sufficient clay minerals to strongly bind the radiocesium ions in the gut (Belli et al., 1993). The high range for radiocesium reflects a high variability associated with the nonspecification of soil type, rather than the lack of data. In the absence of much information for radiostrontium and radioiodine, the values are assumed to be similar to those in the table above for fresh deposit, but with a greater uncertainty.

Question 3. Transfer to meat

Values given here were initially based on those in the recent IAEA Handbook (IAEA, 1994). Further consideration has then been given to additional recent information which was not available for the Handbook, and to whether values at the end of the reported ranges are likely to occur within the 5% and 95% uncertainty, for the parameters as specified in the COSYMA document. Higher uncertainties are given where there are few relevant data. The same considerations apply for sections 4 and 5, for transfer to eggs and milk. The 50% values generally apply to plant incorporated forms of radionuclide, and the 5% values take into consideration possible lower transfer from comparatively unavailable sources, a factor which is well known to be important for radiocesium. In the absence of directly relevant information, similar values would be given for both outdoors and indoors.

The transfer coefficient quoted assumes equilibrium has been attained. However, for many domestic animals equilibrium would not be attained prior to slaughter, and therefore the values given would be too high to be used for slaughter ages. The values quoted have been adjusted to ensure that the observed order of magnitude difference in F_m between cattle and sheep/goats is maintained.

The transfer coefficient (F_f) for dairy cow meat would be expected to be lower than that of beef cattle because of (i) differences in liveweight and (ii) the presence of a significant additional secretory compartment, milk, for both radiocesium and radiostrontium in dairy cows.

There is comparatively little information for transfer of radiostrontium to meat compared with radiocesium. This is probably because the main target tissues for radiostrontium is the bone, with milk as an important secretory route. Much of the available information for radiostrontium is from the former Soviet Union. The high uncertainty for some of the radiostrontium values is due to the few data available. In contrast there is a lot of information available for radiocesium, but in some cases the uncertainty is still quite high as we have a better appreciation of the various factors which can affect transfer, such as physico-chemical form and physiological status. For poultry there is a high variability in reported values, and model predictions. I have given a comparatively high value based on recent data by Voigt et al. (1993) and data for broiler chickens from the Czech Republic reported by Pöschl et al. in Howard (1994).

Question 4. Transfer to egg contents

The data given refer to the total consumable portion of the egg, although transfer to yolk + white varies. There are very few data for radiostrontium and radioiodine transfer to egg contents, therefore 5 and 95% uncertainties are given which are generally outside reported or predicted ranges. The amount of available data for radiocesium transfer to egg contents has increased recently (e.g., Voigt et al., 1993) but overall there are still comparatively few data for eggs compared with other animal products. There is inadequate information to give different values for indoor or outdoor feeding regimes.

Question 5. Transfer to milk

Values are given based on the approach outlined in Section 3. In particular, for radiocesium transfer to cow milk the review by Hansen and Andersson (1994) has been taken into account. Fewer data are available for radiocesium transfer to the milk of the smaller ruminants, sheep and goats.

There is a strong relationship between F_m for radioiodine and radiostrontium, and the rate of dietary intake of stable iodine and calcium respectively. There is a relationship between F_m for radiostrontium and Ca intake (Howard et al., 1995).

The same numbers for radiostrontium transfer to sheep milk have been used as that recommended for goat milk. There are few sheep data, and little evidence to suggest that transfer to sheep milk would be substantially different to that for goats. The comparatively high values for the 95% uncertainty for iodine transfer to goat and sheep milk are given because comparatively low daily milk outputs (<1 liter per day) sometimes occurs in smallholdings (Mayes et al., 1992).

Question 6. Biological half-life in animals

Commonly, biological half-lives are influenced by the longer term component if measurements have not been made at frequent intervals at the start of the loss of radionuclide from the tissues. The weighted average residence time is requested, which should take account of significant short-term losses, and therefore this evaluation has focussed on those studies which do provide early measurements and have biased the uncertainty values accordingly.

Values for biological half-life are based on assumed animal liveweight at slaughter, i.e., for lamb and beef calves.

Data availability to assess the biological half-life for radiostrontium and radioiodine in muscle is poor, particularly for the latter. This is probably because the main target tissues for radiostrontium and radioiodine are the bone and thyroid respectively, with milk as an important secretory route for both radionuclides. The high uncertainty for some of the radiostrontium and radioiodine values is due to the few data available, and consequent lack of confidence in the recommended values currently used in models.

Data for radiocesium have improved considerably after the Chernobyl accident, particularly for sheep. The values used for 5% and 95% uncertainty are due to expected differences caused by metabolic turnover rates, dietary intake rates, and animal liveweight.

Poultry muscle values take account of data for leg and breast muscle, which do have different biological half-lives. For poultry the radiocesium values take into account data from Vandecasteele et al., (unpublished) and Voigt et al., (1993) for the 95% value, but the 5% and 50% values take into account data recently obtained for broiler chickens from the Czech Republic reported by Pöschl et al., in Howard (1994). These results give much smaller biological half-lives than previously reported, and were obtained by carrying out many rapid measurements at short time intervals after administration of radiocesium.

In the absence of relevant data, values for radioiodine are based on the rate of loss of radioiodine from the thyroid, since this will be an important factor determining rates of loss from soft tissues.

Additional Elicitation questions

1. Transfer to meat

<u>a) Lactating cow</u>

Considering the available form of the radiocesium I have given a higher number for the 5% value than in the previous section.

b) Adult sheep

Values are higher for the nonlactating ewes to take account of the lack of the milk secretion pathway.

2. Transfer to milk

Considering the available form of the radiocesium, I have given a higher number for the 5% value than in the previous section.

3. Biological half-life in animals

Values are quoted as % of day 0, when decontamination commenced. The 50% median value is calculated on the basis of an assumed 25-d half-life for adult sheep.

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1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	10.4	19.5	25	9	17	21.7
Silage	10.4	19.5	25	9	17	21.7
Cereals (concentrate)	9.2	15	17.8	8	13	15.5

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	6.9	9.8	13.2	6	8.5	11.5
Silage	8.1	9.2	12.7	6	8.5	11.5
Cereals (concentrate)	5.7	9.2	11.5	5	8	10

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.8	1.3	2.2	0.7	1.1	1.9
Silage	0.8	1.3	2.2	0.7	1.1	1.9
Cereals (concentrate)	0.6	1.2	1.7	0.5	1	1.5

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	11.5	15	18.4	10	13	16

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.06	0.12	0.17	0.05	0.11	0.15

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.01	0.15	0.25
Sheep	0.025	0.13	0.25
Pigs	0.0001	0.015	0.04
Poultry	0.0001	0.005	0.08

2. Availability of ingested feed

Activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	0.01	0.15	0.35
Cesium	0.1	0.35	0.9999
Iodine	0.9	0.99	0.9999

Activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	0.1	0.22	0.4
Cesium	0.63	0.8	0.9999
Iodine	0.9	0.99	0.9999

Activity associated with soil

Element	5%	50%	95%
Strontium	0.008	0.15	0.4
Cesium	0.01	0.6	0.999
Iodine	0.9	0.99	0.9999

3. Transfer to meat (d/kg)

Dairy cows

Element	5%	50%	95%
Strontium	0.0001	0.005	0.009
Cesium	0.007	0.035	0.05

Beef cattle

Element	5%	50%	95%
Strontium	0.0002	0.008	0.014
Cesium	0.012	0.05	0.058

Sheep

Element	5%	50%	95%
Strontium	0.002	0.2	0.6
Cesium	0.3	0.5	0.9

Pigs

Element	5%	50%	95%
Strontium	0.002	0.035	0.05
Cesium	0.03	0.24	1.1

Poultry

Element	5%	50%	95%
Strontium	0.01	0.08	4
Cesium	1.1	9.5	17

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.01	0.22	7
Iodine	0.005	3	10
Cesium	0.06	0.4	1.8

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.0005	0.0028	0.004
Cesium	0.002	0.008	0.02
Iodine	0.001	0.01	0.035

Sheep

Element	5%	50%	95%
Strontium	0.005	0.02	0.05
Cesium	0.008	0.07	0.14
Iodine	0.08	0.49	0.9

Goats

Element	5%	50%	95%
Strontium	0.005	0.02	0.06
Cesium	0.008	0.07	0.16
Iodine	0.08	0.49	1

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	0.2	5	35
Cesium	20	33	50
Iodine	4	7.5	20

Beef cattle

Element	5%	50%	95%
Strontium	0.2	4	26
Cesium	19	29	45
Iodine	0.05	7.5	18

Sheep

Element	5%	50%	95%
Strontium	0.1	2.5	20
Cesium	10	14	22
Iodine	0.05	7.5	14

Pigs

Element	5%	50%	95%
Strontium	0.1	5	40
Cesium	17	30	40
Iodine	1.5	7.5	35

Poultry

Element	5%	50%	95%
Strontium	0.1	3	18
Cesium	4	10	26
Iodine	0.05	7	21

EXPERT L

Introduction

The work undertaken by the Expert Judgement Panels was carried out because of the requirement to assess and estimate the uncertainties associated with probabilistic risk assessment codes such as COSYMA. Although there has been some validation of the uncertainty done by the persons who developed the codes, they were not experts in all areas. Therefore, there is a requirement to consult the opinions of others with appropriate experience in order to obtain a more rigorous assessment. This is required in areas where there is already a fairly complete data set and also other areas where the uncertainty cannot, for cost or logistical reasons, be determined by experiment. In the latter cases the assessments were carried out by persons with appropriate experience, who drew on their knowledge of the behavior of radionuclides to make the assessment.

Described below is the approach taken in assessing the uncertainty around the various parameters posed by the elicitation questions.

In addressing these questions, it was assumed that the source of contamination would be likely to be a nuclear reactor in northwest continental Europe. The assessments were done to give the range of uncertainty arising as a consequence of an accident or incident irrespective of wherever and whenever (i.e., time of year) the event occurs within northwestern Europe and would be applicable to the main agricultural production areas in these regions.

In making the assessments, the range of data available in the international literature was consulted together with other knowledge of the events around which the questions are posed. The references consulted and the data considered are given in Tables 1 through 12. The other considerations which impinged upon the uncertainty are described below.

Question 1. Animals – Consumption Rates

Dairy Cows:

The values used in the response are typical for UK feeding systems (i.e., forage plus cereals). The intake of radioactivity is likely to be via the grass, hay/silage components and it is considered unlikely that cereals would make a significant contribution to radionuclide intake.

Beef Cattle:

Values for beef cattle consumption will vary greatly depending upon the ratio of growing cattle to suckler cows in the population, which is different in the UK from that in the remainder of the EC. However, in accordance with the instructions given, values for silage and cereals for beef cattle and for sheep are theoretical values assuming that an all-cereal or an all-silage diet is fed and so they do not apply to UK practice in which it is normal for mixed diets to be used. No pasture grass figures are given for indoor feeding because "zero grazing" is not a normal UK practice and it is unlikely, in the immediate aftermath of an incident occurring at a time when cattle are being fed indoors, that pasture grass, even zero grazed, would be a significant component of the diet. In the event of an incident during a normal outdoor feeding period, it is possible that zero grazing of radiochemically clean pasture may be used with animals moved indoors and fed pasture grass which has been harvested.

The data provided were obtained in consultation with colleagues with substantial experience of the dry matter intakes of cows and beef cattle in a range of conditions.

Sheep:

In the case of consumption by sheep, the values cited depend greatly upon the ratio of ewes to lambs in the total population. The same caveat applies to sheep as for beef cattle with regard to the "zero grazing" of pasture grass indoors.

Pigs - Indoor Feeding:

The above figures are average values for the indoor feeding of pigs in northwest Europe.

There are two main nutritional regimes.

1. Fattening bacon pigs

For these animals, the cereal intakes vary from approximately 0.5 kg d^{-1} in the 10 kg bodyweight animal at weaning to 3-4 kg d^{-1} in the bacon weight pig (at 100 kg bodyweight).

2. Sows

Intakes can vary from approximately 2 kg d^{-1} for the dry sow to approximately 7 kg d^{-1} for lactating sows (i.e., for a period of 4-5 weeks per year).

The above values are for cereals of approximately 88% dry matter.

The cereals constitute 70-75% of the diet, with the other 25-30% coming from protein sources (fish meal, soybean meal, etc.) and minerals/vitamins.

In pigs, the breed differences are negligible.

Pigs - Outdoor Feeding:

No data are provided for outdoor feeding because it is not a common husbandry practice in the UK. Data should be available from experts with a continental European background.

However, when pigs are fed outdoors, it is considered that most of the feed intake is via the food trough, with relatively little ingestion from pasture.

Poultry - Laying Hens:

Laying hens are commonly housed indoors and receive a cereal-based ration only; pasture grass and silage/hay are not alternative feeding regimes. Where outdoor feeding occurs, hens receive a cereal-based mash and do not consume significant amounts of pasture.

Poultry - Broilers:

The values cited for laying hens are not applicable to broilers where there is a bodyweight-related increase in feed consumption during the rearing period. In male broilers, the feed intake over the period from 3 to 10 weeks of age ranges from approximately 100 g d^{-1} to 230 g d^{-1} (fresh matter - dry matter content typically 88%); broilers would be reared indoors and would receive only cereals. Hence in the immediate aftermath of an incident they would not receive contaminated feed.

Soil Consumption:

The only data provided are for cattle and sheep. No data are given for pigs and poultry because under typical British husbandry systems these species would not consume significant amounts of pasture.

Additional factors which will ultimately influence the importance of soil as a source of ingested radioactivity are:

1. the chemical characteristics of the soil in relation to its clay mineral content.
2. the "characteristics" of the fallout and, thereby, the availability of radioactivity from any fresh deposition.
3. whether the radioactivity is within a matrix (i.e., freshly deposited) or has been weathered.

Question 2. Availability of ingested feed

Pasture Cesium - biologically incorporated:

The availability of a radiocesium biologically incorporated into pasture grass would be the same as for ionic cesium. For ruminant animals (cattle, sheep, goats) the fractional intestinal absorption is typically about 0.6.

In monogastric species (e.g., pigs, poultry) the gastrointestinal absorption is virtually complete (i.e., 1.0) but the ingestion of pasture grass by these species is limited.

Hence, the value is confounded by whether the species in question is ruminant or nonruminant and so the figure given in response to the elicitation question takes this into account i.e., it is a composite response for a population of both ruminants and nonruminants. Clearly it would be better, and preferable, to deal with ruminants and non-ruminants separately.

Pasture Cesium - activity freshly deposited:

The availability of freshly deposited radiocesium on pasture to the animal depends upon the "characteristics" of the incident which results in the release of radiocesium i.e., the radiocesium may be present in a matrix with other materials which limits its availability. Distance of deposition from the site of the incident is also another factor to be taken into account because the physical character of the fallout/ deposition may vary with distance.

In some studies of Chernobyl radiocesium (freshly deposited) against either radiocesium incorporated into plants or given as ionic radiocesium, the availability was 2-3 times greater in the latter two cases.

Therefore, for this component, the availability is confounded by the characteristics of the fallout (both chemical and physical) as well as the animals (ruminants or nonruminants) involved.

Soil Cesium:

Freshly deposited radiocesium on soil would have the same availability as that on pasture grass if the soil was ingested.

Similarly, after weathering, the availability of the soil radiocesium would be the same as that incorporated biologically into pasture grass. However, a major consideration in this is the chemical composition of the soil since the clay mineral content will significantly influence the availability of radiocesium ingested with soil.

Strontium and Iodine:

No values are suggested for the availabilities of strontium and iodine because they are outside the assessor's experience.

Question 3. Transfer to meat

The background data used in the derivation of the above are given in Tables 1 and 2. The uncertainty was assessed by determining the median value of the range of data and then, from the range, assessing the 5% and 95% values.

For pigs and poultry, the data are for housed animals consuming cereal-based diets. For these species, outdoor "field" conditions are probably a small proportion of overall production in these sectors. However, outdoor feeding of cereal-based mashes to such animals would not result in any differences compared with indoor feeding.

Question 4. Transfer to eggs

The background data relevant to this are given in Tables 1 and 2. The uncertainty was again considered by determining the median value of the range of data and then, from the range, assessing the 5% and 95% values.

These values are for hens fed indoors and receiving a cereal-based ration. This is the usual husbandry method for egg production and hence "field" conditions of grazing pasture have not been considered. Hens are unlikely to consume much pasture if cereal-based mash is provided outdoors and so the indoor and outdoor F_f values are likely to be the same.

Question 5. Transfer to milk

The background data for dairy cows, sheep and goats from which these values have been derived are given in Tables 3 through 11. These data include post-Chernobyl studies as well as earlier work on weapons test fallout.

The dairy cow data and the sheep radiocesium information are from wide ranging sources which indicates that breed probably has little effect. Similarly, stage of lactation, milk yield and diet have little effect.

The uncertainty was assessed by examining the available data, determining the median and then determining the 5% and 95% points as ± 2 standard deviations from the data sets.

If the animals were being fed indoors on contaminated conserved forage (hay, silage), no differences in F_m would be expected compared with outdoor grazing of pasture.

A factor which would affect F_m is the character of the radionuclide deposit and thereby the radionuclide availability. However, it is pertinent to include all the available data in the assessment because the character of any future incident is unknown.

Question 6. Biological half-life in animals (dairy cows, beef cattle, sheep and pigs)

Values for strontium and iodine are not given because they are outside the assessor's direct experience and were not immediately available in the scientific literature. However, the following points are relevant.

It should be said that to consider a half-life for iodine is probably not necessary since, in a real practical situation, the animal would be fed radiochemically "clean" foods or the food product (beef, lamb, pork, poultry meat) could be stored for a sufficient period to allow for radiochemical decay.

In relation to the biological half-life of strontium, it must be borne in mind that this is very profoundly influenced by the calcium intake of the animal and, thereby, its calcium status because these two elements interact. This is also of major importance in the determination of F_m and F_f values and has not been taken fully into account in many such studies.

The biological half-lives for radiocesium were assessed from a consideration of the data in the scientific literature (Table 12). It can readily be seen that the amount of available data varies considerably from one species to another.

It should also be noted that a shorter half-life would be expected in lactating dairy cows than in beef animals because milk secretion provides an additional route for radiocesium loss from the animal's body.

Even within species there is substantial variation which presumably reflects age/breed effects.

In poultry, there also appeared to be differences in muscles from different parts of the carcass with different half-lives for radiocesium being recorded in breast muscle and leg muscle.

Additional Elicitation Questions

Question 1. Transfer to meat

(a) A lactating cow fed on hay and food concentrate pellets is administered cesium-134 orally at a constant rate of activity for 4 months. What is the transfer factor for muscle at the end of the period?

Cesium-134 behaves in exactly the same way as cesium-137. Since orally administered ionic cesium-134 would also behave in the same way as biologically incorporated radiocesium, the same values as in Question 3 are cited.

(b) Adult sheep, both lactating and non-lactating are fed on green kale pellets contaminated with Cesium-134 at a constant rate of 16 kBq per day for 34 days. What is the activity concentration in muscle at the end of the period in both lactating and non-lactating animals.

It is assumed that ionic radiocesium behaves in the same way as cesium incorporated into herbage. Hence, the same F_f is used (0.3). The assessor has no direct experience of the F_f in lactating animals and so the same relationship has been applied in sheep (lactating vs. nonlactating) as for dairy cows (i.e., F_f of 0.2); the lower F_f is entirely expected because of the loss of radiocesium via milk secretion.

The tissue radiocesium concentrations have been calculated using a biological half-life of 13 days (from Question 6) and determining the equilibrium value (non-lactating animal: 4,800 Bq kg^{-1}) after 100 days of feeding. A mathematical approach enabled the tissue radiocesium values to be determined after 34 days of feeding.

Question 2. Transfer to milk

A lactating cow fed on hay and food concentrate pellets is administered Cesium-134 orally at a constant rate of activity for 4 months. What is the radiocesium equilibrium transfer factor for milk F_m?

Ionic radiocesium is more available than fallout cesium. Studies with ionic cesium-137 and cesium-134 have given values of 0.0084 - 0.017 d l^{-1} (see Table 4). The median, 5% and 95% values have been determined from this range.

Question 3. Biological half-life in animals

An adult sheep has been fed equal amounts of wheat and dried grass harvested under field conditions which is contaminated with Cesium-137 at a constant rate of a period of 60 days. It is then returned to a contamination free diet. What are the concentrations of Cesium-137 in sheep muscle at 5 days, 10 days, 30 days and 60 days following removal from the contamination diet?

After 60 days, an equilibrium position could be assumed to have been reached in sheep. The decline in radioactivity, expressed against an equilibrium value of 100%, has been calculated using the data for the biological half-life of radiocesium in sheep (13 d together with the 5% and 95% values) given in Question 6.

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Johnson, J.E., Ward, G.M., Firestone, E. and Knox, K.L. 1968. *J. Nutr.* 94, 282-288.

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Shaeffer, D.L. 1981. *Health Physics* 41, 155-164.

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Wagner, H. 1987. *Fleischwirtsch,* 67, 717-723.

Ward, G.M. and Johnson, J.E. 1989. *Sci. Total Environ.* 85, 287-294.

Ward, G.M., Johnson, J.E. and Sasser, L.B. 1967. *J. Dairy Sci.* 50, 1092-1096.

Table 1. Transfer Coefficient (Sr to Meat: d kg^{-1})

Beef
Pröhl, G. et al. (1989). *Sci. Total Environ.* **85**, 107-117. 0.0003 Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, Sweden. 0.0006 Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.008 (expected value) Range: 3×10^{-4} - 8×10^{-3}
Pork
Pröhl, G. et al. (1989). *Sci. Total Environ.* **85**, 107-117. 0.002 Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, Sweden. 0.003 Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.04 (expected value) Range: 2×10^{-3} - 4×10^{-2}
Sheep meat
Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, Sweden. 0.001 Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.04 (expected value) Range: 3×10^{-3} - 4×10^{-2}
Chicken meat
Prister, B.S. et al. (1991). IUR Plant-Animal Working group Meeting. September, Uppsala, Sweden. 0.40 Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.08 (expected value) Range: 1×10^{-2} - 4
Eggs
Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.2 (expected value) Range: 0.2 - 0.6

Table 2. Transfer Coefficients (Cs to Meat: d kg^{-1})

Dairy Cows	
Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338	
0.01	
Ward, G. et al. (1967). *J. Dairy Sci.* **50**, 1092-1096	
Green-chop	0.0205
" "	0.0125
Beef animals	
Heinrich, E. (1987). IUR Plant-Animal Working Group 19-22 October, Grange-over-Sands, UK.	
Steers	0.0072 - 0.0088
Literature values	0.004 - 0.08
Non-lactating young cows	0.016 - 0.025
Pröhl, G. et al. (1989). *Sci. Total Environ.* **85**, 107-117.	
0.04	
Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338	
Heifers	0.03 - 0.04
Bulls	0.03 - 0.04
Ward, G. (1989). *Sci. Total Environ.* **85**, 287-294.	
Beef cows at pasture	0.0073
Ward, G. et al. (1987). *J. Dairy Sci.* **50**, 1092-1096	
0.0054	
0.0069	
Ng, Y.C. et al. (1982). *Nuclear Safety* **23**, 57-71.	
0.02	
Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, UK.	
0.04	
Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg.	
0.05 (expected value) Range: 1×10^{-2} - 6×10^{-2}	
Pigs	
Heinrich, E. (1987). IUR Plant-Animal Working Group. 19-22 October. Grange-over-Sands, UK.	
0.25 d kg^{-1}	
Other literature values	0.04 - 0.026 ?
Pröhl, G. et al. (1989). *Sci. Total Environ.* **85**, 107-117	
0.35 d kg^{-1}	
Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338	
0.35 - 0.45	

Table 2. Transfer Coefficients (Cs to Meat: d kg^{-1}) (Continued)

Pigs (continued)

Andersson, I. et al. (1990). *Swedish J. Agric. Res.* **20**, 43-48
0.46 ± 0.06

Ng, Y.C. (1982). *Nuclear Safety* **23**, 57-71.
mean value 0.30

Wagner, H. (1987). *Fleischwirtsch* **67**, 717-723.
0.397

Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, Sweden.
0.15

Mirna, A. (1979). *Fleischwirtsch* **59**, 1836-1839
0.26
0.38

Coughtrey, P.J (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg.
0.24 (expected value) Range: 3×10^{-2} - 1.1

Lambs

Heinrich, E. (1987). IUR Plant-Animal Working Group. 19-22 October, Grange-over-Sands, UK.
0.43 - 0.51

Vandecasteele, C.M. et al. (1989). *Sci. Total Environ.* **85**, 213-224
0.63

Ng, Y.C. (1982). *Nuclear Safety* **23**, 57-71.
0.12

Andersson, I. (1989). *Swedish J Agric Res* **19**, 85-92.
0.24

Beresford, N. et al. (1989). *J. Environ. Radioactivity* **9**, 251-264.
1.61

Coughtrey, P.J (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg.
0.49 (expected value) Range: 1.0×10^{-1} - 1.6

Sheep's Meat

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.
0.30 - 0.35

Vandecasteele, C.M. et al. (1989). *Sci. Total Environ.* **85**, 213-224.
From CsCl 0.57
Chernobyl fallout 0.14

Table 2. Transfer Coefficients (Cs to Meat: d kg^{-1}) (Continued)

Sheep's Meat (continued)

Ward, G. et al. (1967). *J. Dairy Sci.* **50**, 1092-1096.
0.324

Beresford, N. et al. (1989). *J. Environ. Radioactivity* **9**, 251-264.
0.33

Ng, Y.C. et al. (1982). Lawrence Livermore National Laboratory, Livermore, California. Report UCID - 19464.
0.3

Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, Sweden.
0.08

Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg.
0.17 (expected value) Range: 4.6×10^{-2} - 3.5×10^{-1}

Chicken

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.

breast	1.3		
leg	1.2		

Voigt, G. et al. (1990). IUR Plant-Animal Working Group. 23-25 April, Neuherberg, Germany.

breast	1.6	3.2	laying hens
leg	1.2	2.1	
breast	0.422		broiler chickens
leg	0.354		

Andersson, I. et al. (1990). *Swedish J. Agric. Res.* **20**, 35-42.

breast	4.04 ± 0.78	laying hens
breast	4.56	broiler

Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, Sweden.
0.50

Eckman, L. (1961). *Acta. Vet. Scand.* **2**, suppl 4.
4.55

Coughtrey, P.J (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg.
0.1 (expected value) Range: 0.3 - 10

Eggs

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.

white	0.2
yolk	0.1

Voigt, G. et al. (1990). IUR Plant-Animal Working Group Meeting. 23-25 April, Neuherberg, Germany.

white	0.182	0.492
yolk	0.095	0.242
egg	0.155	0.392

Table 2. Transfer Coefficients (Cs to Meat: d kg^{-1}) (Continued)

Eggs (continued)
Andersson, I. et al. (1990). *Swedish J. Agric. Res.* **20**, 35-42. egg contents 0.80 ± 0.32
Ng, Y.C. (1982). *Nuclear Safety* **23**, 57-72. 0.43 (mean: - range 0.34 - 0.53)
Eckman, L. (1961). *Acta Vet. Scand.* **2**, suppl. 4. 0.43 - 0.55
Coughtrey, P. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.40 (expected value) Range: 6×10^{-2} - 2

Table 3. Transfer Coefficients (Sr to cows milk: d l^{-1})

Summerling, T.J. et al. (1984). *Sci. Total Environ.* **34**, 57-72.

Jan-Mar	0.0033
Apr-Oct	0.0014
Nov-Dec	0.0029

Values by others cited by Green, N (1983) 4th Symposium on the Determination of Radionuclides in Environmental and Biological materials.

0.00045 - 0.0038

Comar, C.L. (1966). In "Radioactivity and the Human Diet" (Ed. Scott-Russell, R.) 247-265.

Ng, Y.C. et al. (1977). Lawrence Livermore Laboratory Report UCRL - 51939.

0.0011 - 0.0040

Van den Hoek, J. et al. (1969). *Health Physics* **17**, 691-700.

0.00068
0.00070
0.00058
0.00049

Pröhl, G. et al. (1989). *Sci. Total Environ.* **85**, 107-117.

0.002

Pelletier, C.A. and Voilleque, P.G. (1971). *Health Physics* **21**, 777-792.

0.0013
0.0023
0.0026

Prister, B.S. et al. (1991). IUR Plant-Animal Working Group Meeting. September, Uppsala, Sweden.

0.0030
0.0030
0.0025
0.0010
0.0020
0.0010
0.0025
0.0010

Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg.

0.0028 (expected value) Range: 1×10^{-3} - 3×10^{-3}

Table 4. Transfer Coefficients (^{137}Cs to cows milk: d l^{-1})

Johanson, K.J., et al. (1989). *Sci. Total Environ.* **85**, 73-80.

Transfer coefficients for 11 farms during summer grazing (1987).
0.0039, 0.0024, 0.0047, 0.0073, 0.0031, 0.0045,
0.0057, 0.0043, 0.0074, 0.0076, 0.0042.

Pröhl, G. et al. (1989). *Sci. Total Environ.* **85**, 107-117.
0.003

Bradley, E.J. and Wilkins, B.T. (1989). *Sci. Total Environ.* **85**, 119-128.
0.002, 0.004

Fulker, M.J. and Grice, J.M. (1989). *Sci. Total Environ.* **85**, 129-138.
0.0043

Summerling, T.J. et al. (1984). *Sci. Total Environ.* **34**, 57-72.
0.007

Vreman, K. et al. (1989). *Sci. Total Environ.* **85**, 139-147.

Dried grass	0.0016	
Fresh grass	0.006	
	0.005	
	0.007	
Grass silage	0.0035	
(individual cows)	0.0029	early lactation
	0.0048	
	0.0048	

	0.0044	mid lactation
	0.0048	

	0.0048	
	0.0037	
	0.0053	late lactation
	0.0047	

Belli, M. et al. (1989). *Sci. Total Environ.* **89**, 169-177.

Meadow grass	0.0033	(± 0.0014)
Alfalfa	0.0026	(± 0.0013)

Voors, P.I. and Van Weers, A.W. (1989) *Sci Total Environ.* **85**, 179-188.

Silage	0.0026
	0.0027

Table 4. Transfer Coefficients (^{137}Cs to cows milk: d l^{-1}) (Continued)

Pearce, J. et al. (1989). *Sci. Total Environ.* **85**, 267-278.		
Silage	0.00297 ± 0.000704	
	0.00230 ± 0.000365	
	0.00233 ± 0.000198	
Ward, G.M. and Johnson, J.E. (1989). *Sci. Total Environ.* **85**, 287-294.		
Fallout on hay diet	0.0048	
Mitchell, N.G. et al. (1989). *Sci. Total Environ.* **85**, 307-316.		
Silage	0.0028	0.0034
(mean values for individual cows over a number of days)	0.0032	0.0035
Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.		
0.0023 - 0.0053		
Unsworth, E.F. et al. (1989). *Sci. Total Environ.* **85**, 339-347.		
Silage fed	0.00255 ± 0.00013	
Bertilsson, J. et al. (1988). *Health Physics* **55**, 855-862.		
150 mm stubble height	0.0067	
50 mm stubble height	0.0019	
Heinrich, E. (1987) Meeting of IUR Plant - Animal Working Group. 19-22 October, Grange over Sands, UK).		
Hay pellets	0.0012	
	0.0018	
Johnson, J.E. et al. (1968). *J. Nutr.* **94**, 282-288.		
High hay	0.0048 (fallout); 0.0092 (ionic ^{134}Cs)	
High grain	0.0121 (fallout); 0.0136 (ionic ^{134}Cs)	
Ward, G.M. et al. (1967). *J. Dairy Sci.* **50**, 1092-1096.		
Pasture feeding	0.0035	
Green-cut alfalfa	0.0025	
Winter feeding	0.0041	
Stewart, H.F. et al. (1965). *J. Dairy Sci.* **48**, 709.		
0.0025 - 0.0072		
Summerling, T.J. et al. (1984). *Sci. Total Environ.* **34**, 57-72.		
Summer grazing	0.0038	
Van den Hoek, J. et al. (1969). *Health Physics* **17**, 691-700.		
0.0031 - 0.0045		

Table 4. Transfer Coefficients (^{137}Cs to cows milk: d l^{-1}) (Continued)

Ng, Y.C. et al. (1977). Lawrence Livermore Laboratory, University of California, Livermore Report UCRL-51939. 0.0025 - 0.012
Ng, Y. (1982). *Nuclear Safety* **23**, 57-71 0.0071
Cragle, R.G. (1961). *J. Dairy Sci.* **44,** 352. 0.017 (tracer ^{134}Cs)
Sansom, B.F. (1966). *J. Agric. Sci.* **66**, 389 0.0084 (tracer ^{134}Cs)
Kahn, B. et al. (1965). *J. Dairy Sci.* **48**, 556 0.0074 (fallout ^{137}Cs from pasture and feedlot)
Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.0079 (expected value) Range: 1×10^{-3} - 2.7×10^{-2}

Table 5. Transfer Coefficients (I_2 to cows milk: d l^{-1})

Bertilsson, J. et al. (1988). *Health Physics* **55** 855-862.

High stubble height	0.018
Low stubble height	0.002

0.002 to 0.054 [Hoffamn, F.O. (1979)]

Hoffman, F.O. (1978). *Health Physics* **35**, 413-416.

0.01
0.011
0.0042
0.013
0.0067
0.0081
0.035
0.0099
0.008
0.01
0.0055

The author recommended 0.01 d l^{-1}

Assimakopoulos, P.A. et al. (1989). *Sci. Total Environ.* **85**, 295-305.

0.0051 ± 0.0019

Sam, D. et al. (1980). *J. Dairy Sci.* **63**, 1447-1450.

0.0088

According to Sam et al. (1980) the recorded transfer coefficient for 131I range from 0.02 to 0.027 d l^{-1} with 90% of the results in the range 0.005 to 0.02 d l^{-1}.

Shaeffer, D.L. (1981). *Health Physics* **41**, 155-164.

0.0038

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.

0.007

Daburon, F. et al. (1971). *Lait* **51**, 8.

0.0035 - 0.0125

Bonka, H. et al. (1986). Report for the EC, Brussels, Belgium, 25-26 June 1986.

Kuhn, W. et al. (1986). Niedersächsisches Institut für Radioökologie, Universität Hannover.

0.002

Table 5. Transfer Coefficients (I_2 to cows milk: d l^{-1}) (Continued)

Daburon, F. et al. (1989). *Sci. Total Environ.* **85**, 253-261. 0.0035 - 0.0050 (summer) 0.0075 - 0.0125 (winter)
Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.01 (expected value) Range: 1×10^{-3} - 3.5×10^{-2}

Table 6. Transfer Coefficients (Sr to sheeps milk: d l^{-1})

Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.056

Table 7. Transfer Coefficients (Cs to sheeps milk: $d\ l^{-1}$)

Howard, B.J. (1989). *Sci. Total Environ.* 85, 189-198.

Range of values cited

Chernobyl fallout (3d old) on Lolium perene	0.057 ± 0.003
Chernobyl fallout (<1 month) on grass	0.058 ± 0.007
Ariel discharge from Sellafield on pasture	0.05
Chernobyl fallout (<3 months) on lowland pasture	0.07
Chernobyl fallout (>3 months old) in dried grass pellets	0.06

Assimakopoulos, P.A. et al. (1989). *Sci. Total Environ.* **85**, 279-285.
0.063 ± 0.005
(mean of values from 2 experiments of 0.058 ± 0.007 and 0.071 ± 0.009)

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.
0.06

Vandecasteele, C.M. et al. (1989). *Sci. Total Environ.* **85**, 213-224.
0.09

Ward, G. et al. (1966). *J. Dairy Sci.* **50**, 1092-1096.
0.03 (hay)
0.0324 (green-chop alfalfa)

Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg.
0.058 (expected value) Range: 6.0×10^{-3} - 1.2×10^{-1}

Table 8. Transfer Coefficients (I_2 to sheeps milk: $d\ l^{-1}$)

Assimakopoulos, P.A. et al. (1989). *Sci. Total Environ.* 85, 295-305.
$0.94 \pm 0.32\ d\ l^{-1}$

Daburon, F. et al. (1971). *Lait.* **51**, 8.
$0.1\ d\ l^{-1}$

IAEA (1994). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. Technical Reports Series No 364. Vienna.
0.49 (expected value) Range: 8×10^{-2} - 9.4×10^{-1}

Table 9. Transfer Coefficients (Sr to goats milk: d l^{-1})

Coughtrey, P.J. (1990). Radioactivity Transfer to Animal Products, Rep. EUR 12608 EN, EC Luxembourg. 0.028 (expected value) Range: 6×10^{-3} - 3.9×10^{-2}

Table 10. Transfer Coefficients (Cs to goats milk: d l^{-1})

IAEA (1994). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. Technical Reports Series No. 364. Vienna. 0.1 (expected value) Range: 9.0×10^{-3} - 4.7×10^{-1}

Table 11. Transfer Coefficients (I_2 to goats milk: d l^{-1})

Hoffman, F.O. (1978). *Health Physics* **35**, 413-416.
0.5
0.48
0.62
0.37
0.47
0.65
0.28
0.48
0.17
0.06
The author recommended a value of 0.5 d l^{-1}
Hoffman, F.O. et al. (1988). *J. Environ. Radioactivity* **8**, 53-71
0.45

Table 12. Biological Half-Lives for Radiocesium in the Meat of Various Species

Beef Cattle

Coughtrey, P.J. (1990). *Radioactivity Transfer to Animal Products.* Rep. EUR 12608 EN. EC, Luxembourg.
29 d

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.
30-40 d

Twardock, A.R. and Crackel, W.C. (1969). *Health Physics* **16**, 315-323.
31.5 d, 34.6 d and 46.2 d (individual animal results)

Dairy Cows

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.
20-30 d

Sansom, B.F. (1966). *J. Agric. Sci.* **66**, 389-393.
28 d

Sheep

Coughtrey, P.J. (1990). *Radioactivity Transfer to Animal Products.* Rep. EUR 12608 EN. EC, Luxembourg.
14 d

Coughtrey, P.J. and Thorne, M.C. (1982). In "*Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems*", Vol **1**, pp 321-424. A.A. Balkema, Amsterdam and Boston.
19 d

Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.
35-40 d

Howard, B.J. et al. (1987). *J. Soc. Radiol. Prot.* **7**, 71-73.
10 d

Twardock, A.R. and Crackel, W.C. (1969). *Health Physics* **16**, 315-323.
25.5 d

Howard, B.J. and Livens, F. (1987). *New Scientist* (23 April 1987), pp. 46-49.
10 d

Colgan, P.A. (1988). A Report on the Levels of Radiocesium Activity in Mountain Sheep. The Nuclear Energy Board, Ireland. 87 pp.
10-12 d

Andersson, I. (1989). *Swedish J. Agric. Res.* **19**, 85-92.
12.8, 11.6 and 17.4 d (individual animal results)

Vandecasteele, C.M. et al. (1989). *Sci. Total Environ.* **85**, 213-224.
11 d

Table 12. Biological Half-Lives for Radiocesium in the Meat of Various Species (Continued)

Pigs	
Coughtrey, P.J. (1990). *Radioactivity Transfer to Animal Products.* Rep. EUR 12608 EN. EC, Luxembourg.	
19 d	
Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.	
30-40 d	
Andersson, I. et al. (1990a). *Swedish J. Agric. Res.* **20**, 43-48.	
24.5 d	
Eckman, L. (1961). *Acta Vet. Scand.* **2** (suppl. 4).	
23.4 - 28 d	
Nielsen, P. et al. (1988). *Experientia* **44**, 502-504.	
21.6 d	
Twardock, A.R. and Crackel, W.C. (1969). *Health Physics* **16**, 315-232.	
34.7 d	
Poultry	
Coughtrey, P.J. (1990). *Radioactivity Transfer to Animal Products.* Rep. EUR 12608 EN. EC, Luxembourg.	
28 d	
Voigt, G. et al. (1989). *Sci. Total Environ.* **85**, 329-338.	
18 d (breast)	
11 d (leg)	
Andersson, I. et al. (1990b). *Swedish J. Agric. Res.* **20**, 35-42.	
5.9 d (breast)	
6.1 d (leg)	
Voigt, G. et al. (1990). IUR Plant-Animal Working Group, 23-25 April, Neuherberg, Germany.	
25 d and 16 d	(breast - separate experiments)
9 d and 13 d	(leg muscle - separate experiments)

1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	10	14	18	NR	NR	NR
Silage	NR	NR	NR	7	11.5	14.5
Cereals (concentrate)	0.000001	2	4	2	7	14

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	3	8	13	NR	NR	NR
Silage	2	6	10	2	6	10
Cereals (concentrate)	3	9	14	3	9	14

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.4	1.2	2.4	NR	NR	NR
Silage	0.3	0.8	1.3	0.3	0.8	1.3
Cereals (concentrate)	0.5	1.3	2.5	0.5	1.3	2.5

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	NR	NR	NR	0.68	1.6	2.9

Poultry (laying hens and boilers)

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate) - laying hens	NR	NR	NR	0.071	0.097	0.123
Cereals (concentrate) - boilers	NR	NR	NR	0.088	0.145	0.202

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.3	0.9	1.5
Sheep	0.05	0.15	0.25
Pigs	NR	NR	NR
Poultry	NR	NR	NR

2. Availability of ingested feed

Activity freshly deposited on pasture grass

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	0.2	0.29	0.38
Iodine	NR	NR	NR

Activity biologically incorporated in pasture grass

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	0.5	0.72	0.95
Iodine	NR	NR	NR

Activity associated with soil (freshly deposited)

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	0.2	0.29	0.38
Iodine	NR	NR	NR

Activity associated with soil (after weathering)

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	0.5	0.72	0.95
Iodine	NR	NR	NR

3. Transfer to meat (d/kg)

Dairy cows

Element	5%	50%	95%
Strontium	0.003	0.0027	0.0051
Cesium	0.002	0.019	0.036

Beef cattle

Element	5%	50%	95%
Strontium	0.0003	0.0042	0.008
Cesium	0.0028	0.03	0.0572

Sheep

Element	5%	50%	95%
Strontium	0.003	0.04	0.0797
Cesium	0.05	0.3	0.55

Pigs

Element	5%	50%	95%
Strontium	0.002	0.04	0.0798
Cesium	0.153	0.335	0.517

Poultry

Element	5%	50%	95%
Strontium	0.01	0.4	0.79
Cesium	0.3	2.1	3.9

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.01	0.3	0.59
Iodine	1	3	5
Cesium	0.06	0.46	0.86

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.0009	0.0021	0.0043
Cesium	0.0012	0.0044	0.0076
Iodine	0.001	0.011	0.034

Sheep

Element	5%	50%	95%
Strontium	0.006	0.056	0.106
Cesium	0.005	0.047	0.089
Iodine	0.05	0.5	0.95

Goats

Element	5%	50%	95%
Strontium	0.006	0.028	0.05
Cesium	0.06	0.1	0.5
Iodine	0.07	0.41	0.75

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	20	25	30
Iodine	NR	NR	NR

Beef cattle

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	26	33	40
Iodine	NR	NR	NR

Sheep

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	10	13	16
Iodine	NR	NR	NR

Pigs

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	21	28	35
Iodine	NR	NR	NR

Poultry

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	1.6	3.75	5.9
Iodine	NR	NR	NR

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1. Animal Feed Consumption (Annual Average)

Feed consumption was calculated from the feed requirements to produce the various animal products of interest. Requirements in terms of digestible energy and protein were calculated from tables published by the National Academy of Science - National Research Council for all species of domestic animals. Livestock consume a great variety of feeds and protein supplements, but for purposes of this exercise it was assumed that dairy and beef cattle consumed some combination of pasture grass, alfalfa hay, corn silage, corn grain, and soybean meal, since these are the most common feeds in the US. Pigs and poultry were assumed to obtain their nutrient requirements from corn grain and soybean meal. Actually, feeds used, and for which nutrient analyses are published, number in the hundreds. Daily intakes of feed are assumed based upon common feeding systems and the requirements for dietary energy and protein to meet production requirements, i.e., average milk production per cow per year of 6,100 kg, and average weight gains for beef cattle of 1.2 kg per day and for grass fed cattle of about 0.5 kg per day.

A. Dairy Cows

Geographic Distribution

- Midwest and Northeast—60% of cows and two-thirds of US milk production.
- Southeast (excluding Florida)—10% of cows and less than 8% of US milk supply.
- Three West Coast states—15% of cows and 20% of milk.

1. Pasture Intake

Consumption of forage from pasture (or daily-cut green chop) is the most direct link between milk and fallout and was very significant in the past. However, dairy feeding practices have changed dramatically over the years and most dairy cows are fed harvested and stored forage all year.

Estimates of pasture intake by cows was obtained from phone interviews with experts in the area. For the Midwest and Northeast (Minnesota to Maryland), the estimate is 5% of feed intake for the year (Satter, University of Wisconsin). More cows are on pasture, but partly for exercise.

For the mid-South (Tennessee, Kentucky, Arkansas, South Carolina, North Carolina), about 75% of cows are on pasture at some time, with highest percentage in spring months. Pasture season is 9 months, so the average is about 20% per year of feed intake (John Bernard, University of Tennessee). In Georgia, 60% of cows have access to pasture with significant consumption in February and March. Annual average for pasture consumption is 5 to 10% of feed intake for Georgia, Alabama, Louisiana, South Carolina and upper Florida (Lane Ely, Georgia).

Conclusion

Pasture intake is significant only in the Southeast, and there primarily only in spring.

2. Typical diet for US dairy cow producing 15,000 lbs milk/yr

Table 1.

kg per day	Feedstuff	kg per year
8.0	alfalfa hay	2,920
4.0	corn silage	1,460
8.0	corn grain	2,920
1.0	soybean meal	365
21.0		7,785

Feed intake will be 30% higher in the West and 30% lower in the Southeast than the average. Any pasture forage would be deducted from hay intake. Corn silage would be produced on the farm, hay may or may not be, and grain and soybean meal are nationally traded commodities.

B. Beef Cattle

Geographical Distribution

In the United States in 1993, 78% of beef supply was from "finished cattle" (feedlot-fed), about 8% was imported beef, approximately 5% from dairy cows (not on pasture), which leaves only a small percentage of beef from cattle grazing pasture. Beef cattle are found mostly in the Central and Southeastern states (only 1% in 15 Northeastern states), but cattle feeding is concentrated in the Midwest and Plains states.

1. Average diet for finishing cattle fed in a feedlot (850 to 1200 lbs) for 120 days (2 1/2 changes/yr = 300 days)

8.0 kg corn grain × 300 days =	2,400
1.0 kg corn silage × 300 days =	300
0.5 kg soybean meal × 300 days =	150
	2,850 kg/yr

2. Grass-fed beef (1100 lbs)

10 kg dry matter from grass × 365 days = 3,650 kg/yr

C. Pigs

Swine are raised mostly in the Midwest and North Carolina.

Slaughtered 5 1/2 months 110 kg (100-125 kg)
Fed 2 kg/d for 120 d (14% protein)

Corn grain 1.6 kg × 365 d =	584 kg/yr
Soybean meal 0.3 kg × 365 d =	146 kg/yr

D. Poultry

1. Broilers

Broilers are produced mostly in the Southeast and fed on grain produced in the Midwest.

Fed 0-8 weeks	6 kg feed (20% protein)
Corn 5.5 kg × 6 =	33 kg/yr
Soybean meal 1.5 kg × 6 =	9.0 kg/yr

2. Layers

100 g feed/d for 12 months (15% protein) = 36.5 kg

Corn	28 kg/yr
Soybean	6 kg/yr

2. Soil Consumption by Cattle and Availability

Soil consumption studies have been related only to cesium because its availability varies with the clay content of soil. Soil binding is not known to affect availability of strontium or iodine. Clay particles in soil bind cesium almost irreversibly. Most agricultural soils in the United States have sufficient clay (10-40%) to bind cesium after some period (1 month?). Binding and unavailability are readily apparent from the very low amounts of cesium in the food chain in the years following worldwide fallout, even though soil levels peaked at that time.

Radiocesium associated with soil can represent significant intake by grazing animals and to a lesser extent from harvested forages. Dairy cows not on pasture were found to consume 0.14% to 0.96% of soil with the percentage increasing from confinement on concrete, to housing, to unpaved lots (Fries et al., 1982). Assuming consumption of 20 kg dry matter per day, soil consumption would be 20 to 200 grams per day. Dry lots for dairy cows mostly range from 400 to 1000 sq. ft. per dairy cow. Feedlots for beef cattle average 200 sq. ft. per animal, which is not much surface for daily soil consumption.

Healy (1968) reported soil ingestion of 0.5 to 1.2 kg/d for grazing dairy cows in New Zealand. Lowest levels were found during periods of rapid growth.

Experimental data on the availability of cesium from soil is limited. A study in Italy, with soil containing 11 to 16% clay, found F_m's of 3.7 to 6.1×10^{-4} (Belli et al., 1993) for sheep, which was 2-3 orders of magnitude lower than for cesium in forages. Ward and Johnson (1964) inadvertently contributed to the confusion about cesium availability by suggesting that the higher F_m for grain-fed cows was due to lower fiber intakes. It now seems certain that soil contamination accounted for the difference. In interesting studies from Sweden (Bertlelsson and Anderson, 1991), pasture cut at 6 cm height had 10-fold higher cesium concentration than that cut at 10-20 cm, while the F_m was 3.5 times higher for that cut at 10-20 cm. The difference was attributed to soil contamination. Crout et al. (1993) used most of the available data in their RUINS model and concluded that soil contributions of cesium to meat and milk would be minor.

It should be noted that Assimopoulous et al. (1987) collected soil from Chernobyl site, said to contain 12% clay, and fed it to sheep whose F_m was 2.6×10^{-2}. Much of the soil in the Ukraine and Byelorussia near Chernobyl is very sandy, and Russian scientists found differences in cesium concentrations of different natural pastures that varied by 100 times in the Gomel regions which were attributed to clay contents of soils.

3. Transfer Coefficients

A. Milk

The literature is replete with information on the transfer coefficients of cesium to milk (F_m) for cows and less for meat (F_f). Much less information is available for transfer coefficients of ^{90}Sr to milk and very little for ^{90}Sr transfer to meat. The cesium transfer to milk, beef and other meats has been investigated quite extensively by EC contractors since Chernobyl.

Both transfer factors and biological half-times assume equilibrium which is unlikely because in the case of fresh forages, radionuclide concentrations change rapidly with time after deposition. Stored hay is likely a mix of forage harvested at different times and subject to variable fallout. A particular grain crop would be subject to less variability, but the grains fed to cattle, pigs and poultry are likely to be from highly diverse sources because they are seldom produced today on the farms where they are fed. Biological half-lives of 20-40 days for cattle and pigs means that equilibrium conditions will seldom be present.

For the most part, biological half-times of ^{131}I and ^{90}Sr will not be of much significance because the values available are for the whole animal, while I is primarily concentrated in the thyroid and Sr in bones, neither of which are consumed by humans.

Four rather different F_m's for Cs in cow milk have been described in some detail: (1) high soil intake the lowest, (2) Chernobyl fallout, 1 to 2×10^{-3}, (3) worldwide fallout, 3 to 6×10^{-3}, and (4) ionic cesium, 10 to 15×10^{-3}, as reviewed by Ward et al. (1989). Although these F_m's are not absolute, sufficient data exist to support the trends indicated above. Many experiments on Chernobyl fallout indicate low F_m's originally and increasing over the years as activity decreased and more of the cesium presumably was translocated from leaf surfaces in the ionic form.

Estimates will be more accurate if the factors above are considered. In the absence of information, a compromise would be 5.0×10^{-3} from ^{137}Cs.

^{131}I	2.6×10^{-3} (Handl and Pfau, 1986 and Heeschen, 1987)
	1.0×10^{2} (Comar et al., 1961)
	1.0×10^{-2} (Ng et al., 1979)
	3-7 $\times 10^{-3}$ (Voigt et al., 1989b)
^{90}Sr	1.4×10^{-3} (Ng et al., 1979)
	5 to 7×10^{-3} (Van der Hoek et al., 1969)
	3×10^{-3} (Pelletier and Voilleque, 1971))

B. Beef Ff (equilibrium)

Meat transfer coefficient from laboratory experiments are at equilibrium. Some values are not, but have been corrected to equilibrium. In the real world, meat values will seldom represent equilibrium conditions.

^{137}Cs	2.0×10^{-2} (Ng et al., 1979)
	4.0×10^{-2} (Crout et al., 1993)
	0.7 to 4.2×10^{-2} (Johnson et al., 1968)
^{90}Sr	3×10^{-4} (Ng et al., 1979)
^{131}I	7.2×10^{-3} (Ng et al., 1979)

Note: Sr and I levels are very low in meat (muscle).

C. Pork

^{137}Cs	0.30 (Ng et al., 1979)
	0.06 to 0.29 (Voigt et al., 1989a)
^{90}Sr	2.9×10^{-3}
^{131}I	2.7×10^{-2}

D. Chicken – Broilers

^{137}Cs	4.4 (Ng et al., 1979)
	1.3 (Voigt et al., 1989a)
	3.9 (Anderson, 1988a, b)
^{90}Sr	3.2×10^{-2} (Ng et al., 1979)
^{131}I	0.2 (Ng et al., 1979)

E. Eggs

^{137}Cs	0.43 (Ng et al., 1979)
	0.80 (Anderson, 1988a)
^{90}Sr	0.22
^{131}I	4.4

4. Biological Half-Life in Animals

A. Dairy cows (milk)

1. Cs

Technically, the $BT_{1/2}$ for milk ^{137}Cs is about 5.0 d because of a long component, but for practical purposes it is about 1 d or less. Pearce et al. (1989) have nicely demonstrated that milk responds rapidly to contaminated feed. Eighty percent of activity has 1.5 d $BT_{1/2}$ (Voigt et al., 1989b).

2. ^{131}I

Five days (Van der Hoek, 1969).

B. Beef

1. Cs

Thirty-five days (Johnson et al., 1968).
Thirty eight days (Crout et al, 1993).

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1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	6.0	4.0	2.0	NR	NR	NR
Hay	2.0	4.0	6.0	12.0	8.0	6.0
Cereals (concentrate)	5.0	8.0	10.0	4.0	8.0	12.0
Other (e.g., maize silage)	NR	4.0	8.0	NR	4.0	3.0
Protein	1.0	1.0	1.0	0	4.0	8.0

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	6.0	8.0	15.0	NR	NR	NR
Hay	NR	2.0	4.0	2.0	4.0	6.0
Cereals (concentrate)	NR	NR	0	6.0	8.0	10.0
Other (e.g., maize silage)	2.0	NR	NR	2.0	1.0	3.0
Protein	NR	0.2	0.4	0.4	0.5	0.6

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	0.1	NR	NR
Hay	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	NR	NR	NR	1.3	1.5	1.7
Protein	NR	NR	NR	0.3	0.4	0.5

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	0.001	NR	NR
Hay	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.08	0.1	0.12	0.08	0.1	0.14
Protein	0.02	0.02	0.03	0.015	0.015	0.015

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.01	0.1	0.2
Pigs	NR	0.01	0.02
Poultry	NR	0.001	0.002

3. Transfer to meat (d/kg)

Dairy cows, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	NR	3.0×10^{-4}	NR
Cesium	1.0×10^{-3}	3.0×10^{-2}	8.0×10^{-2}

Beef cattle, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	NR	3.0×10^{-4}	NR
Cesium	1.0×10^{-3}	3.0×10^{-2}	8.0×10^{-2}

Dairy cows, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	NR	3.0×10^{-4}	NR
Cesium	2.0×10^{-2}	8.0×10^{-2}	2.0×10^{-1}

Beef cattle, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	NR	3.0×10^{-4}	NR
Cesium	2.0×10^{-2}	8.0×10^{-2}	2.0×10^{-1}

Pigs, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	NR	3.0×10^{-3}	NR
Cesium	1.0	4.0	6.0

Poultry (broilers), activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	NR	3.0×10^{-2}	NR
Cesium	NR	3.0×10^{-3}	NR

Dairy cows, activity associated with soil

Element	5%	50%	95%
Strontium	NR	3.0×10^{-2}	NR
Cesium	NR	3.0×10^{-3}	NR

4. Transfer to eggs (d/kg)

Chicken eggs, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	NR	0.2	NR
Iodine	0.05	3.0	4.4
Cesium	0.3	0.6	1.0

5. Transfer to milk (d/l)

Dairy cows, activity freshly deposited on feed stuff

Element	5%	50%	95%
Strontium	0.5×10^{-3}	1.0×10^{-3}	7.0×10^{-3}
Cesium	5.0×10^{-3}	2.0×10^{-3}	5.0×10^{-3}
Iodine	1.0×10^{-3}	5.0×10^{-3}	1.0×10^{-2}

Goats, activity freshly deposited on feed stuff

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	NR	2.0×10^{-3}	NR
Iodine	NR	NR	NR

Dairy cows, activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	NR	1.0×10^{-3}	NR
Cesium	4.0×10^{-3}	8.0×10^{-3}	1.0×10^{-2}
Iodine	0.0×10^{-2}	1.0×10^{-2}	5.0×10^{-2}

Dairy cows, activity associated with soil

Element	5%	50%	95%
Strontium	NR	1.0×10^{-3}	NR
Cesium	1.0×10^{-5}	1.0×10^{-4}	NR
Iodine	NR	1.0×10^{-2}	NR

6. Biological half-life in animals (days)

Dairy cows (milk)

Element	5%	50%	95%
Strontium	1.0	3.0	5.0
Cesium	0.5	1.0	5.0
Iodine	0.5	1.0	3.0

Beef cattle (meat)

Element	5%	50%	95%
Strontium	NR	730.0	NR
Cesium	20.0	25.0	50.0
Iodine	NR	5.0	NR

Pigs

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	20.0	30.0	50.0
Iodine	NR	NR	NR

Poultry

Element	5%	50%	95%
Strontium	NR	NR	NR
Cesium	1.0	5.0	10.0
Iodine	NR	NR	NR

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Question 1. Animals' consumption rates

1.a. Feed consumption

The energy requirements of animals depend on:

- their size (basic metabolism),
- their requirements for a possible developing foetus (gestation in mammals) and,
- their production yield (lactating mammals, laying hens and growing animals).

Their ingestion capacity, however, which is limited by the capacity of their gastrointestinal tract, may limit their intake (especially in the case of rough forages) and prevent the energy requirement to be fully met; in such cases, the roughage in the diet would be reduced and the diet would be complemented by concentrates to meet the animal's requirements.

Nutrition tables allow calculation of the amount of feed to be given to an animal in relation to the quality of the feed.

The energetic value for lactation (FUL/kg dw) of many green forages ranges from 1.03 to 0.56 (the lower values characterizing old or flowering grass); a 0.85 value for green forage appears as a good estimate in normal agricultural practice. The energetic value for silage from different grass species and maize ranges from 1.08 to 0.61 and that for hay, from 0.82 to 0.55. Combining these two sets of data and considering the fact that silage feeding tends to be preferred to hay feeding, a slightly lower value (0.80) than for fresh forage can be accepted. The energetic values for cereals and their by-products range from 1.32 to 0.82, so a value of 1.1 can be accepted as representative for this feed type.

The energetic values for meat production (FUM/kg dw) appear roughly to be 10% less than the corresponding FUL.

1.a.1. Dairy cattle:

We can estimate that the expected liveweight of dairy cattle in temperate areas will range between 300 and 750 kg, and that their production yield can vary from no milk production (dry cows) to 45 l/d. The average animal would be a 400 kg cow, producing 15 l/d. Based on these assumptions, the requirement (expressed in "forage unit for lactation" [FUL]), defined as the quantity of energy provided by 1 kg of reference barley) amounts to about 3.2 and 26 for the extremes and the median is established at 10.

Therefore, the minimum value for fresh forage consumption can be estimated to be about 4 kg (dw)/d while the maximum would be 31 kg (dw)/d. However such a huge amount of rough forage cannot be ingested by a 750 kg cow, which will be limited to about 18 kg (dw)/d. The ingestion of fresh forage by the average animal would be 12 kg (dw)/d. The median will be lower than the mean so that I suggest a median value of 10 kg (dw)/d. The 5% value is increased to 5 kg (dw)/d and the 95% is kept at 18 kg (dw)/d.

The values for silage and hay would differ from those for fresh forage by only 5%, it is therefore probably reasonable to keep the same set of values.

A diet composed of 100% fresh forage or silage/hay is not very common and concentrates will be supplied by the farmer to sustain the milk production of the animal. For very high milk yield, concentrates have to be provided.

For cereals, the minimum value is estimated to be 3 kg (dw)/d and the maximum to be 24 kg (dw)/d. The average cow would consume 9 kg (dw)/d. Once more, the maximum consumption will be limited by the stomach capacity to a maximum of about 18 kg (dw)/d. But on the top of that, a ruminant cannot be fed permanently with concentrated feed and needs a minimum amount of rough forage. Due to the cost and to the animal physiology, a 100% cereal scenario is completely unrealistic in cattle and sheep/goats.

The fact that animals are stalled or free grazing is not expected to modify the energetic requirement to a large extent since it is mainly ruled by the milk yield.

1.a.2. Beef cattle:

The same approach is applied to beef cattle, taking into account their specific requirement range, and the transformation coefficients (FUM/kg dw) of each feed type. Since beef cattle are growing animals, their requirements (expressed in "forage unit for meat production" [FUM]) increase with the increase of their liveweight (from 3 FUM up to 13 FUM). The calculated ranges of mass intake are respectively, 4 to 17 for green forage, 4 to 18 for silage/hay and 3 to 13 for cereals and by-products. However, the maximum admissible intake is limited by the stomach capacity (a maximum value of 15 kg was found for adult cows re-oriented for meat production).

The median value is moved towards the 95% limit to take into account that the last months of the animal fattening are probably the most important for the contamination levels in meat.

1.a.3. Sheep:

The requirements for meat sheep and lactating ewes range from 0.4 forage units to 2.6 forage units. The calculation of the expected intake leads to the value given in the corresponding table, taking into account the general remarks already mentioned before.

1.a.4. Pigs:

The requirements for pigs range from 3000 to 9000 kcal of digestible energy (DE) per day. A sow with 10 piglets however has energy requirements up to 18000 kcal/d.

The nutritional value of the cereals ranges between 3500 to 4000 kcal/kg dw. The ratios of these two parameters give a minimum value of 0.75 kg (dw)/d and a maximum value of 5.1 kg (dw)/d.

It is probably not relevant to consider diet that would consist entirely of fresh grass or silage/hay.

1.a.5. Poultry:

Although free-ranging poultry eat grass, neither grass nor silage/hay can be realistically considered as a poultry diet. Cereals and cereal by-products are the most common component of poultry diet. Chicken was considered as the most important representative of poultry meat and eggs. The consumption by poultry increases with age (from a few g/d at birth) until the animal is adult and then varies with the egg production. For laying chicken and broilers, literature values provide values in the order of 100-150 g/d. These values are dependent on the animal liveweight. A median value of 0.1 kg (dw)/d has been chosen. A 95% limit was stated at 0.2 kg (dw)/d to take into account heavier poultry species.

1.a.6. References:

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1.b. Soil ingestion

1.b.1. Estimated values

Based on the experimentation conducted in the framework of the EC-FARM program (B.J. Howard, coordinator) and on the publication by Zack and Mayoh (1984), the soil contamination of grass can vary over a wide range of values (from 0% up to more than 20%), depending on the grass height and the climatic conditions, which depend themselves on parameters like the season, the grazing pressure, the pasture fertility, the pasture age (permanent or temporary pastures), etc. A soil load of 3 to 4% (dw/dw) of soil adhering to grass appears as a reasonable mean estimate.

Taking into account the extreme values for the ratios soil-to-grass and the grass daily intake for cows and beef, the lowest limit of soil ingestion would be nil and the highest limit would be close to 4 kg (dw)/d (20% × 20 kg (dw)/d). The combination of the mean values gives a soil intake of 0.4 kg (dw)/d.

Compared to cows, sheep graze closer to the ground and probably have a relatively higher soil ingestion. They can also be expected to show an increased variability.

Pigs do not feed on fresh grass but, living outside in fields which are rapidly transformed into mud, it is probable that they will accidentally ingest soil particles. However, a value of 0.4 kg (dw)/d (10% of the 95% limit for food consumption) does not seem very probable. The median and 5% limit are what I consider a reasonable guess.

The same justification can apply to poultry.

1.b.2. Reference:

Zach, R. and Mayoh, K.R. 1984. "Soil ingestion by cattle: a neglected pathway," *Health Physics* 46:426-431.

Question 2. Availability of ingested feed

2.a. Cesium:

Experiments carried out with sheep, at Mol and in the UK, in the framework of the EC-FARM contract, have demonstrated a gastrointestinal availability of ionic cesium close to 80%. Similar tests using bioincorporated Cs in different plant species, fed fresh, frozen, dried, or as silage, show that the availability of Cs was not affected by its incorporation into plant tissues (true absorption is about 80%, which is the value that is suggested as the median).

After Chernobyl, some authors reported a lower availability of Cs deposited on grass (namely B.J. Howard); our observations at Mol do not support this reduced availability. Experiments (Mol) with simulated aerosol (in the framework of the RESSAC program) also show no differences in availability between ionic and aerosol Cs. A lower availability was observed in the region close to Chernobyl.

During the formation of aerosols, due to its high volatility, Cs tends to diffuse out of the particle and during cooling condenses on the external surface of particles. Therefore one can expect that a fraction of the Cs (more or less important) will be easily dissolved on contact with water and hence will be available as the ionic form. The type of particles changes with the travel distance of the cloud from the damaged reactor; the availability of Cs associated with these particles also changes.

In conclusion, it is probable that the availability of Cs in deposited particles can be reduced compared to that of the ionic form (median = 50%); however the uncertainty associated with the extent of this reduction is very large (from a complete availability to a total unavailability).

The behavior of Cs in soil and its association with clay minerals contribute to progressively diminish its availability regardless of that of the initial source (ionic or particle). Therefore I propose a median value of 40%, lower than that given for Cs associated with particles. However, in very organic soils, the Cs may remain available since no stable complex of Cs is formed with organic matter, so that the 95% limit can be maintained at 99% of availability.

2.b. Strontium:

Strontium is less available than cesium. Experiments carried out with sheep, at Mol and in Norway and the Chernobyl zone (K. Hove), in the framework of the EC-FARM and ECP-9 contracts, have demonstrated a gastrointestinal availability of ionic strontium of between 2 and 25%, depending on the method used to determine the true absorption coefficient. Similar tests using bioincorporated Sr in different plant species, fed dried or as silage, show that the availability of Sr was also not affected by its incorporation into plant tissues (true absorption is about 10%, which is the value that is suggested as the median).

Sr, being more refractory, tends to remain within the particles emitted during the accident and is therefore less soluble, hence less available. The availability of Sr associated with direct deposit on plants is thus expected to be less than the ionic form (median proposed = 5%). In this case too the uncertainty is large, the speciation being dependent on the accident type as well as on the distance travelled by the plume.

Strontium solubility is much less affected than that of Cs by reactions in the soil. However it can be (co-) precipitated under high pH conditions.

2.c. Iodine:

The different species of iodine, including the organic forms, are very available, even if certain species (iodate) are less available than others (iodide). Its incorporation into plants does not reduce its availability in ruminants. Its volatility is such that, in case of an accident, it will not be included within particles and the iodine associated with particles will be found at their surface in rather soluble forms. Therefore no marked difference in availability is expected. Also, in soil, especially because mineral forms of iodine are anions, no change in availability for animals is expected by its association with soil.

3. Transfer to meat

3.a. Beef cattle

Four years ago, a literature review to define best estimates for biosphere parameters (ONDRAF/NIRAS contract) was performed by the CEN/SCK. Cs and Sr were among the radionuclides considered. The results of this survey provided a best estimate (generally a geometric mean of reported values or ranges) and a geometric standard deviation. The geometric mean was used as the median value. The 5 and 95% limits were defined by dividing or multiplying the mean by the double of the geometric standard deviation. The individual data and references are given in the two annexes FF-Cs and FF-Sr.

3.b. Dairy cows

Some F_f values reported for cows indicate a lower value than for beef (annex FF-Cs); other authors report an F_f for cows which is similar to that for beef cattle. Moreover, under usual practice, the older cows intended for slaughter used to be fattened when they have limited or no milk production. Therefore I suggest keeping the same median value as for beef cattle but to lower the 5% limit to take into account an increased uncertainty. The same rule is applied for Sr.

3.c. Sheep

Based on the data found in the literature for Cs in sheep tissues and the experiments carried out within the FARM program, a median value of 0.3 d/kg looks realistic. Due to a generally large variability observed in sheep compared to cows and to the larger variation in grazing conditions, the 2-σ limits were broadened.

The median value for Sr is set to 0.005, between the 0.04 value derived from Coughtrey's model and values cited (Coughtrey, 1989). The uncertainty regarding Sr is even greater than for Cs, therefore the 5-95% range is increased.

3.d. Pigs

A comparison of the literature data (Coughtrey, 1989) for Cs and Sr in pigs with those given for sheep shows similar ranges for both animals. The estimates for sheep can be used for pigs too.

3.e. Poultry

Data from a Mol experiment with broilers and laying hens and literature data (Coughtrey, 1989) converge toward an F_f value of 4-5 d/kg for Cs. The variation of the reported data is rather narrow.

Very few data are available for Sr. Coughtrey suggests a mean F_f of 0.08 d/kg. The F_f ratio for Cs and Sr in beef indicates a 40 times less availability of Sr compared to Cs. Based of the F_f value for Cs in chicken, a 0.1 d/kg value is suggested as the median. A very large uncertainty is reported for the wide 5-95% confidence limits.

3.f. Indoors vs. outdoors

Animals fed indoors can be expected to ingest less soil particles, which reduces the Cs availability in the gut; therefore, a slightly higher F_f could be expected in stalled cattle. Other factors like temperature effect, exercise, etc, are less predictable.

4. Transfer to eggs

4.a. Estimated values

Most of the strontium of the egg is accumulated in the shell (95%). Ng et al. (1982) report a range of literature data from 0.28 to 0.39 d/kg. Russian data cited in Coughtrey (1989) give a transfer of 6.8 d/kg to the whole egg; a correction to consider only the edible part gives a figure of 0.3 d/kg.

Values for iodine transfer to eggs were found in Ng et al. (1982). They range from 1.5 to 3 for the whole egg. The activity in the shell is negligible and the shell contributes to about 10% of the egg weight. A median value of 2.5 d/kg can be suggested.

The proposed median value for the transfer of Cs to the edible part of eggs is derived from our own experience. Our value agrees fairly well with other reported ones (Coughtrey, 1989). The range of the available data is rather narrow.

4.b. References

Coughtrey, P.J. 1989. *Radioactivity transfer to animal products*, Associated Nuclear Services Ltd., ANS Report no. 2223-R1.

Ng, Y.C., Colsher, C.S., and Thompson, S.E. 1982. *Transfer coefficients for assessing the dose from radionuclides in meat and eggs*, US Nuclear Regulatory Commission: Final Report NUREG/CR-2976 UCID-19464.

4.c. Indoors vs. outdoors

I do not expect any marked difference in transfer.

5. Transfer to milk

5.a. Dairy cattle

Four years ago, a literature review to define best estimates for biosphere parameters (ONDRAF/NIRAS contract) was performed by the CEN/SCK. Cs, Sr and I were among the radionuclides considered. The results of this survey provided a best estimate (generally a geometric mean of reported values or ranges) and a geometric standard deviation. The geometric mean was used as the median value. The 5 and 95% limits were defined by dividing or multiplying the mean by the double of the geometric standard deviation. The individual data and references are given in the three annexes FM-Cs, FM-Sr and FM-I.

More recent published data do not disagree with the proposed estimates.

5.b. Sheep

Strontium is more heavily transferred to sheep milk than to cow's milk. From the few data available (Howard et al., 1995), a median value of 0.5 d/l is proposed. Due to the larger variability between sheep breeds and grazing conditions, the confidence interval has been increased in comparison with that used for cows.

Cesium is also more heavily transferred to sheep milk than it is to cow's milk. The data gathered by the FARM group and other literature data support a median value of 0.1 d/l. Here too the 5-95% range has been increased to cope with a larger uncertainty.

The same is true for iodine which is ten times more heavily transferred to sheep milk than to cow's milk.

5.c. Goats

The parameters proposed for sheep are likely applicable to goats. The uncertainty ranges were increased to cope with my personal uncertainty, except towards the 95% limit, to be sure that no more than was ingested is secreted into the milk.

5.d. References

Howard, B.J., Beresford, N.A., Kennedy, V.H., and Barnett, C.L. 1995. *A review of current knowledge of the transfer of radiostrontium to milk and possible countermeasures*, Draft report, ITE Merlewood, UK.

5.d. Indoors vs. outdoors

Animals fed indoors can be expected to ingest less soil particles, which reduces the Cs availability in the gut; therefore, a slightly higher F_f could be expected in stalled cattle. Other factors like temperature effect and exercise are less predictable.

6. Biological half-life in animals

The main problem linked with the quantification of the biological half-life parameters is that they are estimated by nonlinear regressions taking into account a number of different compartments of increasing half-lives. The number of these compartments is mainly influenced by the observation period. Even if several compartments exist, a short observation period will not allow identification of them, although long-lasting compartments can then influence the estimation of the half-life of short-lived nuclides and artificially increase them. On the other hand, most experimental data reported concern experiments carried out over a "relatively" short observation period and do not allow the identification of long-lived compartments. For humans, the generally accepted half-life for Cs is 30 d and for Sr more than one year, based on its turnover rate in bones.

6.a. Dairy cows

From Coughtrey's review (1989), the weighted retention of Sr in soft tissues can be estimated to be about 10 d.

From Coughtrey (1989), a half-life of 33 d for Cs is suggested for the long-term compartment. This compartment represents only a fraction of the body burden. In an attempt to take into account the contribution of short-lived compartments, a weighted average half-life of 15 d is proposed for dairy cows.

Iodine is rapidly excreted after administration to lactating cows, with a half-life close to 1 d (Voigt, 1989).

6.b. Beef cattle

The values for dairy cows are also proposed for beef cattle, except for Sr for which the absence of elimination by the milk and a slower turnover rate of calcium would suggest an significant increased half-life.

6.c. Sheep

The metabolism of smaller animals being higher, the parameters were reduced proportionally to their values for cows.

6.d. Pigs

In the absence of more information, the values for sheep are suggested for pigs too.

6.e. Poultry

The strontium values are derived from Coughtrey (1989). Those for Cs are taken from our own experiments with laying hens and broilers, and other data cited in Coughtrey (1989). For iodine, the parameters used for sheep and pigs are suggested.

6.f. References

Voigt, G., Pröhl, G., Müller, H., Bauer, T., Lindner, J.P., Probstmeier, G., and Röhrmoser, G. 1989. "Determination of the transfer of cesium and iodine from feed into domestic animals," *The Science of the Total Environment,* 85:329-338.

Annexe FF-Cs.
Individual values for Cs transfer to cow's muscles

Mean	Range	Ref
	4.7 E-2 to 5.1 E-2	[1]
3.5 E-2	3.0 E-2 to 4.0 E-2	[2] beef
1.0 E-2	5.0 E-3 to 1.5 E-2	[2] cow
	5.6 E-2 to 1.1 E-1	[3]
	1.5 E-2 to 3.0 E-2	[4]
	1.8 E-2 to 3.2 E-2	[5]
	4.7 E-3 to 3.1 E-2	[6]
	9.0 E-3 to 9.3 E-2	[7]
2.0 E-2	7.3 E-3 to 9.3 E-2	[8]
2.0 E-2		[9]
	8.0 E-3 to 5.0 E-2	[10]
	1.6 E-2 to 2.7 E-2	[11]
2.3 E-2		[12]
4.0 E-2		[13]
1.4 E-2		[14]
	5.7 E-3 to 9.6 E-2	[15]
2.0 E-2		[16]
2.6 E-2	7.2 E-3 to 9.2 E-2	[17]
3.8 E-2		[18] beef
1.0 E-2		[18] cow
	2.0 E-2 to 2.7 E-2	[19]
4.0 E-3		[20]
6.0 E-		[21]
2.0 E-2		[22]
1.5 E-2	4.7 E-3 to 9.7 E-2	[23]

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routine releases: Exposure of critical groups, IAEA Safety Series No. 57, IAEA Vienna.

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Annexe FF-Sr.
Individual values for Sr transfer to cow's muscles

Mean	Range	Ref
3.0 E-4		[1]
8.0 E-3		[2]
3.0 E-4		[3]
3.0 E-4	6.4E-5 - 5.7E-4	[4]
6.0 E-4		[5]
	6.0 E-4 - 2.8 E-3	[6]
8.0 E-4	1.0E-4 - 1.8E-3	[7]
8.0 E-4	7.0E-5 - 5.0E-3	[8]
6.0 E-4		[9]
3.0 E-4		[10]
3.0 E-4		[11]

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Annexe FM-Cs.
Individual values for Cs transfer to cow's milk

Mean	Range	Ref
	2.2 E-3 to 2.0 E-2	[1]
1.0 E-2		[2]
1.3 E-2		[3]
2.5 E-2		[4]
	1.6 E-3 to 7.2 E-3	[5]
8.4 E-3		[6]
	5.8 E-3 to 8.4 E-3	[7]
1.4 E-2		[8]
6.5 E-3		[9]
1.5 E-2	7.5 E-3 to 2.7 E-2	[10]
	5.5 E-3 to 7.7 E-3	[11]
	3.1 E-3 to 4.5 E-3	[12]
	3.1 E-3 to 4.5 E-3	[13]
6.0 E-3		[14]
1.1 E-2		[15]
	7.0 E-4 to 4.9 E-3	[16]
	7.0 E-4 to 4.9 E-3	[17]
	3.4 E-3 to 4.7 E-3	[18]
	1.6 E-3 to 2.1 E-2	[19]
4.0 E-3		[20]
4.6 E-3	2.9 E-3 to 7.0 E-3	[21]
	2.3 E-3 to 5.7 E-2	[22]
	4.8 E-3 to 1.2 E-2	[23]
4.9 E-3	3.6 E-3 to 6.4 E-3	[24]
	2.4 E-3 to 9.0 E-3	[25]
8.0 E-3		[26]
8.0 E-3	2.5 E-3 to 1.6 E-2	[27]
	1.9 E-3 to 2.2 E-3	[28] for radiotracer Cs
3.6 E-3		[28] for stable Cs
	1.8 E-3 to 1.6 E-2	[28] for fallout Cs
5.2 E-3	2.4 E-3 to 7.6 E-3	[29]
	2.0 E-3 to 9.0 E-3	[30]

	2.0 E-3 to 9.0 E-3	[31]
	1.6 E-3 to 6.0 E-3	[32]
	9.1 E-4 to 3.4 E-2	[33]
	2.0 E-3 to 3.0 E-3	[34]
3.0 E-3		[35]
3.8 E-3	2.4 E-3 to 5.2 E-3	[36]
1.1 E-2		[37]
7.1 E-3		[38]
8.0 E-3		[39]
1.2 E-2		[40]
1.5 E-2	8.4 E-3 to 2.2 E-2	[41]
1.0 E-2		[42]
8.0 E-3	2.1 E-3 to 2.2 E-2	[43]
7.0 E-3		[44]
	3.0 E-3 to 1.3 E-2	[45]
	9.2 E-3 to 1.4 E-2	[46]

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Annexe FM-Sr.
Individual values for Sr transfer to cow's milk

Mean	Range	Ref
	8.2 E-3 to 2.0 E-2	[1]
6.0 E-4	5.0 E-4 to 7.0 E-4	[2]
6.0 E-4	5.0 E-4 to 7.0 E-4	[3]
	1.3 E-3	[4]
1.6 E-3	7.0 E-4 to 3.2 E-3	[5]
1.0 E-3		[6]
	7.4 E-4 to 1.4 E-3	[7]
	4.0 E-4 to 1.4 E-3	[8]
2.2 E-3		[9]
1.2 E-3	7.0 E-4 to 1.7 E-3	[10]
3.0 E-4		[11]
1.0 E-3		[12]
	3.5 E-4 to 3.8 E-3	[13] for radiotracer Sr
	4.5 E-4 to 3.0 E-3	[13] for stable Sr
	4.5 E-4 to 2.7 E-3	[13] for fallout Sr
	6.0 E-4 to 3.8 E-3	[14]
6.0 E-4	5.0 E-4 to 7.0 E-4	[15]
	2.2 E-3 to 3.0 E-3	[16]
3.0 E-3		[16] for stable Sr
	5.0 E-4 to 2.9 E-3	[17]
	9.0 E-4 to 4.3 E-3	[18]
	4.1 E-4 to 1.4 E-3	[19]
1.4		[20]
3.0 E-3		[21]
8.0 E-4		[22]
8.0 E-4	7.9 E-4 to 8.0 E-4	[23]
6.5 E-4	6.2 E-4 to 6.9 E-4	[24] for 85Sr
2.0 E-3		[25]
1.3 E-3	4.3 E-4 to 2.8 E-3	[26]
1.4 E-3		[27]
	4.0 E-4 to 2.4 E-3	[28]

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Annexe FM-I.
Individual values for I transfer to cow's milk

Mean	Range	Ref
1.0 E-2		[1]
1.2 E-2	2.7 E-3 - 3.5 E-2	[2]
	1.7 E-3 - 3.4 E-2	[3]
2.4 E-3		[4]
am= 5.0 E-3, astd= 2.0 E-3		[5]
7.0 E-3		[6]
	3.5 E-1 - 1.3 E+0	[7]
am= 1.7 E-3, astd= 4.0 E-4		[8] (I-127)
am= 2.0 E-3, astd= 9.0 E-4		[8] (I-129)
	2.7 E-3 - 6.4 E-3	[9]
am= 5.0 E-3, astd= 2.0 E-3		[10]
	1.2 E-2 - 1.5 E-2	[11]
9.9 E-3		[12]
1.2 E-2	3.5E-3 - 3.0E-2	[12]
1.0 E-2		[13]
6.0 E-3		[14]
4.3 E-3	4.2E-3 - 4.4E-3	[15]
1.1 E-2	1.1E-2 - 1.2E-2	[16]
1.2 E-2	3.5E-3 - 3.0E-2	[17]
7.2 E-3		[18]

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1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	5	10	18	5	10	18
Silage	5	10	18	5	10	18
Cereals (concentrate)	4	7	13	4	7	13

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	5	11	15	5	11	15
Silage	5	11	15	5	11	15
Cereals (concentrate)	4	8	12	4	8	12

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.4	1.2	3	0.4	1.2	3
Silage	0.4	1.2	3	0.4	1.2	3
Cereals (concentrate)	0.3	0.8	2.5	0.3	0.8	2.5

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.8	1.6	4	0.8	1.6	4

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.03	0.1	0.2	0.03	0.1	0.2

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.01	0.4	2
Sheep	0.01	0.06	0.5
Pigs	0.01	0.03	0.4
Poultry	0.0001	0.002	0.02

2. Availability of ingested feed

Activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	0.0001	0.05	0.3
Cesium	0.01	0.5	0.99
Iodine	0.7	0.9	0.99

Activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	0.005	0.1	0.3
Cesium	0.6	0.8	0.99
Iodine	0.7	0.9	0.99

Activity associated with soil

Element	5%	50%	95%
Strontium	0.0001	0.03	0.3
Cesium	0.01	0.4	0.95
Iodine	0.7	0.9	0.99

3. Transfer to meat (d/kg)

Dairy cows

Element	5%	50%	95%
Strontium	0.00003	0.0008	0.006
Cesium	0.002	0.03	0.12

Beef cattle

Element	5%	50%	95%
Strontium	0.0001	0.0008	0.006
Cesium	0.008	0.03	0.12

Sheep

Element	5%	50%	95%
Strontium	0.0002	0.005	0.1
Cesium	0.05	0.3	1.5

Pigs

Element	5%	50%	95%
Strontium	0.0002	0.005	0.1
Cesium	0.05	0.3	1.5

Poultry

Element	5%	50%	95%
Strontium	0.005	0.1	2
Cesium	1	5	25

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.1	0.3	1
Iodine	1	2.5	5
Cesium	0.2	0.4	0.8

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.0003	0.0012	0.005
Cesium	0.00015	0.007	0.03
Iodine	0.0005	0.005	0.05

Sheep

Element	5%	50%	95%
Strontium	0.005	0.05	0.5
Cesium	0.01	0.1	1
Iodine	0.001	0.03	0.6

Goats

Element	5%	50%	95%
Strontium	0.002	0.05	1
Cesium	0.01	0.1	1
Iodine	0.001	0.1	1

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	1	10	100
Cesium	4	15	60
Iodine	0.1	1	3

Beef cattle

Element	5%	50%	95%
Strontium	1	15	150
Cesium	4	15	60
Iodine	0.1	1	3

Sheep

Element	5%	50%	95%
Strontium	1	8	80
Cesium	2	10	40
Iodine	0.1	0.5	2

Pigs

Element	5%	50%	95%
Strontium	1	8	80
Cesium	2	10	40
Iodine	0.1	0.5	2

Poultry

Element	5%	50%	95%
Strontium	0.5	5	50
Cesium	1	5	20
Iodine	0.1	0.5	2

EXPERT O

General Comments

I have worked with the evaluation of uncertainties in food chain transfer models for more than 20 years, yet I consider myself to have only a limited base of personal knowledge for many of the parameters for which information is requested in this expert elicitation. The parameters for which I am most confident in submitting a subjective estimate of uncertainty are those for which I have spent either a dedicated effort reviewing original research papers or on which I have conducted specific experiments. These parameters are:

- the fraction of material deposited with wet and dry deposition that is initially retained onto the surfaces of vegetation (Hoffman et al., 1982; Bondietti et al., 1984; Hoffman et al., 1992; IAEA, 1996a);
- the post-deposition retention of deposited materials onto pasture vegetation (Miller and Hoffman, 1983; IAEA, 1996a); and
- the milk transfer coefficients for cow's and goat's milk for radioactive iodine (Hoffman, 1978).

For all other parameters, my base of knowledge is limited to a less extensive survey of the literature, reviews by other scientists, and personal experience with validation studies designed to test the predictions of exposure assessment models (Ng and Hoffman, 1987; Richmond et al., 1988; Hoffman et al., 1988; Köhler et al., 1991; IAEA, 1995, 1996b). The source of much of the data that I will use in forming these judgments will be from previous uncertainty analyses that I have performed (Hoffman and Baes, 1979; O'Neill et al., 1981; Schwarz and Hoffman, 1981; Hoffman and Miller, 1983; Hoffman et al., 1984; Shevenell and Hoffman, 1993) and from experience gained while working on projects with the IAEA (1982, 1994) and NCRP (1989, 1995). Much of my knowledge about the potential uncertainty in model parameters was developed from 1978 through 1988 while collaborating with the late Dr. Yook C. Ng of Lawrence Livermore National Laboratory. Dr. Ng dedicated almost one quarter of a century to the evaluation of original references and the derivation of element specific transfer coefficients.

Animals

Question 1. Animals' consumption rates

I have limited personal expertise about this subject. The source of information I would draw upon to answer the question posed in this elicitation is the 1979 review performed by Roberta W. Shore at Oak Ridge National Laboratory using data from the Dairy Herd Improvement Association for 3000 dry lot dairy herds and about 11,500 partially pastured herds of dairy cows (Hoffman and Baes 1979). The values are representative of the Holstein breed which produces the majority of milk consumed by the US population. In the response, I have had to make a judgmental guess at the ratio of hay and silage as the two values are reported by Shore as a single category. The uncertainty reflects differences in feeding regimes that could occur at any time of the year in which an accident could occur. These feeding rates have been estimated knowing that total dry matter intake per cow should not exceed 25 kg/day. On the average, this value may be between 15 and 20 kg/day.

At this time, I will defer to others who have more expertise than I on the appropriate values to use for beef cattle, pigs, and poultry. I will also not attempt to estimate the amount of soil ingested by livestock.

Question 3. Transfer to meat

I have not been personally involved with either field experiments or in-depth reviews of original references for this parameter. To answer this question, I have drawn upon the reviews by Ng (1982) and Ng et al. (1982b). The availability of data for strontium is much less than for cesium. I have noted, however, that the expected value reported in the IAEA Handbook of transfer factors for strontium is too high by more than a factor of ten (1994). This is probably due to a typographical error. I do not believe that the data are sufficient to make distinctions between animals fed indoors and those kept predominantly on pasture. Because of my limited expertise in this area, I will keep my ranges fairly wide, but not necessarily as wide as reported for individual reports or single observations.

For estimates of transfer coefficients for the meat of sheep, pigs, and poultry, I would have to consult the references of other authors, most of which are summarized in the IAEA Handbook (1994). For this reason, I will not provide estimates for these parameters.

Question 4. Transfer to eggs

I have no experience evaluating studies for this parameter. This should not be an important pathway for estimation of the collective dose, however. Information about this parameter may be important for emergency response activities, but that is not within the scope of this elicitation.

Question 5. Transfer to milk

This is consistently one of the most important food types that determines the collective dose from the ingestion of contaminated foods in the first few years after an accident (IAEA, 1995, 1996b). This is the parameter for which I have spent the most time researching original references in preparation for this elicitation. My first reviews of the transfer of radioactivity into the milk of cows and goats was in 1978 followed by numerous studies that relied on Chernobyl fallout data to test the predictions of exposure assessment models (Hoffman, 1978; Hoffman et al., 1988; Ng and Hoffman, 1988; Köhler et al., 1991; IAEA, 1995, 1996b). In addition, I have been provided with an extensive unpublished survey of milk transfer factors for radioiodine by Andre Bouville. This is the most extensive literature compilation ever performed for the milk transfer coefficient for radioiodine. It contains more than 40 original references. Most of my reviews have dealt with the transfer of iodine and to a lesser extent, cesium. I have limited experience investigating the transfer of strontium; therefore, I will have to rely on reviews by the IAEA (1994) and Ng (1982) to obtain values for this element.

For radioiodine, estimating a mean value is problematic given the large number of relatively low transfer coefficients observed after the Chernobyl accident and elsewhere. For this reason, I am listing values that may appear somewhat lower than others (or even I) have used historically. If I had to recommend a distribution rather than provide fixed percentiles, I would say that it is most probable that the regional average value for the iodine milk transfer factor for dairy cows should most probably be between 2e-3 and 6e-3 d l^{-1} but highly unlikely to exceed 1e-2 d l^{-1} or be less than 1e-3 d l^{-1}.

The database is not as well developed for goat milk as it is for cows. Again most of my personal experience has been in the form of reviews on the transfer of radioiodines. The range of reported values for iodine extends from 8e-2 to 6.5e-2 d l^{-1} with the most frequently observed values being within 2e-1 to 4 e-1 d l^{-1}. For a regional average value, it is perhaps easier to first estimate the 5th and 95th percentiles and then provide an estimate of the 50th percentile. For strontium and cesium, I will have to rely on values reported in the IAEA handbook.

Questions 6 and 7. Biological half-lives and correlations.

I have not had sufficient time to research biological half-lives nor have I had time to research the potential for correlations. Basically, however, I believe that the only areas where potentially strong correlations could occur is with the transfer factors for iodine and cesium. I do not yet know of the mechanism that would explain this strong correlation, but based on my experience with reviews of data during the aftermath of the Chernobyl accident, I suspect that if studies could be made on the milk transfer coefficients of ^{131}I and ^{137}Cs from the same animal, a strong dependency might be found.

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These references were used as resource documents during my attempts to answer the elicitation questions. An additional set of primary references will also be provided.

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1. Animals' consumption rates

Dairy cows daily consumption rates (kg dry matter d^{-1})

	Outdoors (Grazing)			Indoors (Not Grazing)		
Feedstuff	5%	50%	95%	5%	50%	95%
Pasture grass	4.5	6.8	11			
Hay	5.0	7.0	11			
Cereals (concentrate)	4.0	6.2	9			
Other (e.g., maize silage)	2.5	3.0	1.0			

3. Transfer to meat

Dairy and beef cows, activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	1e-4	6e-4	4e-3
Cesium	5e-3	2e-2	6e-2

5. Transfer to milk

Dairy cows, activity freshly deposited on feed stuff

Element	5%	50%	95%
Strontium	5e-4	1e-3	3e-3
Cesium	3e-3	6e-3	1e-2
Iodine	2e-3	4e-3	1e-2

Goats, activity freshly deposited on feed stuff

Element	5%	50%	95%
Strontium	5e-4	1e-3	3e-3
Cesium	8e-2	2e-1	5e-1
Iodine	2e-1	3e-1	5e-1

EXPERT P

Discussion of the Elicitation Questions

Generalities

Whatever set of data reviewed, it must be kept in mind that a portion of subjectivity is implied in the different responses to the elicitation questions. If not, the assumed experience of the "experts" would be unuseful and the problem would be reduced to a simple statistical analysis.

In fact, it was asked to draw out reliable median values and as narrow as possible ranges from scarce, often incomplete and dissimilar values spread out in the literature, derived from experiments not easily comparable.

Data Analysis

When a consistent body of observations related to the same type of environmental contamination was available, the median value was chosen after verification of the normality of the distribution (Kolmogorov-Smirnov test); in most of these cases, median and mean were rather close. Very few distributions needed a log-normal distribution. All the data were tested for their validity (•) and incomplete observations (with sometimes only one animal, very few samples of contaminated feedstuffs or animal products or too short follow-up) were discarded. On the other hand, the confidence limits chosen were the minimal and maximal range of the selected data, if these extreme values were not isolated but confirmed by close ones. We thought that in this case the real extreme values were more valid than those given by the statistical analysis.

At least there was a subjective weighing between median and mean, according to the repartition of values given by very complete and good experiments relative to the criteria expressed above (•), or resulting from a homogeneous group of animals.

When results were scarce, neither mean or median or range could be considered as valid. The uncertainty was important and the responses were based on the most likely occurring values (or best estimates), taking into account the diet, the availability of the radionuclides, the transfer in similar species or with similar mechanisms, and the values derived from stable isotope (Ng et al., 1977; 1979) or tracer studies.

Uncertainty

One major source of uncertainty lay in the "not specified" part of the elicitation question: in some cases age, weight, and season (temperature and quality of pasture) could play a very important role in the median and range of the response.

The second point was the heterogeneity of the results available from the literature, according to the region, the varieties of soils and the agricultural practices, and the delay after the Chernobyl accident. Few analyses were carried out on the possible influence of these parameters, and anyway it did not seem very realistic to sum the uncertainties in all the cases.

The third point was the duration of the experiments or observations: few experiments were long enough to obtain an equilibrium state. With regard to experiments "in the field," the small number of samples of grass, hay, milk or meat at slaughter induced an important uncertainty: few results were given for animal groups which could be useful to determine a range in the region studied.

Question 1. Animals' Consumption Rate

(a) The values given for daily consumption rates were provided by the two reference books edited by the French National Institute of Agronomic Research. As a tendency to homogeneity in agricultural practices has been observed in France and in west Europe for the past 10-15 years, the values given for the different species are representative of the majority of feeding methods used at the present time, for lowlands and middle uplands. On the other hand, a tendency to select animals with high growth performances and high milk yields and thus with high feeding requirements has been developing since the Sixties.

The range takes into account the variability of animal weight, milk yields and season (quality of feed and temperature).

In the normal diet of cattle and sheep in France, about 10% of the dry matter (dm) consumed outdoors and 30% of the dm consumed indoors is from cereals: the tables give these values (between brackets) which are to be added to the amount of dm from pasture grass or silage/hay if the cereals are contaminated.

Though a number of different races of sheep are bred in France, the feeding practices are at the present time rather standardized (except for the few flocks specialized in milk production like Roquefort).

About 10% of pigs and poultry are bred outdoors in France (particularly in the west or southwest). The feedstuffs supplied are essentially cereals; it may be assumed that the daily outdoors consumption would be increased by 10-15% (wasting and temperature effect). Moreover in these rearing practices, animals could ingest soil.

(b) For dairy cows the percentage of soil ingested was taken between about 4 and 10%; the same range was taken for beef cattle with nevertheless a rather high median value (7.5 vs. 6.2) because beef cattle generally graze more and are less supplemented.

For sheep the range was taken between 5 and 25%, with a median value of 14%.

No information was available for pigs and poultry; we assumed that soil consumption was between 2 and 10% of total dm ingested for the two species.

Question 2. Availability of Ingested Feed

The larger range of results is given by Coughtrey and Thorne (1983).

The season, which determines grass density and then the amount of soil absorbed, has to be taken into account, because of the influence of some soil components on intestinal absorption.

Results were given for apparent absorption, i.e.,

$$\frac{\text{ingested - fecal}}{\text{fecal}}$$

As concerns radionuclide availability from the ingested soil, the presence of Ca^{++} for strontium and clay for cesium is an important factor in decreasing digestive absorption.

Only four results were available: two for Cs (Assimakopoulos, 1993 and Belli, 1993) in mineral soil, one (Hansen and Hove, 1991) in organic soil, and one for Sr (Assimakopoulos, 1993).

Results were very scarce for poultry; recent work in process indicates a higher availability of ^{137}Cs for ducks and turkeys than for hens.

Studies on fallout contamination showed that for a recent deposit, a parallelism did exist between meat and milk contamination for the three radionuclides concerned. Later when only cesium and strontium remained at significant levels, a difference appeared because of the different availability of Sr and Cs in the soil for plant absorption. After the Chernobyl accident, the availability of the radionuclides during the successive years was estimated, i.e., the years when Cs and Sr were biologically incorporated. It might be assumed that radionuclides freshly deposited on the soil would be more available than after their migration and incorporation in soil; in this latter case the influence of associated elements (Ca, K, nitrates, clay) would be more effective.

Questions 3, 4, and 5. Meat, Eggs and Milk Transfer

The transfer values were collected in the literature since Chernobyl, excluding results obtained with tracers. In our opinion, tracer experiments were interesting in a "radiation protection" context, giving the highest values for transfer and so more security; in a "modeling" context, results more closely related to the field were needed to avoid overestimation.

The normality of the distribution was verified; in this case the median was close to mean and was taken for the 50% value. On the other hand, comparisons (mean and variance) with fallout results were done. In some cases, results could be pooled. The quartiles and exclusion intervals were determined using the cumulated frequencies.

The body of data was rather large (30-50) for milk transfers in cows for ^{90}Sr, ^{137}Cs and ^{131}I; for ewes and goats, results were very scarce for ^{90}Sr, larger for ^{137}Cs (30) or ^{131}I (10). For meat, about 10-15 data were available for cows, beef cattle and ewes.

Data were very scarce for pigs and poultry.

When animals were fed indoors, we assumed that all the radioactivity was biologically incorporated in the feedstuff (grass, hay, silage): the value of F_f or F_m could be increased by about 30%. On the other hand about 30% of the dm were concentrates or grain, which are generally not directly exposed to fallout.

As concerns outdoors transfer, soil consumption, especially in clayey soil, could reduce the availability of cesium.

As chickens fed outdoors generally receive grain and concentrates, the difference between feeding indoors and outdoors should be very small.

The uncertainty considered for the transfer values F_f and F_m was in keeping with the range given for the availability of the ingested radionuclides. The age and the nature of soil (eventually ingested) was a supplementary factor in the uncertainty.

Meat transfer

Values were given for the mean weight when the animals of the different species were slaughtered.

For meat, the age was not specified: young animals have a higher transfer coefficient than older ones.

For sheep, the ratio between F_f observed in lactating or nonlactating animals was about 1.6 (range 1-1.8). (Lengemann, 1962; Howard, 1989; Daburon, 1992).

Milk transfer

Milk yield has no influence on the F_m value for Cs and Sr; for iodine, milk excretion changes in relation (but not directly correlated) to milk yield. The influence of the thyroid state (especially according to the season) is most important.

Question 6. Biological Half-Life in Animals

The formula taken for weighted average residence time of the radioactivity in the meat was:

$$TB_{1/2} = A(\%) \times T1_{1/2}\,(\text{day}) + B(\%) \times T2_{1/2}\,(\text{day}) + \ldots$$

The unspecified age was a factor of uncertainty; generally young animals have a shorter half-life than older ones (Daburon et al., 1992)

On the other hand, the Cs biological half-life is reduced by a low outdoor temperature.

For strontium, the difference between meat and bones is very important and since both are sold to consumers in the butcher's, it seems logical to combine these different components in the value of the weighted average residence time.

Question 7. Correlations Between Parameters

The following is a summary table with semiquantitative appreciations is given in addition to the elicitation questionnaire. As soil consumption increases in winter and in poor pasture land it seems logical that a large intake of high-quality grass reduces the possibility of soil ingestion.

In the questionnaire, an ambiguity remains on the possible correlation between the combination of cereals and hay/ silage: either cereals are substituted for other feed (the correlation will be highly negative) or combined with other feed in animals with high alimentary requirements (the correlation will be highly positive).

Correlations Between Parameters

	Animal Consumption Rate		Soil Consumption	Availability of Ingested Food
	Outdoors	Indoors		
Animal consumption rate				
Soil consumption	- -			
Availability of ingested feed			- -	
Transfer to meat	+	+	-	++
Transfer to milk	+	+	-	++
Biological half-life			-	

\+ Significant positive correlation
++ Highly significant positive correlation
\- Significant negative correlation
\- - Highly significant negative correlation

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1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	8	14.5	20	NR	NR	NR
Silage	NR	NR	NR	7	12	16
Cereals (concentrate)	NR	NR	NR	NR	NR	NR

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	4.5	6	9	NR	NR	NR
Silage	NR	NR	NR	3	6	9
Cereals (concentrate)	NR	NR	NR	NR	NR	NR

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	1	1.4	2	NR	NR	NR
Silage	NR	NR	NR	0.8	1.1	1.9
Cereals (concentrate)	NR	NR	NR	0.4	0.5	0.9

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	2.3	2.8	4.5	2	2.4	4

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.08	0.13	0.2	0.07	0.12	0.17

Soil consumption rate

Animal	5%	50%	95%
Dairy Cows	0.4	1	2
Beef Cattle	0.2	0.5	0.9
Sheep	0.05	0.2	0.5
Pigs	0.05	0.2	0.45
Poultry	0.001	0.006	0.015

2. Availability of ingested feed

Activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	0.02	0.1	0.2
Cesium	0.2	0.35	0.7
Iodine	0.65	0.85	0.95

Activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	0.05	0.15	0.3
Cesium	0.4	0.7	0.9
Iodine	0.7	0.85	0.95

Activity associated with soil

Element	5%	50%	95%
Strontium	0.01	0.08	0.15
Cesium	0.01	0.1	0.5
Iodine	0.6	0.8	0.95

3. Transfer to meat (d/kg)

Dairy cows

Element	5%	50%	95%
Strontium	0.0003	0.002	0.005
Cesium	0.005	0.016	0.05

Beef cattle

Element	5%	50%	95%
Strontium	0.0003	0.003	0.008
Cesium	0.007	0.037	0.085

Sheep

Element	5%	50%	95%
Strontium	0.005	0.02	0.05
Cesium	0.08	0.3	0.8

Pigs

Element	5%	50%	95%
Strontium	0.003	0.02	0.05
Cesium	0.1	0.4	0.7

Poultry

Element	5%	50%	95%
Strontium	0.003	0.02	0.08
Cesium	1	4	10

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.01	0.27	0.4
Iodine	1	2	4
Cesium	0.1	0.45	0.8

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.0003	0.0017	0.005
Cesium	0.0017	0.005	0.02
Iodine	0.002	0.004	0.018

Sheep

Element	5%	50%	95%
Strontium	0.01	0.02	0.06
Cesium	0.03	0.06	0.1
Iodine	0.08	0.45	0.94

Goats

Element	5%	50%	95%
Strontium	0.01	0.0025	0.05
Cesium	0.02	0.07	0.12
Iodine	0.06	0.42	0.77

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	7	40	110
Cesium	15	25	35
Iodine	8	14	35

Beef cattle

Element	5%	50%	95%
Strontium	7	20	100
Cesium	10	20	40
Iodine	6	13	30

Sheep

Element	5%	50%	95%
Strontium	10	30	110
Cesium	7	17	30
Iodine	7	18	40

Pigs

Element	5%	50%	95%
Strontium	20	40	120
Cesium	7	10	35
Iodine	8	20	40

Poultry

Element	5%	50%	95%
Strontium	5	15	50
Cesium	2	12	28
Iodine	6	14	30

EXPERT Q

General Conditions (As Provided at Start of Exercise)

The results of the analysis will be used to make estimates of the uncertainty associated with the collective dose from ingestion and the consequences of banning food that are representative of the majority of reactors within Europe and the US. Inevitably, given the diversity of siting land for reactors within Europe and the US, the results cannot be universally applicable. In this study the regions of interest are restricted to those typical of warm temperate climates, for example Northwestern Europe, and northeastern and southeastern US. Mediterranean countries, arid areas of the US, and areas subject to arctic conditions are not included. The estimates of uncertainty made by the experts should be applicable to the main agricultural production areas in these regions. Areas such as seminatural environments should only be considered insofar as they contribute to the food production for the regions of interest in this study.

In general, the questions are asked for the generic case and the expert is asked to define the assumptions he or she has made in determining a generic value. In some cases, more detailed information is asked for, such as a parameter value as a function of soil type. The uncertainty considered in answering the elicitation questions should include the effects of typical variations of weather conditions (e.g., amounts and frequencies of rain) and soil type (where appropriate). In general, the ranges provided should include the uncertainty resulting from the possible range of values for all conditions which are not specified in the information given with the question. For each question a list of conditions are given which are not specified in the question. This list is not exhaustive and does not preclude the experts considering other factors which they believe are important in contributing to the uncertainty.

The quantity used in the models is the best estimate of the value for the various parameters. The uncertainty ranges specified must correspond to this. In this context, the quantity required is the uncertainty on the average value for the region described above. For example, this means that where a parameter refers to the behavior of material in animals, the ranges given must describe the uncertainty on that quantity averaged over a group or groups of animals in the region of interest, rather than the variability between animals in these groups. Where a parameter refers to behavior in crops, then it must reflect the average over different crop growing areas and different stages of the growing season, and not the variability between areas or times of the year.

Some questions refer to transfer from "average" or "generic" soils to crops. In these cases, the experts must consider which types of soil are likely to support the crop under consideration in the region described and take into account the relative amounts of these in deriving the generic value.

Unless otherwise stated the effect of radioactive decay should not be taken into account.

For the crops considered in COSYMA and FARMLAND, the generic terms green vegetables, grain, and root vegetables are used. Green vegetables include all leafy green vegetables and brassicas, e.g., cauliflower and cabbages. Grain is representative of cereals grown for human consumption which are dominated by wheat. Root vegetables include potatoes and other vegetables such as carrots and onions. The consumption of root vegetables is typically dominated by potatoes and this should be taken into account in answering the questions relating to root vegetables.

1. Animals' consumption rates

1.1 Feedstuff consumption rates

1.1.1 Question and background material

What are the daily consumption rates of feedstuffs, for dairy cows, beef cattle, sheep, pigs and poultry?

The answers should be given in kg per day, dry weight. Please provide values for outdoor and indoor feeding for as many of the feedstuffs listed that you believe are appropriate for each animal. You should assume that the animal consumes 100% of each feedstuff and not combinations of feedstuffs, i.e., the consumption of different feedstuffs is not related. These parameters are used to determine the intake of radioactive material; you should not increase these consumption rates to allow for any additional uncontaminated supplementary feed if you feel that this would be used during the periods considered. You should assume that there is sufficient feed for the animals to eat what they require.

Not specified: *animal weight*
milk yields / stage of lactation
quality of feed

1.1.2 Rationale

Additional sources of uncertainty
- Animal husbandry.
- Animal condition.
- Environmental conditions.

Assumptions
- The weight of soil contaminating the diet is not included as part of the intake.
- Dairy and beef cattle do not consume pasture grass indoors or silage/hay outdoors.
- Cereals taken to include concentrates (but note that concentrate intake is related to feed intake and to milk production).
- Sheep do not consume pasture grass indoors or silage/ hay and cereals outdoors.
- Pigs and poultry do not consume pasture grass or silage/hay in any conditions.

Main sources of data

Coughtrey, P.J. et al. 1987. *Incorporation of experimental data, review and documentation of the SPADE database.* ANS R598-2. Ministry of Agriculture.

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1.2 Soil consumption

1.2.1 Question and background material

What is the daily consumption of soil by cattle, sheep, pigs and poultry?

The answers should be given in kg per day, dry weight. It should be assumed that the animals are outdoors on an inland site. The feeding practice assumed should be continuous grazing of pasture grass for cattle and sheep and the consumption of cereals and cereals/grass for pigs and poultry, respectively.

Not specified: *animal weight*
consumption rate of grass
weather conditions
time of year
stocking density
quality of pasture

1.2.2 Rationale

Additional sources of uncertainty
- Husbandry system.
- Soil type.
- Dairy versus beef cattle.

Assumptions
- Data on soil intakes are generally given as percentage of overall dietary intake but it is not appropriate to combine 5% or 95% percent dietary intake with 5% or 95% soil intake since maximum soil intake for cattle and sheep is most likely to occur when pasture is limited.
- For pigs, production systems are generally designed to limit the damaging the effects of soil intake.
- For hens there are few data but birds require soil intake.
- Percent soil intakes assumed:

Animal	5%	50%	95%
Cattle	5	10	20
Sheep	2	5	20
Pigs	5	10	30
Poultry	10	20	40

Main source of data

Coughtrey, P.J. et al. 1987. *Incorporation of experimental data, review and documentation of the SPADE database.* ANS R598-2. Ministry of Agriculture.

2. Availability of ingested feed

2.1 Question and background material

What fraction of the activity associated with consumed pasture grass would you expect to be available for transfer across the gut? Please provide values for radioactive material freshly deposited onto grass and for radioactive material biologically incorporated into grass. Would you expect the availability of soil associated activity to be the same? If not, what is the difference?

The feeding practice assumed should be continuous grazing of pasture grass.

Not specified: *animal species*
soil type
type of deposit

2.2 *Rationale*

Additional sources of uncertainty
- Animal age.
- Environmental conditions.
- Time of year.

Assumptions
- It is assumed that what is required here is true absorption, not apparent absorption.
- It is assumed that pigs are excluded (since they do not graze pasture grass).
- It is assumed that fresh deposit for iodine should include all potential chemical forms.

Main sources of data

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3. Transfer to meat

3.1 *Question and background material*

Consider an animal which is continuously fed Sr or Cs at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, Ff to the meat of the animal for each element? The quantity should be expressed as the fraction of the daily intake which is in each kg of the animal's meat, once an equilibrium situation has been reached, units d kg^{-1}. Please provide values for dairy cows, beef cattle, sheep, pigs and poultry.

Values should be for the edible meat of animals at slaughtering age, i.e., for beef, lamb, pork and chicken. The field conditions assumed should that animals are outdoors either continuously grazing pasture grass or consuming cereals.

Would your answer be different if the animals are being fed indoors? If so, what would the difference be?

Not specified: *animal weight*
milk yield / stage of lactation

3.2 *Response*

The answers would be different from those given in the tables if the animals were indoors because of differences in soil contamination - it would be necessary to scale values for different assumptions in gastrointestinal absorption and proportion of soil in the diet.

3.3 *Rationale*

Additional sources of uncertainty
- Form of contamination of the diet.
- Definition of 'meat'.
- Animal husbandry.
- Environmental conditions.
- Dietary composition.

Assumptions
- Equilibrium has been reached between dietary intake and meat concentration (this is unlikely to be the case for strontium in the lifetime of many animals).
- Any contribution from inhalation can be ignored.

Main source of data

Coughtrey, P.J. 1990. *Radioactivity Transfer to Animal Products*. EUR 12608. EC, Luxembourg.

Coughtrey, P.J. et al. 1991. *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems After the Chernobyl Disaster.* EUR 13436. EC, Luxembourg.

Coughtrey, P.J. 1993. *Effects of Countermeasures on Radionuclide Transfer to Animal Products.* IUR Pub R-9301-03. International Union of Radioecologists.

4. Transfer to eggs

4.1 *Question and background material*

Consider a laying hen which is continuously fed Sr, I or Cs at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, F_f to an egg for each element? The quantity should be expressed as the fraction of the daily intake which is in each kg of the edible fraction of the egg, once an equilibrium situation has been reached, units d kg^{-1}.

The field conditions assumed should that animals are outdoors either continuously grazing pasture grass or consuming cereals.

Would your answer be different if the chicken is being fed indoors? If so, what would the difference be?

Not specified: *animal weight*
egg production rate

4.2 Response

Chickens fed indoors receive a completely different diet than animals in free-grazing conditions and one with a much lower soil contamination. The results would be different than those for free-ranging animals given in the tables. Without some detailed modeling I would not hazard an answer as to how different.

4.3 Rationale

Additional sources of uncertainty
- Distinction between yolk and white of egg.
- Variety of chicken.
- Environmental conditions.
- Degree of soil contamination of diet.

Assumptions
- None.

Main sources of data
Coughtrey, P.J. et al. 1983-1985. *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Volumes 1-6.* AA Balkema, Rotterdam.

Coughtrey, P.J. 1990. *Radioactivity Transfer to Animal Products*. EUR 12608. EC, Luxembourg.

Coughtrey, P.J. 1993. *Effects of Countermeasures on Radionuclide Transfer to Animal Products*. IUR Pub R-9301-03. International Union of Radioecologists.

5. Transfer to milk

5.1 Question and background material

Consider an animal which is continuously fed Sr, Cs or I at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity, F_m to the milk of the animal for each element? The quantity should be expressed as the fraction of the daily intake which is in each litre of the animal's milk, once an equilibrium situation has been reached, units d l^{-1}. Please provide values for dairy cows, sheep and goats.

The field conditions assumed should be the agricultural practices assumed should be continuous grazing of pasture.

Would your answer be different if animals are being fed indoors? If so, what would the difference be?

Not specified: *animal weight*
milk yield / stage of lactation

5.2 Response

Results for housed animals would be different from those given in the tables and could be calculated from assumptions concerning soil intake and gastrointestinal absorption.

5.3 Rationale

Additional sources of uncertainty
- Environmental conditions.
- Dietary composition.

Assumptions
- Equilibrium has been reached within the lifetime of the animal.

Main sources of data
Coughtrey, P.J. 1990. *Radioactivity Transfer to Animal Products*. EUR 12608. EC, Luxembourg.

Coughtrey, P.J. et al. 1991. *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems After the Chernobyl Disaster.* EUR 13436. EC, Luxembourg.

Coughtrey, P.J. 1993. *Effects of Countermeasures on Radionuclide Transfer to Animal Products*. IUR Pub R-9301-03. International Union of Radioecologists.

6. Biological half-life in animals

6.1 Question and background material

If an animal has been fed Sr, Cs or I at a constant rate for some period of time under field conditions and equilibrium within the animal's body has been reached, what is the weighted average residence time of the activity in the meat of the animal? Please provide values for dairy cows, beef cattle, sheep, pigs and poultry.

The required quantity is the weighted average residence time. The retention function of material within the animal tissues is likely to have several components with different residence times. The required quantity is the weighted average of these residence times.

Not specified: *animal weight*

6.2 Rationale

Additional sources of uncertainty
- Definition of parameter (the title refers to biological half-life and the text to "weighted average of residence times").
- Animal weight (it is stated that animal weight is not specified yet it is also stated that the animal has been fed for some time - therefore it cannot be young).
- Environmental conditions.
- Animal husbandry.
- Dietary composition.

Assumptions
- Required parameter is the whole body biological half-life expressed in days.

Main sources of data

Coughtrey, P.J. 1990. *Radioactivity Transfer to Animal Products*. EUR 12608. EC, Luxembourg.

Coughtrey, P.J. et al. 1991. *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems After the Chernobyl Disaster.* EUR 13436. EC, Luxembourg.

Coughtrey, P.J. 1993. *Effects of Countermeasures on Radionuclide Transfer to Animal Products*. IUR Pub R-9301-03. International Union of Radioecologists.

7. Correlations between parameters

7.1 Background material

Some of the quantities for which ranges of values have been obtained are likely to be correlated. The final set of questions relate to the degree of correlation between these parameters.

Please indicate if you believe there are correlations between any of the parameters addressed in the previous questions including those between different elements for the same parameter. Please indicate if you believe there is a correlation whether it is strong or weak and positive or negative.

7.2 Response

See Table 1.

Responses to additional questions

Transfer to meat

Question a)

Summary of question
- Lactating cow fed on hay and food concentrate pellets.
- Administered Cs-134 orally for 4 months.
- What is the TF for muscle at the end of the period.
- Weight and yield not specified.

Response

50%	-	0.05
95%	-	0.15
5%	-	0.03

Basis and assumptions
- For cattle in the weight range 300 to 500 kg and an absorption factor of 0.6, I estimate values in the range 0.03 to 0.10.
- With a soluble tracer the maximum could rise to 0.17.

Question b)

Summary of question
- Adult sheep, lactating and non-lactating.
- Green kale pellets contaminated with Cs-134 [tracer?].
- 16 kBq/d for 34 days.

Response

	TF	Conc (kBq/kg)
50%	0.25	4
95%	0.35	5.6
5%	0.10	1.6

Basis and assumptions
- If the milk yield/stage of lactation is not specified, no sensible distinction can be made between lactating and nonlactating animals.
- For sheep and lamb of weight 30-60 kg and an absorption of 0.6, I estimate values in the range 0.17 to 0.31 at 100 days.

- This is based on assumed long-term Tb values in the range 14 to 18 days and therefore may be overestimating the values at 34 days by a factor of 1.3.
- At the same time, it can be assumed that the absorption of Cs-134 as a tracer in green kale pellets will be greater than 0.6 by about the same factor.

Transfer to milk

Summary of question
- Lactating cow.
- Hay and food concentrate pellets.
- Cs-134 oral administration for four months.

Response

50%	0.010
95%	0.015
5%	0.007

Basis and assumptions
- For an absorption of 0.6 I would anticipate a value of 0.08.
- The true value would be higher due to oral administration, say 0.12.
- it is a single cow and the variation could be substantial.

Biological half-life in animals

Summary of question
- Adult sheep.
- Equal amounts of wheat and dried grass harvested under field conditions contaminated with ^{137}Cs for 60 days.

Response

Time (d)	5%	50%	95%
5	0.7	0.75	0.9
10	0.5	0.6	0.7
30	0.15	0.25	0.4
60	0.05	0.09	0.2

Basis and assumptions
- The results can not be given as concentrations since the original contamination is not specified. They are therefore given as fractions.
- The results have been obtained using models incorporated within the SPADE suite of codes.

1. Animals' consumption rates (kg/day)

Dairy Cows

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	10	15	20	NR	NR	NR
Silage	NR	NR	NR	10	15	20
Cereals (concentrate)	0.4	3	6	1	1.5	2.5

Beef Cattle

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	3	7	12	NR	NR	NR
Silage	NR	NR	NR	3	7	12
Cereals (concentrate)	1	1.5	2	1	2	4

Sheep

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	0.5	1.3	2	NR	NR	NR
Silage	NR	NR	NR	0.5	1.3	2
Cereals (concentrate)	NR	NR	NR	0.2	0.5	0.9

Pigs

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	1	2	3	1	2	3

Poultry

Feedstuff	Outdoors (Grazing)			Indoors (Not Grazing)		
	5%	50%	95%	5%	50%	95%
Pasture grass	NR	NR	NR	NR	NR	NR
Silage	NR	NR	NR	NR	NR	NR
Cereals (concentrate)	0.05	0.07	0.15	0.05	0.07	0.15

Soil consumption rate

Animal	5%	50%	95%
Cattle	0.5	1	2.5
Sheep	0.02	0.07	0.3
Pigs	0.04	0.2	0.5
Poultry	0.01	0.02	0.06

2. Availability of ingested feed

Activity freshly deposited on feedstuff

Element	5%	50%	95%
Strontium	0.2	0.5	0.8
Cesium	0.2	0.5	0.95
Iodine	0.3	0.7	0.95

Activity biologically incorporated in feedstuff

Element	5%	50%	95%
Strontium	0.2	0.6	0.8
Cesium	0.8	0.9	0.95
Iodine	0.8	0.9	0.95

Activity associated with soil

Element	5%	50%	95%
Strontium	0.2	0.6	0.8
Cesium	0.1	0.6	0.8
Iodine	0.8	0.9	0.95

3. Transfer to meat (d/kg)

Dairy cows

Element	5%	50%	95%
Strontium	0.005	0.008	0.01
Cesium	0.02	0.05	0.06

Beef cattle

Element	5%	50%	95%
Strontium	0.005	0.008	0.01
Cesium	0.02	0.05	0.06

Sheep

Element	5%	50%	95%
Strontium	0.01	0.04	0.1
Cesium	0.05	0.17	0.4

Pigs

Element	5%	50%	95%
Strontium	0.01	0.04	0.1
Cesium	0.05	0.25	1

Poultry

Element	5%	50%	95%
Strontium	0.02	0.08	0.2
Cesium	1	8	10

4. Transfer to eggs (d/kg)

Chicken eggs

Element	5%	50%	95%
Strontium	0.05	0.2	0.4
Iodine	1	2	4
Cesium	0.06	1.5	2.5

5. Transfer to milk (d/l)

Dairy cows

Element	5%	50%	95%
Strontium	0.001	0.003	0.004
Cesium	0.002	0.008	0.2
Iodine	0.002	0.01	0.02

Sheep

Element	5%	50%	95%
Strontium	0.01	0.06	0.4
Cesium	0.03	0.06	0.1
Iodine	0.2	0.5	0.7

Goats

Element	5%	50%	95%
Strontium	0.01	0.02	0.04
Cesium	0.05	0.1	0.3
Iodine	0.1	0.4	0.6

6. Biological half-life in animals (days)

Dairy cows

Element	5%	50%	95%
Strontium	50	100	200
Cesium	10	20	30
Iodine	2	5	10

Beef cattle

Element	5%	50%	95%
Strontium	50	100	200
Cesium	10	20	30
Iodine	2	5	10

Sheep

Element	5%	50%	95%
Strontium	20	50	100
Cesium	5	15	30
Iodine		*	

Pigs

Element	5%	50%	95%
Strontium	20	50	100
Cesium	5	15	30
Iodine		*	

Poultry

Element	5%	50%	95%
Strontium	10	30	60
Cesium	3	15	30
Iodine		*	

* Notes: No appropriate data have been identified for iodine in these animals and therefore no response is provided.

APPENDIX F

Short Biographies of Food Chain Experts

Short Biographies of Food Chain Experts

Animal transfer and behavior panel

Peter J. Coughtrey, U.K.

Dr. Coughtrey earned his B.Sc. and Ph.D. in biology at Bristol University. He is a member of the Society for Radiological Protection and General-Secretary of the International Union of Radioecology. A consultant for L.G. Mouchel & Partners Ltd., his principal experience is in the fields of: mathematical modeling of toxic materials and radioactivity in ecosystems and man; experimental and field investigations on toxic materials in soils, plants and animals; biological monitoring; radiological and environmental risk assessment; and accident assessment and remediation. He is an advisor to national and international bodies.

Francois Daburon, France

Dr. Daburon received his Ph.D. in veterinary medicine in 1960. Currently he is the head of the Radiopathology Group of the Département de Radiobiologie et Radiopathologie of the Direction des Sciences du Vivant of the Commissariat à l'Energie Atomique. He also works as an expert to the CGC X in Brussels. His principal areas of research are: alimentary chain contamination and radionuclide transfer to cattle; transfer of radionuclides from nuclear weapon fallout (1962 - 1970) and post-Chernobyl contamination (1986 - 1991) from diet to cattle, eggs and pigs; the gastro-intestinal syndrome in pigs; graft tolerance in pigs; and diagnosis, pathogenesis and treatment of acute local irradiation in pigs.

Owen Hoffman, US

Dr. Hoffman has studied the transfer of radionuclides and other trace contaminants in terrestrial and aquatic systems for 25 years. His practice of radioecology began in Colongue, Germany in 1971 and continued from 1976 to the present in Oak Ridge, Tennessee. During the late 1970s through the 1980s, he collaborated closely with the late Dr. Y.C. Ng of Lawrence Livermore Laboratory to develop screening models and to investigate the uncertainty associated with element specific transfer coefficients in radiological assessment models. His field research has been concerned with the uptake of technetium from soil by plants and the transfer to vegetation of soluble and insoluble radionuclides in rain. He is a co-founder of both the International Biospheric Model Validation Study (BIOMOVS) and the International Atomic Energy Agency Coordinated Research Programme on the Validation of Assessment Model Predictions (VAMP). Dr. Hoffman is currently the President and Director of SENES Oak Ridge, Inc., Center for Risk Analysis where he has focused his attention on quantifying the effects of trace levels of contaminants on human health and the ecosystem. He is a member of the US Environmental Protection Agency Science Advisory Board, Radiation Assessments Committee, the National Council on Radiation Protection and Measurements, and a corresponding member to the International Commission on Radiological Protection.

Brenda J. Howard, U.K.

Dr. Howard earned her Ph.D. in biology at Reading University. Her principal expertise is in the field of environmental behavior of radionuclides. She carried out an investigation of the factors controlling the movement of radionuclides deposited in the environment, with emphasis on the transfer into animal tissues and on heavy metal physiology. Currently she performs investigations into the fate of Chernobyl fallout, particularly radiocesium in upland pastures grazed by sheep. She coordinates multi-national research programs for studies in Western Europe and Belarus, Ukraine, and Russia. Dr. Howard also does consultancy work for the International Atomic Energy Agency (IAEA) on environmental behavior of radionuclides and appropriate countermeasures.

Jack Pearce, U.K.

Professor Pearce received his Ph.D. in biochemistry at the University of Liverpool in 1967. Currently he is professor in food science and works at the Department of Agriculture in Belfast, Ireland. He has acquired substantial experience in assessing the consequences of the Chernobyl accident on the agricultural and food industries in Northern Ireland. He has been involved in research into the soil-plant-animal transfer of radioactivity, especially the plant-animal component, and was a member of the Plant-Animal Working Group of the International Union of Radioecology. In addition Professor Pearce has worked on countermeasures to reduce or block the plant-animal transfer; mainly through studies of the use of Prussian blue.

He has served as a consultant to Food and Agricultural Organization/International Atomic Energy Agency in a project to reduce the radiocesium contamination of milk and meat in the former USSR. Professor Pearce also is an Assistant Editor of British Poultry Science and an Editorial Advisor to the British Journal of Nutrition.

Per Strand, Norway

Dr. Strand earned his M.S. in 1986 and his Ph.D. in 1994 in physics at the University of Oslo. Since 1986, he has been a senior scientist at the Norwegian Radiation Protection Authority. He is also deputy director of the Environmental Protection Department. He was appointed as an expert for the International Atomic Energy Agency and Food and Agricultural Organization in the International Chernobyl Project. As such, he is member of the joint Norwegian-Russian expert group on the investigation of radioactive contamination in the North Sea. For the EC, he coordinates the projects "Radiation risk - Information, perception and reactions" under the Radiation Protection Program and "Fluxes of Radionuclides in the Environment" under the EU/CIS agreements on the consequences of the Chernobyl accident.

Christian M. Vandecasteele, Belgium

Dr. Vandecasteele became a engineer in agronomy in 1978, got his Master's degree in application of radioisotopes and radiation protection in 1981, and earned his Ph.D. in agronomy in 1987, all at the Catholic University of Louvain. Currently he is head of the Radioecology Laboratory at the Studiecentrum Voor Kernenergie Centre d'Étude de l'Énergie Nucléaire and is a lecturer in Radioecology at the universities of Brussels and Liège. His principal field of expertise is radioecology, with emphasis on terrestrial radioecology, transfer mechanisms of radionuclides through the soil-plant-animal-human food-chain, and transfer parameters and countermeasures.

Gabriele Voigt, Germany

Dr. Voigt graduated in biology in the fields of genetics, microbiology, biochemistry and radiation biology and did experimental work on the transfer of genes (plasmids) between different bacteria species for her Ph.D. At the Institute of Radiation Protection of GSF-Research Centre for Environment and Health, she works on the validation and verification of model predictions (ECOSYS) by experimental results regarding food chain pathways. This involves investigating the transfer of radionuclides in agricultural ecosystems, including experimental work with different farm animal species and factors (e.g., countermeasures) influencing this transfer. In addition, Dr. Voigt performs experimental work on the transfer and translocation of radionuclides in vegetation and reduction factors due to food processing. She is also occupied in overcoming the consequences of the Chernobyl accident, especially retrospective dosimetry for children with thyroid cancer in Belarus. In 1986 she worked as a guest scientist in the US on transfer and biokinetics of Tc-radioisotopes in goats.

Gerry Ward, US

Gerald Ward has graduate degrees in animal nutrition from Washington State University and the University of Wisconsin and has been on the faculty of Colorado State University since 1953. He began research of radionuclide fallout in the food chain at Los Alamos Laboratories in 1960. From 1961 to 1967 he headed an Atomic Energy Commission funded study of world-wide fallout in the agricultural system and developed the concept of transfer coefficients for radionuclides. He was head of the Animal Production and Health Section of the International Atomic Energy Agency in Vienna from 1968-70. He has been an active participant in dose reconstruction studies for the Nevada Test Site and the Hanford Site. He was involved in studies of Chernobyl fallout in Austria, Hungary and the former Soviet Union.

Soil/plant transfer and processes panel

Martin J. Frissel, the Netherlands

Dr. Frissel earned his Ph.D. in physical chemistry in 1961 at the Rijks Universiteit Utrecht. He has studied the physic al-chemical properties of soils and the availability of radionuclides, nutrients and organic compounds such as herbicides and pesticides to vegetation. He was a principal consultant for International Atomic Energy Agency "Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments." Dr. Frissel is the General Secretary of the European Branch of the International Union of Radioecologists and Chairman of the Steering Committee on Radionuclide Transfer in (Semi)Tropical Areas. Since 1988, he has been working as a private consultant.

John A. Garland, U.K.

John Garland graduated in physics at Bristol University in 1960 and joined the U.K. Atomic Energy Authority (AEA) the same year. His research career has included aspects of health physics and occupational hygiene, but since the mid-1960s his work has focused on the environmental behavior of radionuclides and pollutants discharged into the atmosphere. The process of deposition from the atmosphere to the surface of the earth differs for each combination of pollutant and depositional surface, and John Garland helped develop an understanding of the deposition of gaseous and particulate pollutants, including ^{131}I, tritium, ^{137}Cs, sulphur dioxide, ozone, and sulfate particles to various land and aquatic surfaces. He has also quantified the process of resuspension of previously deposited materials. An additional interest of his is the influence of pollution on visibility. He is currently a consultant at the National Environmental Technology Centre, AEA Technology, with responsibility for the Environmental Radioactivity Programme, and participates in projects involving sampling, measurement, modeling and assessment of non-radioactive pollutants in the environment.

René Kirchmann, Belgium

René Kirchmann presently is a retired professor of Radioecology, University of Liège, Belgium. He has over 30 years experience in the field of transfer of radionuclides in the food chain. He was involved in research on the behavior of strontium and cesium in plants and plant/soil interactions. He is currently the Chairman of the Advisory Panel to the Board of the International Union of Radioecology (IUR). He is the author of over 200 peer-reviewed publications.

Gerhard Pröhl, Germany

Dr. Pröhl earned his Ph.D. with a dissertation on modeling of radionuclide transfer in food chains after deposition of ^{90}Sr, ^{137}Cs and ^{131}I onto agricultural land. He works as a scientist at the Institute for Radiation Protection in the Risk Analysis Group of GSF-Research Centre for Environment and Health. As a result of his scientific activities, he is experienced in the analysis of the uncertainty of dose assessment and food chain models applied to emergency situations.

George Shaw, U.K.

Dr. Shaw received his Ph.D. in Environmental Botany and Geography at the University of Sheffield in 1988. Currently he is a lecturer in Environmental Science at the Imperial College's Centre for Analytical Research in the Environment. He has been a member of expert judgement panel before: in 1988 of a panel on soil-to-plant transfer of radionuclides in connection with Her Majesty's Inspectorate of Pollution (HMIP) enquiry into a proposed radioactive waste repository and in 1992 of a panel on solid-liquid distribution coefficients for plutonium in Cumbrian soils in connection with Harwell's Disposal Safety Assessment Team (DSAT).

F. Ward Whicker, US

Professor Whicker received his Ph.D. in Radioecology from Colorado State University in 1965, where he is currently a faculty member involved in graduate teaching and research. He is also affiliated with the Savannah River Ecology Laboratory at the US Department of Energy's Savannah River Site in South Carolina and with the Georgia Institute of Technology. He has conducted research on the behavior of radionuclides in a wide variety of aquatic and terrestrial ecosystems, developed the PATHWAY food chain model, and studied the effects of radiation on terrestrial ecosystems. He serves as a Council Member and on the Board of Directors of the National Council on Radiation Protection and Measurements. He has been active in several international projects with International Atomic Energy Agency, International Biospheric Model Validation Study (BIOMOVS), and the International Commission on Radiological Units.

APPENDIX G

Aggregated Results of Expert Responses

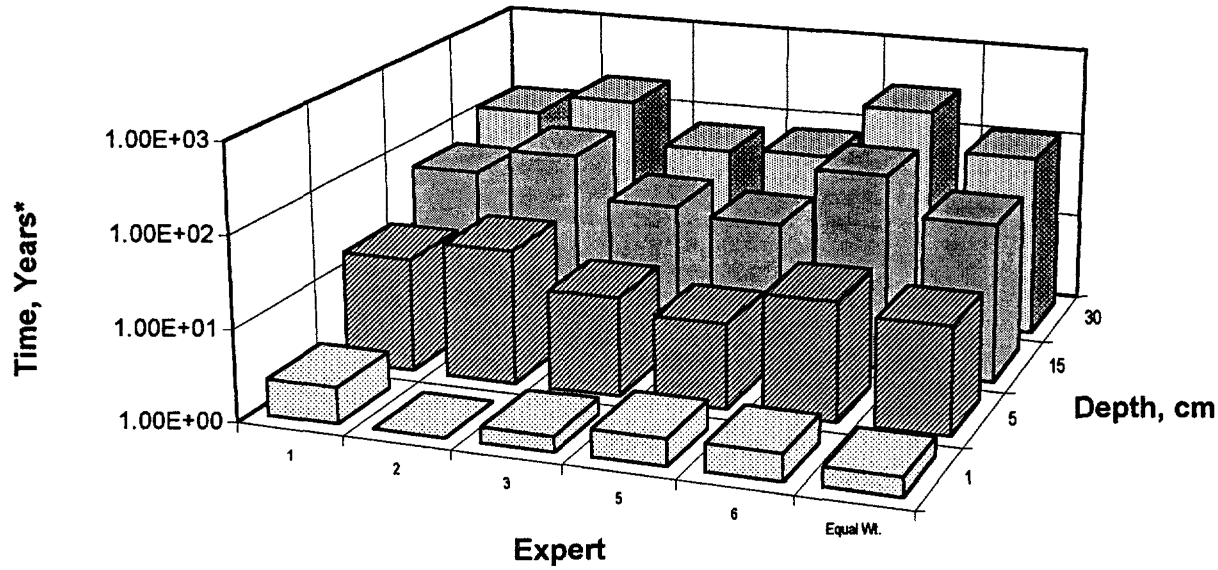

Figure G.1 Median values for migration of cesium in generic European soil as a function of soil depth.
*** The variable representing soil migration is expressed as the time taken for 50% of initial deposit to migrate to below the specified depth in soil.**

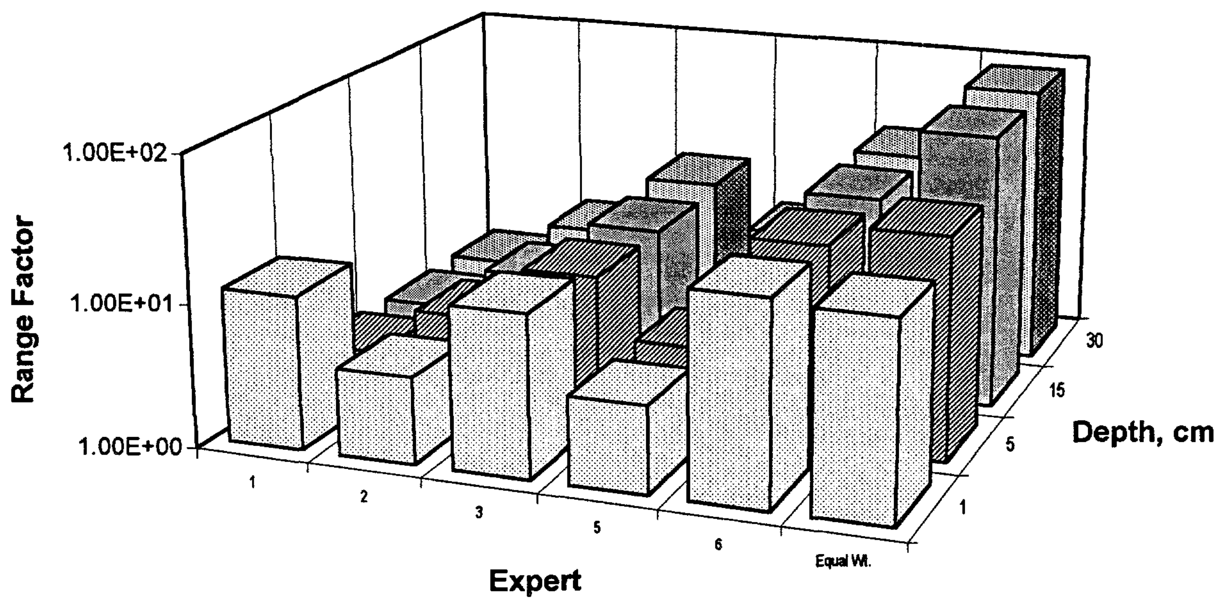

Figure G.2 Range factors (ratio of 95th/5th percentile) for migration of cesium in generic European soil as a function of soil depth.

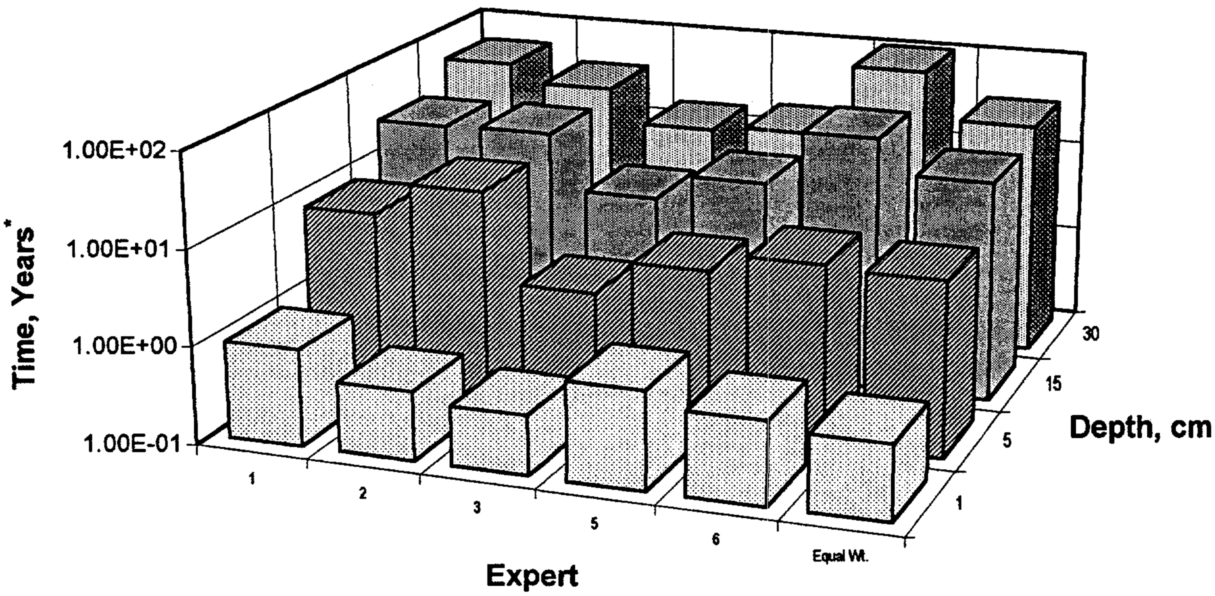

Figure G.3 Median values for migration of strontium in generic European soil as a function of soil depth.
*** The variable representing soil migration is expressed as the time taken for 50% of the initial deposit to migrate to below the specified depth in soil.**

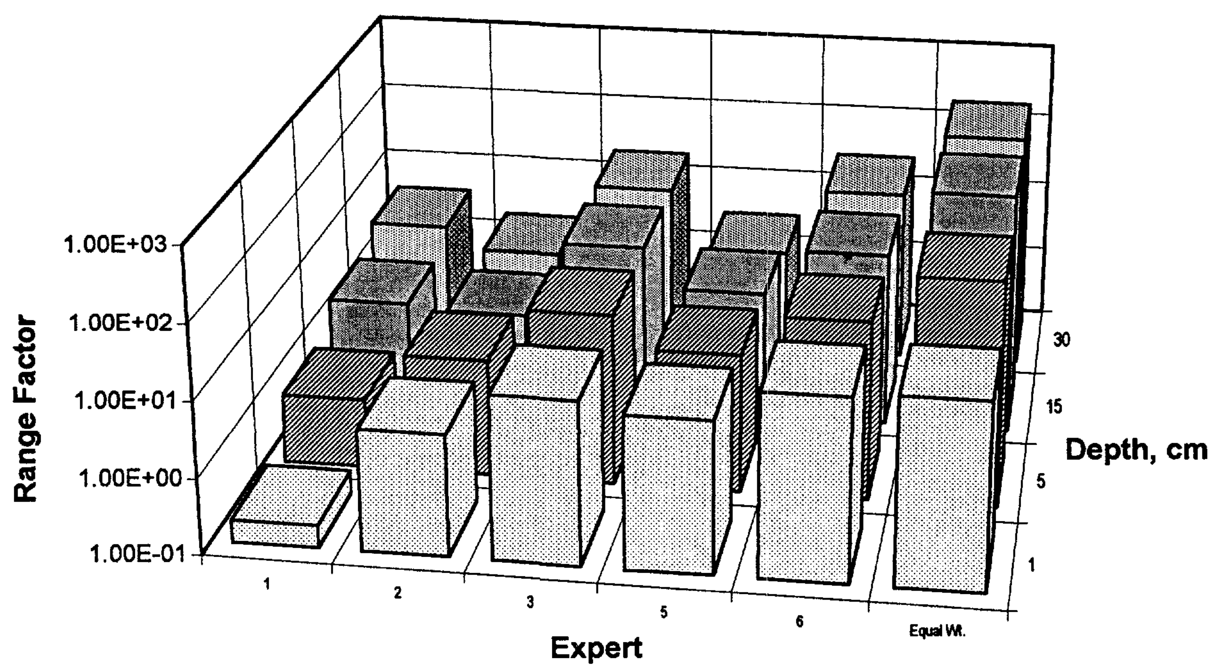

Figure G.4 Range factors (ratio of 95th/5th percentile) for migration of strontium in generic European soil as a function of soil depth.

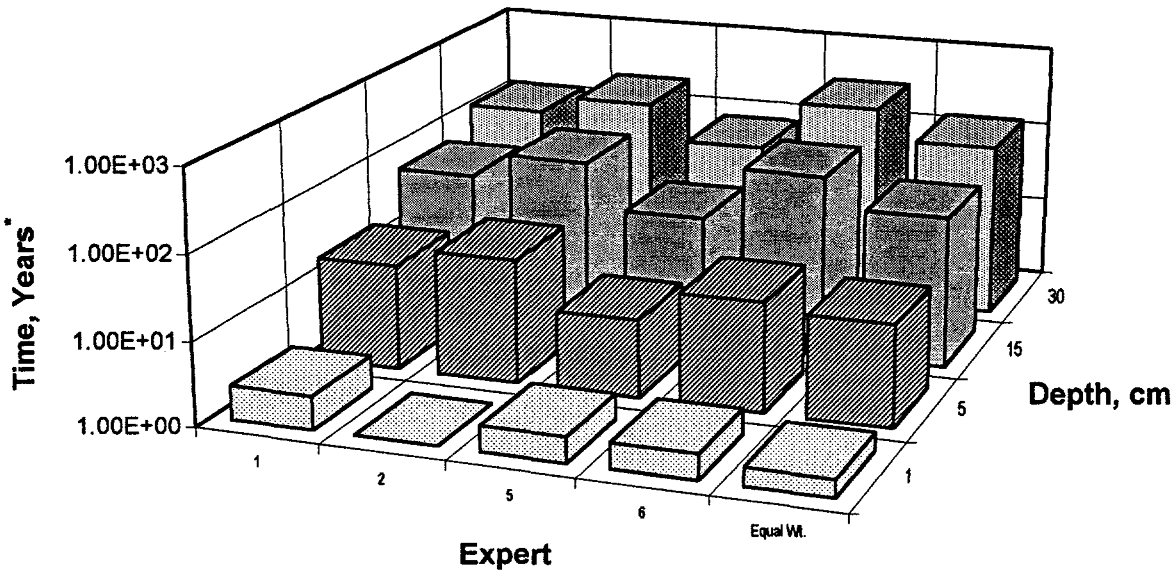

Figure G.5 Median values for migration of cesium in generic US soil as a function of soil depth. * The variable representing soil migration is expressed as the time taken for 50% of the initial deposit to migrate to below the specified depth in soil.

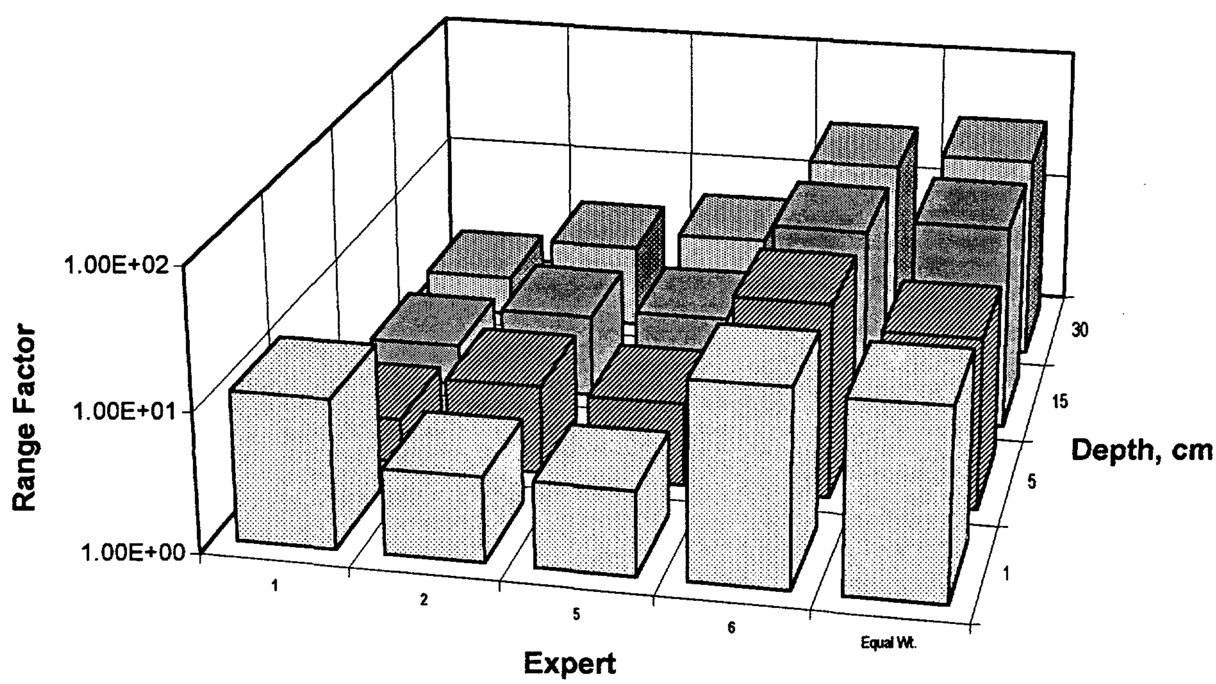

Figure G.6 Range factors (ratio of 95th/5th percentile) for migration of cesium in generic US soil as a function of soil depth.

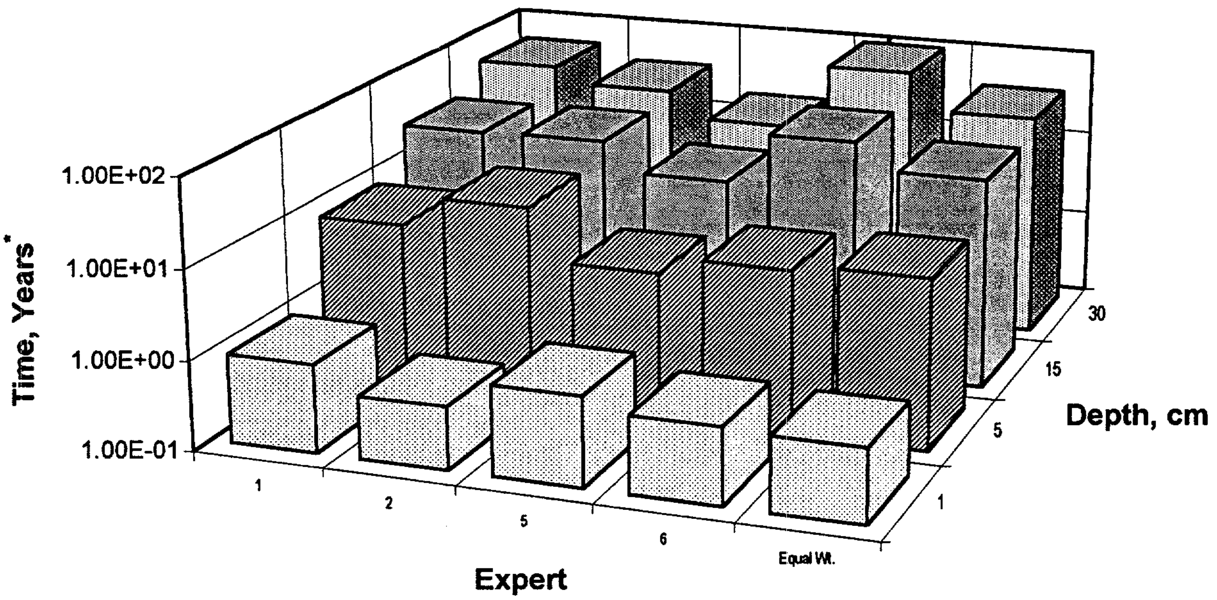

Figure G.7 Median values for migration of strontium in generic US soil as a function of soil depth. * The variable representing soil migration is expressed as the time taken for 50% of the initial deposit to migrate to below the specified depth in soil.

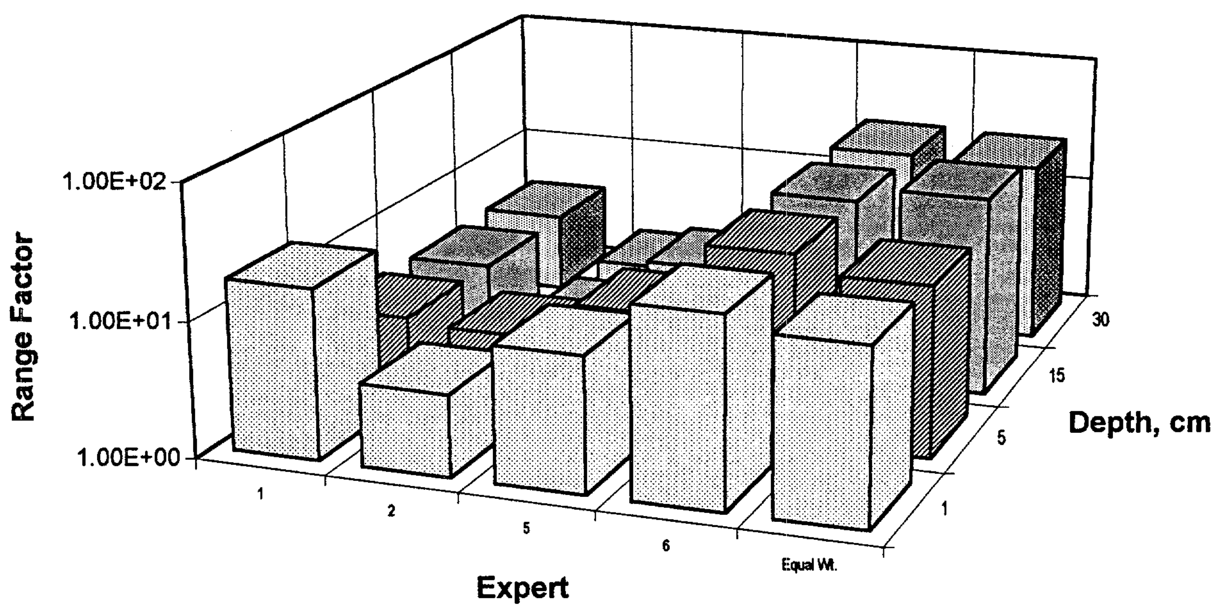

Figure G.8 Range factors (ratio of 95th/5th percentile) for migration of strontium in generic US soil as a function of soil depth.

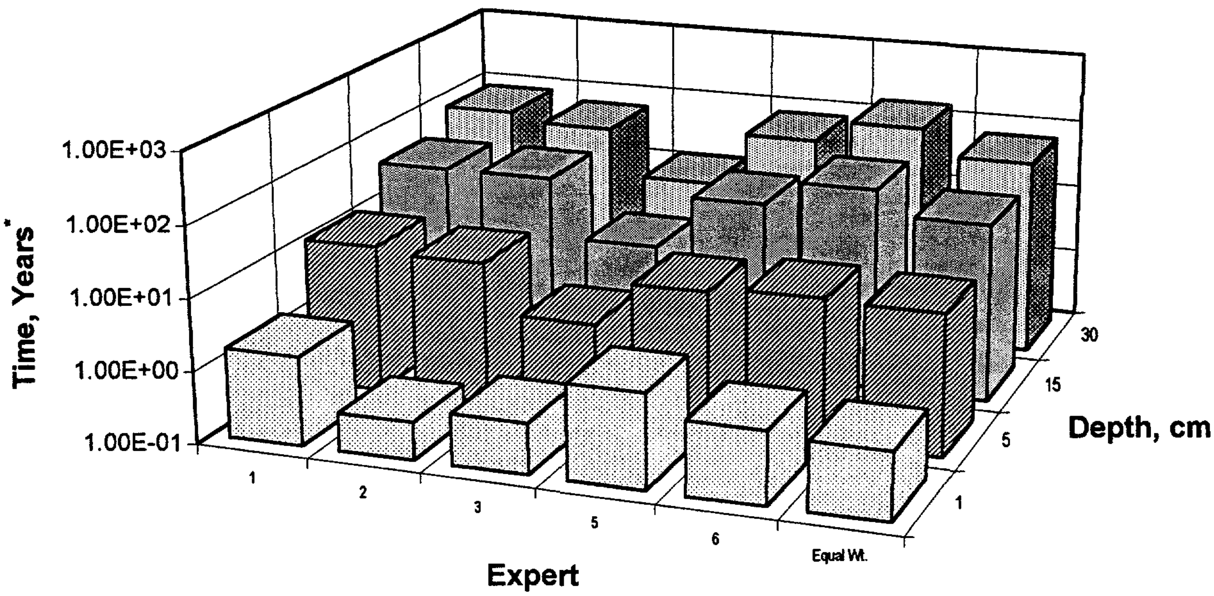

Figure G.9 Median values for soil migration for sandy soil with depth for cesium. * The variable representing soil migration is expressed as the time taken for 50% of the initial deposit to migrate to below the specified depth in soil.

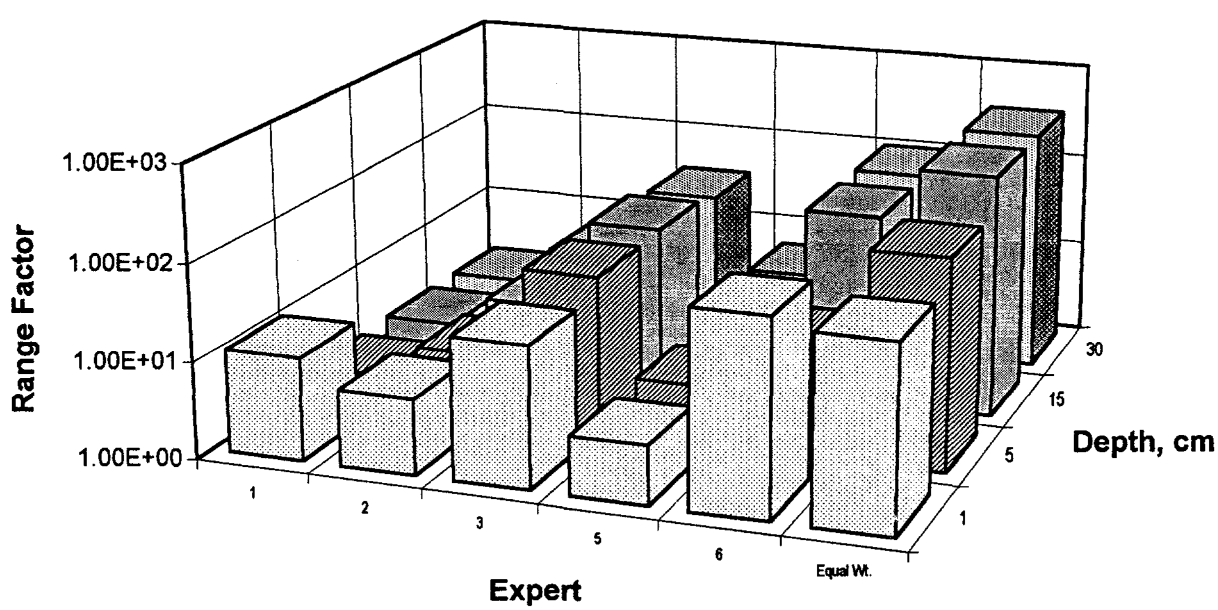

Figure G.10 Range factors (ratio of 95th/5th percentile) for soil migration for sandy soil with depth for cesium.

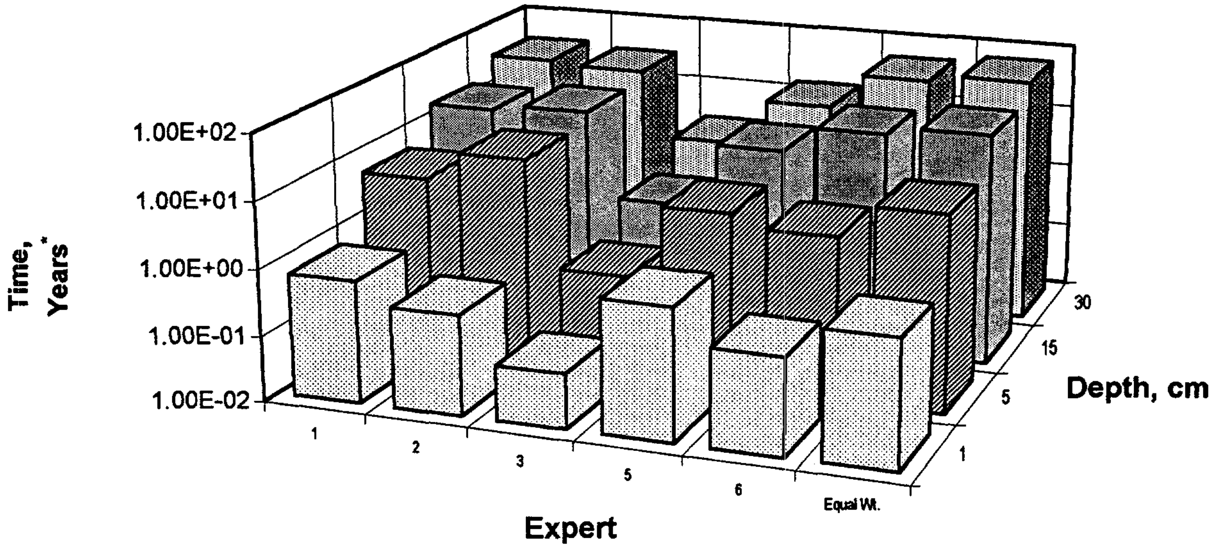

Figure G.11 Median values for soil migration for sandy soil with depth for strontium. * The variable representing soil migration is expressed as the time taken for 50% of the initial deposit to migrate to below the specified depth in soil.

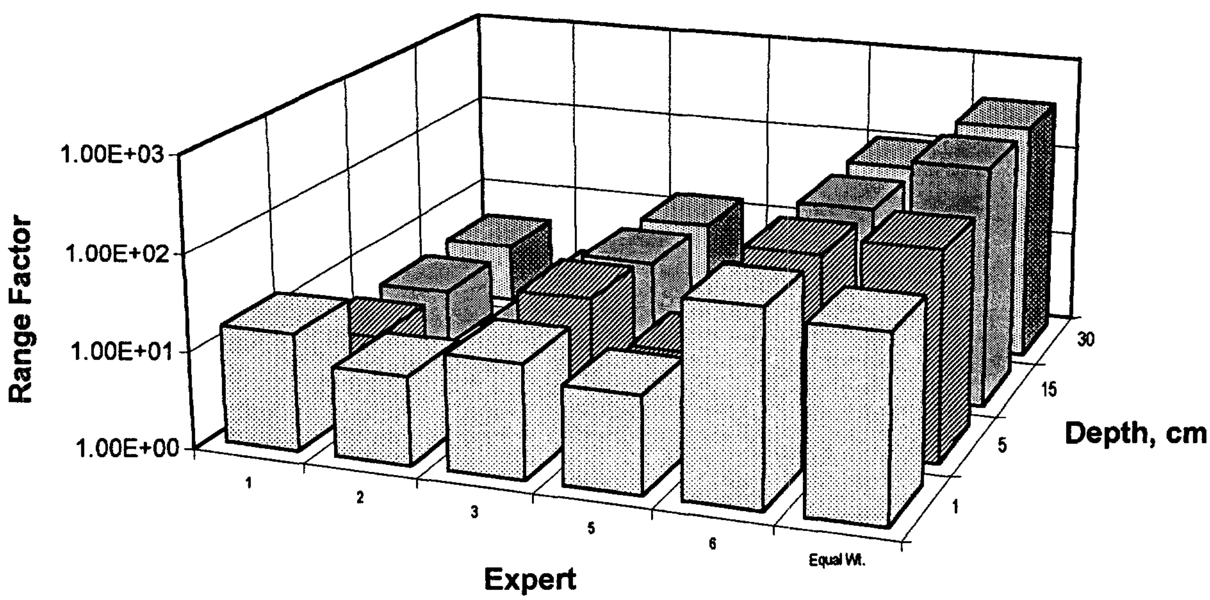

Figure G.12 Range factors (ratio of 95th/5th percentile) for soil migration for sandy soil with depth for strontium.

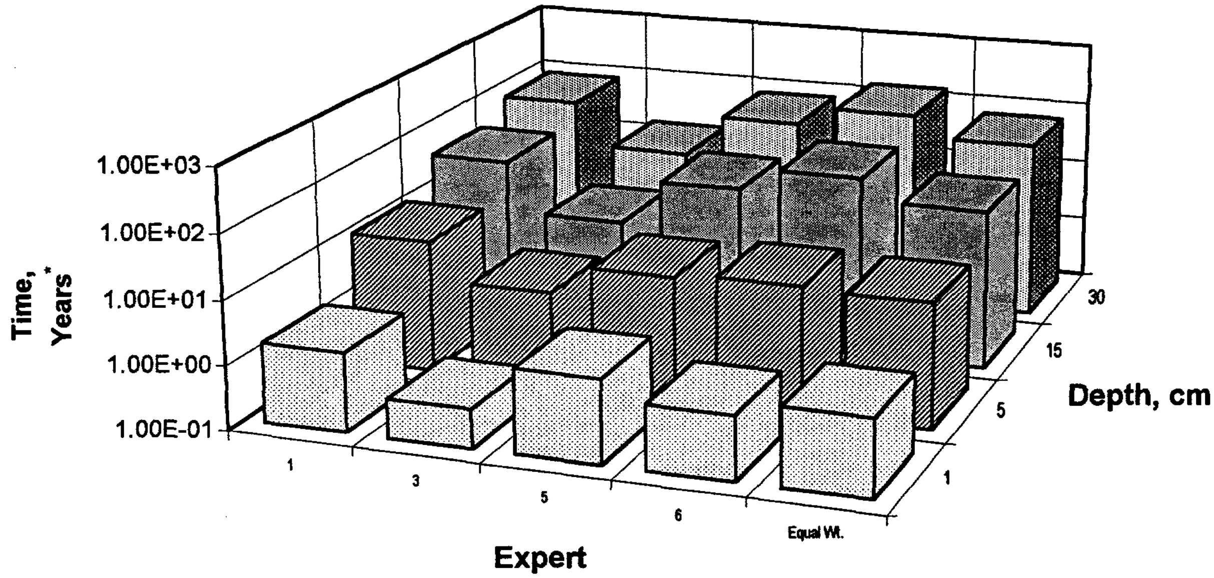

Figure G.13 Median values for soil migration for highly organic soil with depth for cesium. * The variable representing soil migration is expressed as the time taken for 50% of the initial deposit to migrate to below the specified depth in soil.

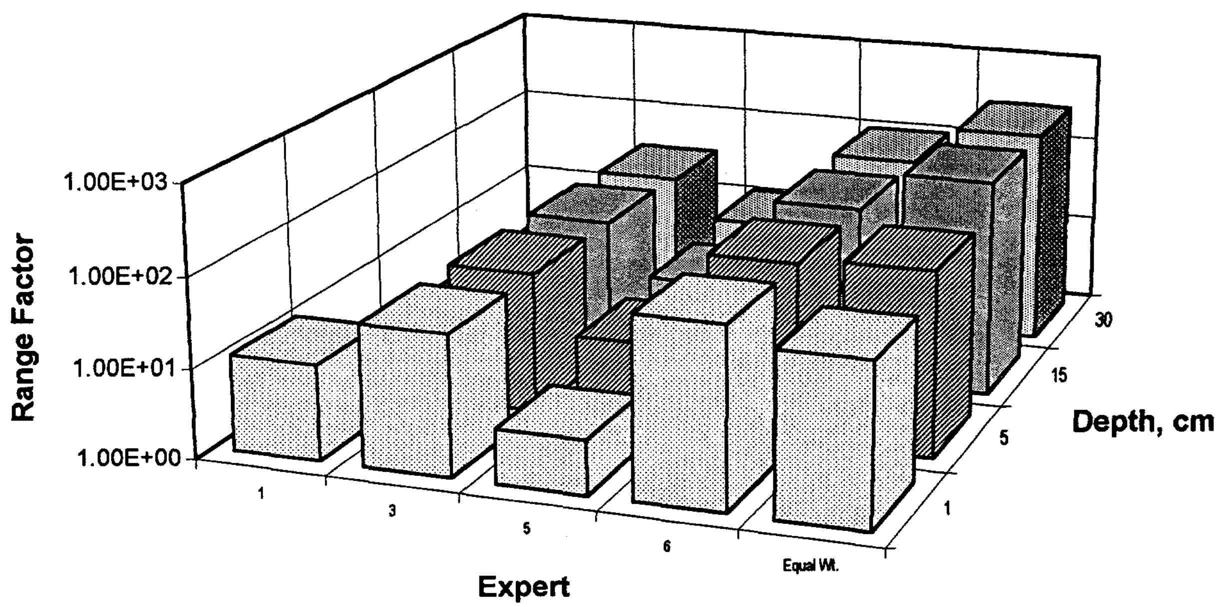

Figure G.14 Range factors (ratio of 95th/5th percentile) for soil migration for highly organic soil with depth for cesium.

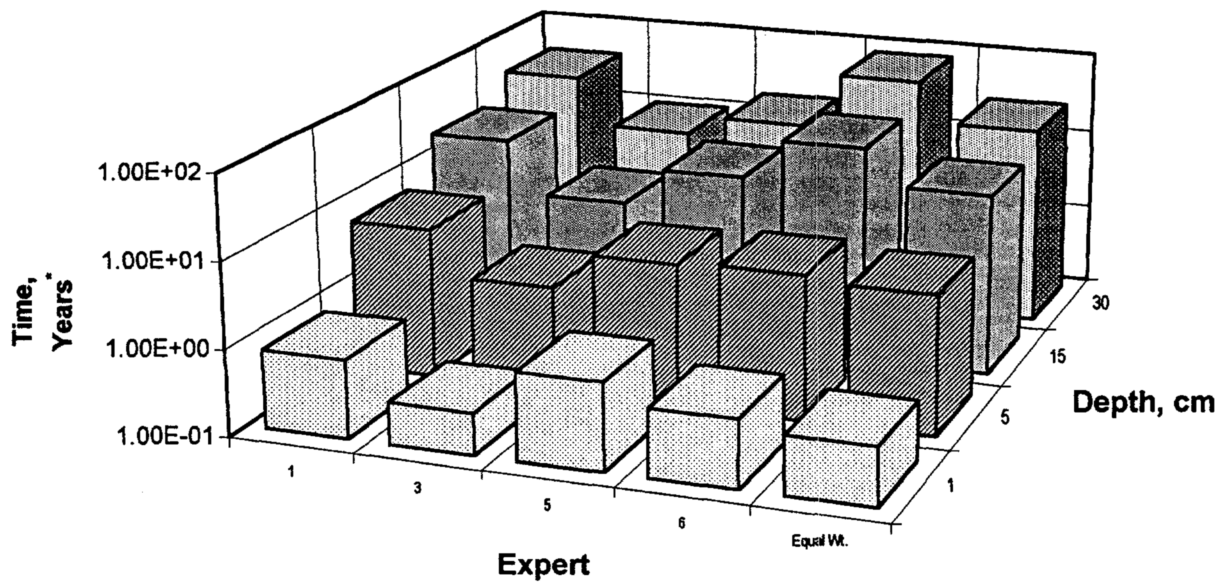

Figure G.15 Median values for soil migration for highly organic soil with depth for strontium. * The variable representing soil migration is expressed as the time taken for 50% of the initial deposit to migrate to below the specified depth in soil.

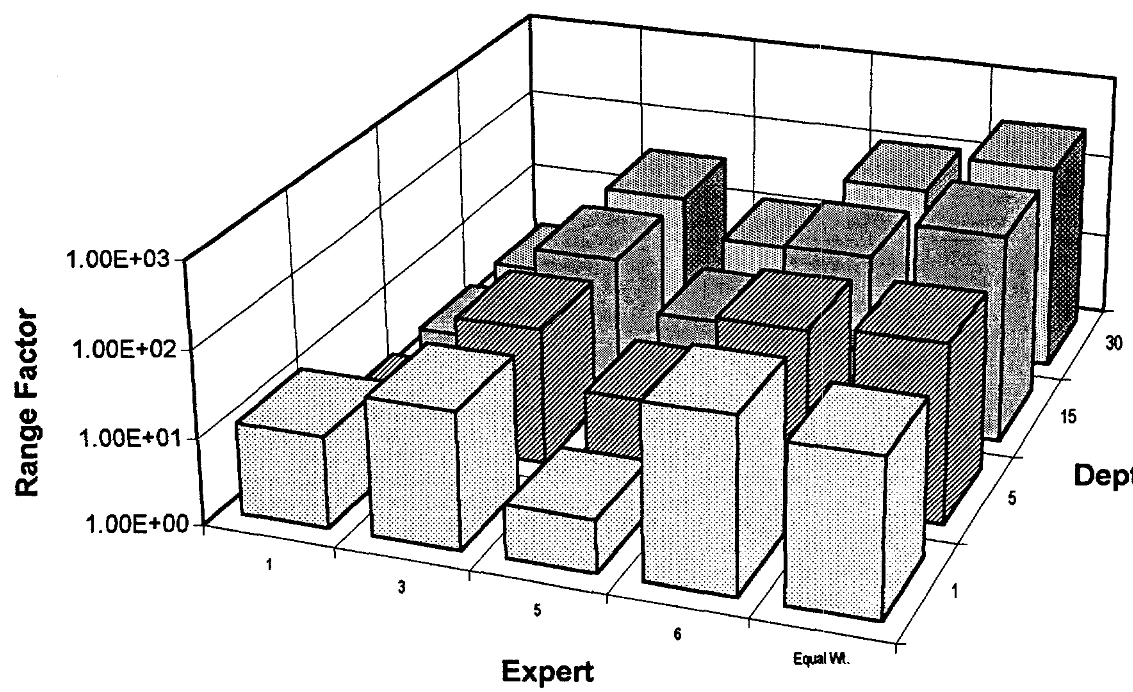

Figure G.16 Range factors (ratio of 95th/5th percentile) for soil migration for highly organic soil with depth for strontium.

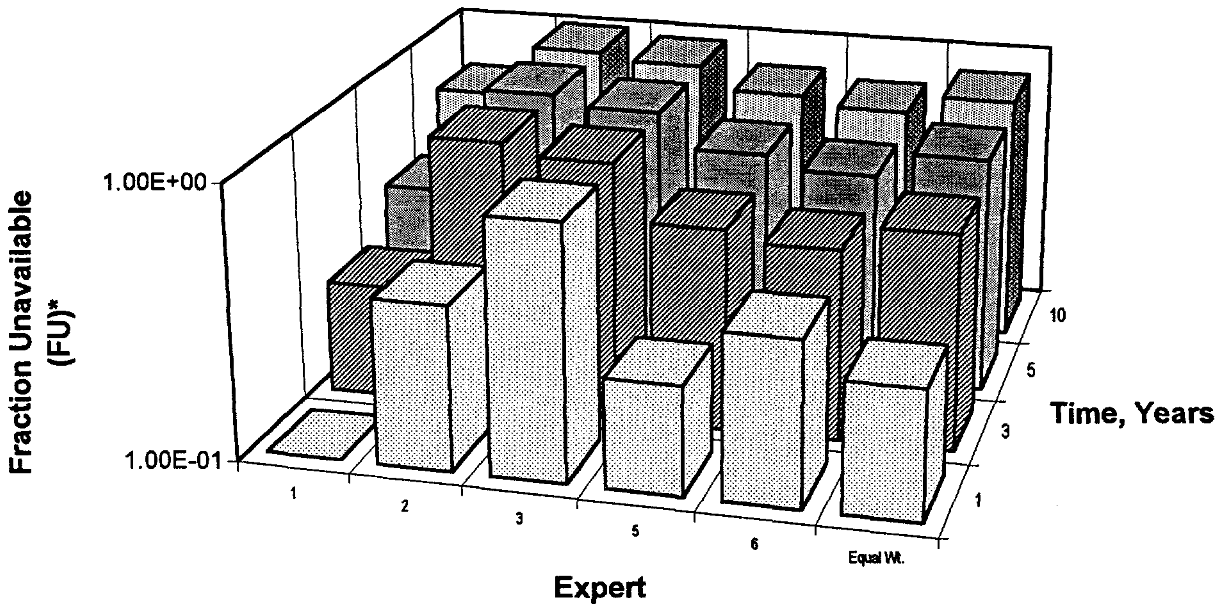

Figure G.17 Median values for fixation of cesium in generic European soil as a function of time. * The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.

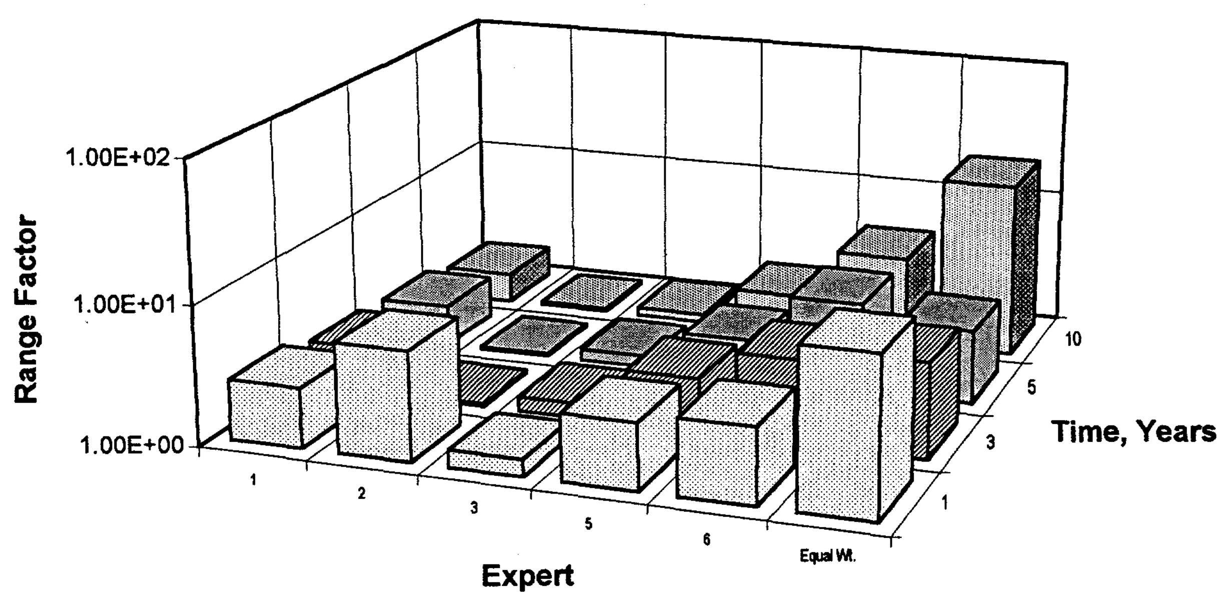

Figure G.18 Range factors (ratio of 95th/5th percentile) for fixation of cesium in generic European soil as a function of time.

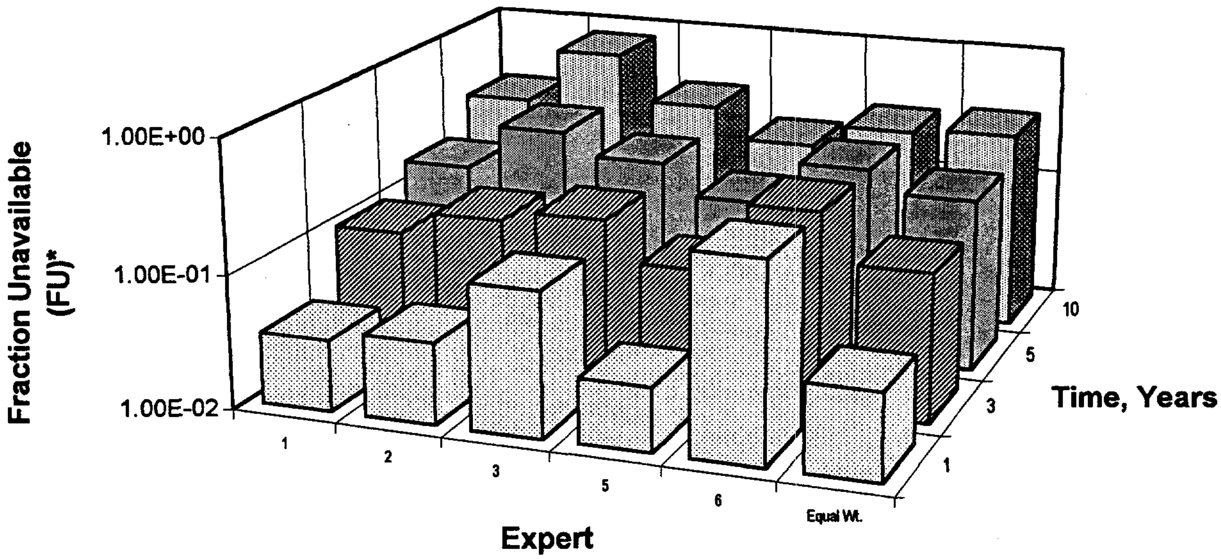

Figure G.19 Median values for fixation of strontium in generic European soil as a function of time.
*** The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.**

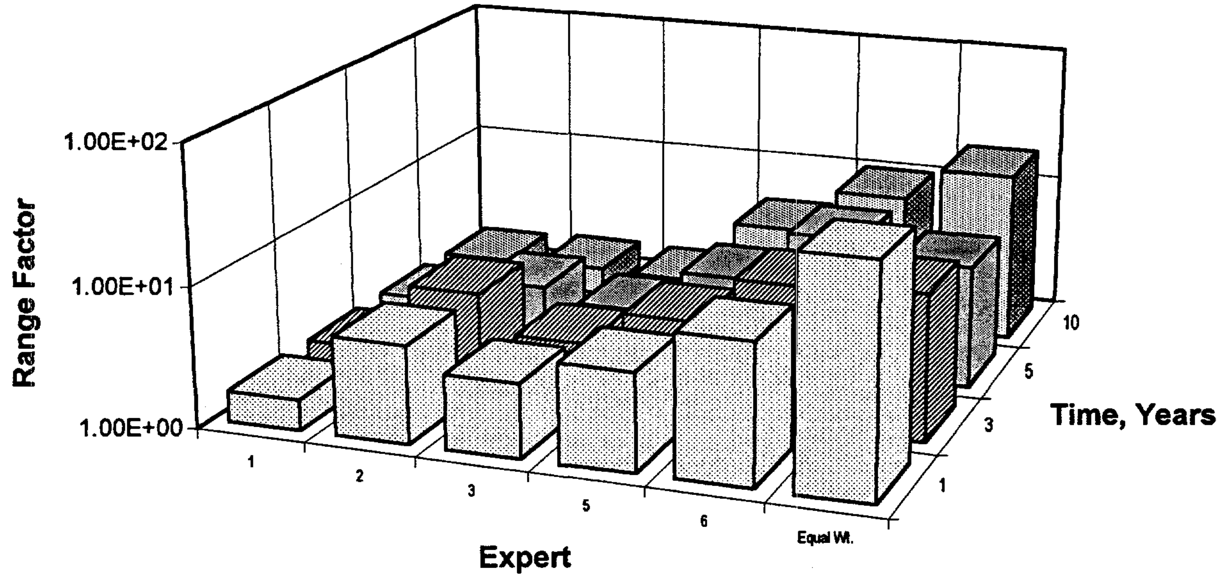

Figure G.20 Range factors (ratio of 95th/5th percentile) for fixation of strontium in generic European soil as a function of time.

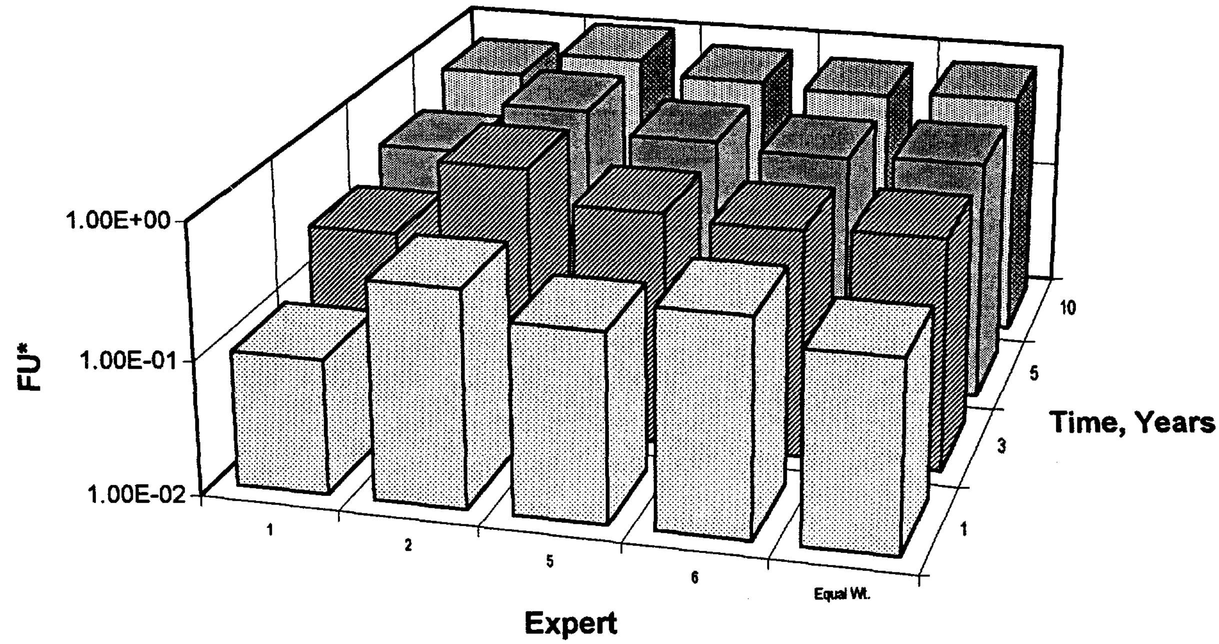

Figure G.21 Median values for fixation of cesium in generic US soil as a function of time. * The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.

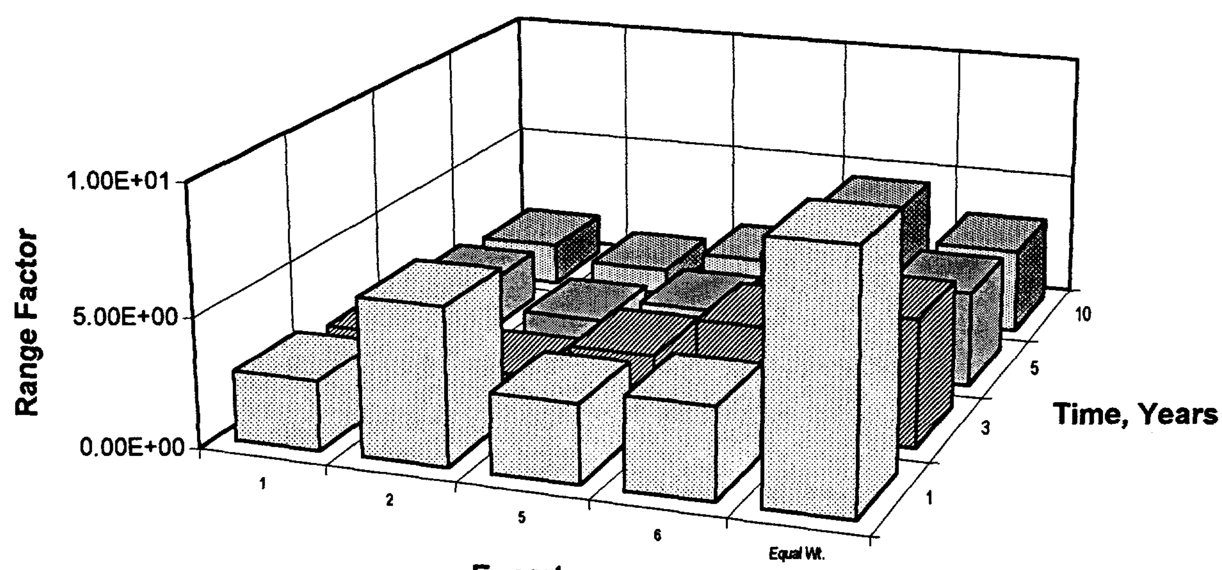

Figure G.22 Range factors (ratio of 95th/5th percentile) for fixation of cesium in generic US soil as a function of time.

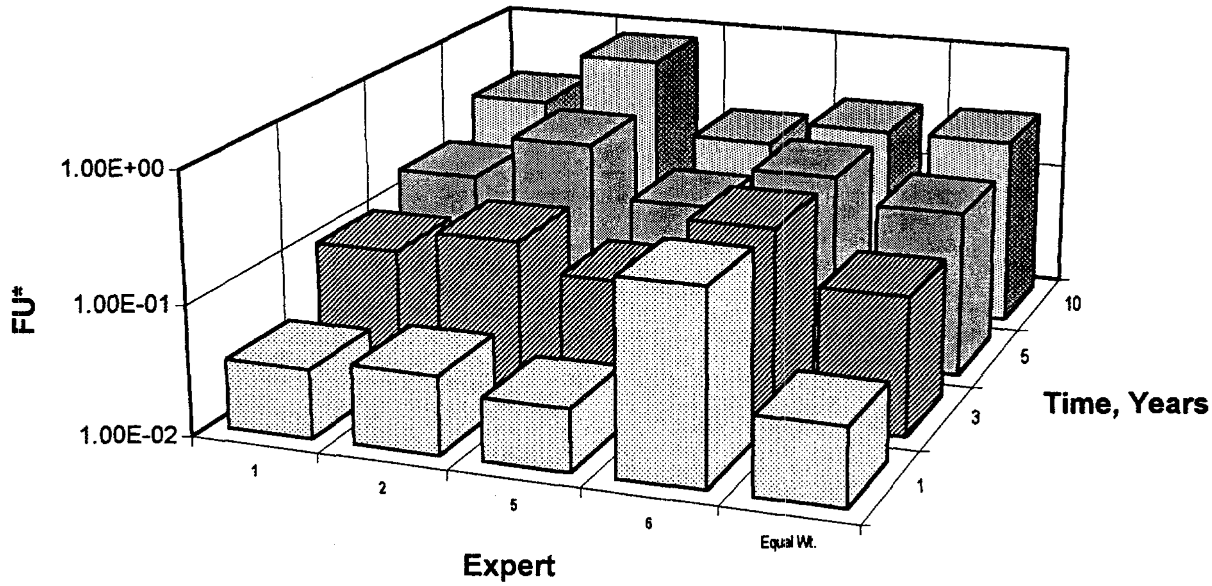

Figure G.23 Median values for fixation of strontium in generic US soil as a function of time. * The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.

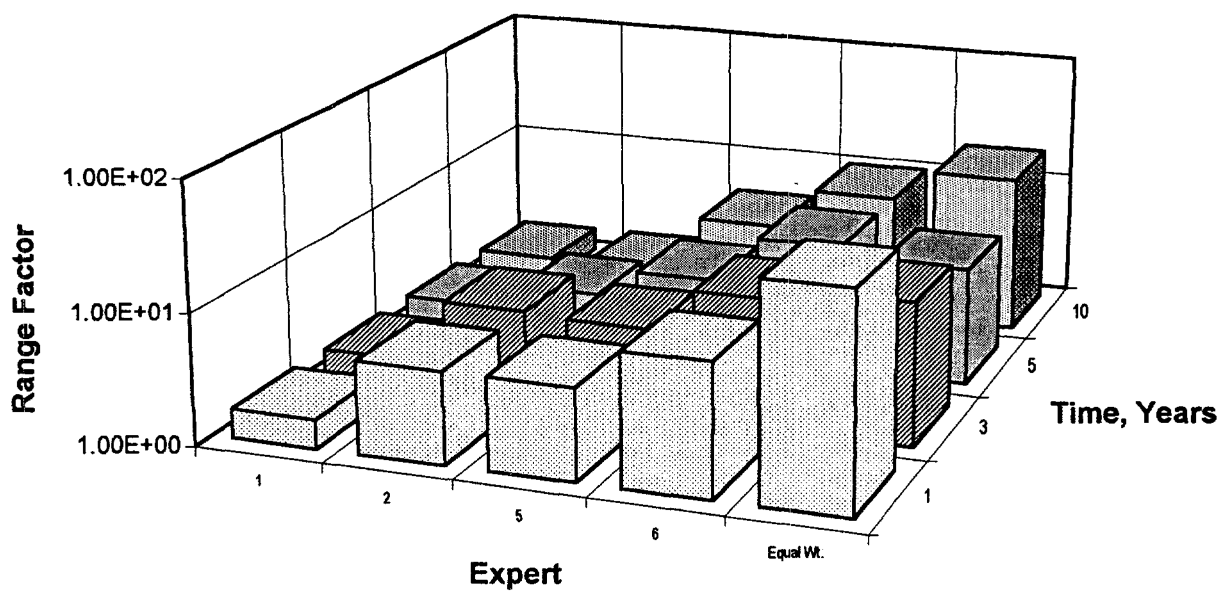

Figure G.24 Range factors (ratio of 95th/5th percentile) for fixation of strontium in generic US soil as a function of time.

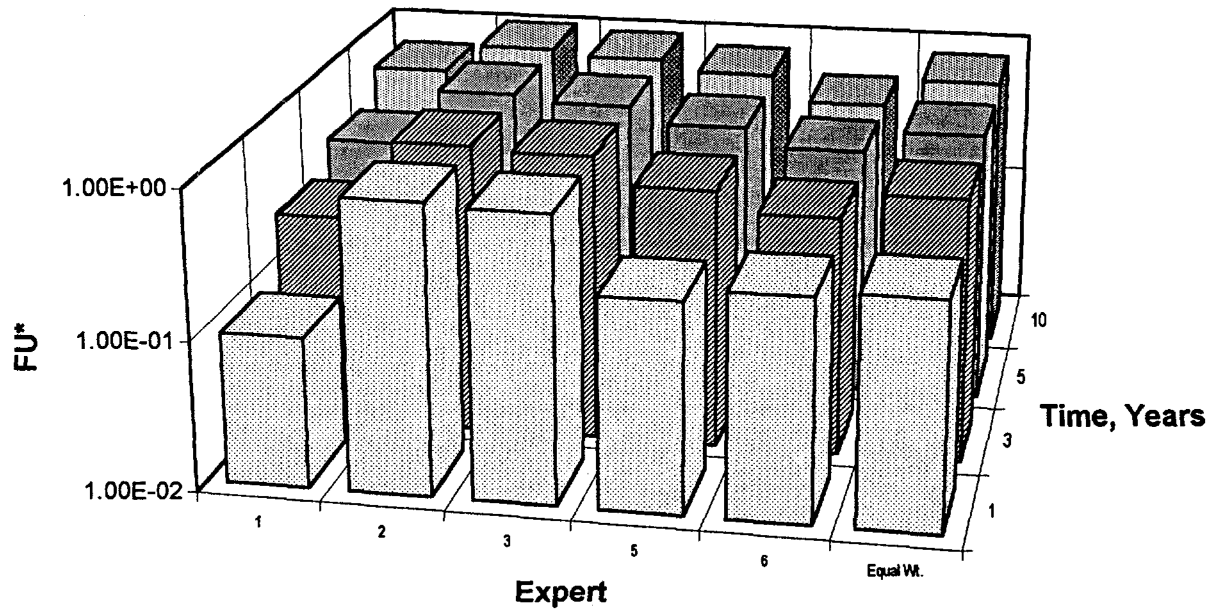

Figure G.25 Median value for fixation of cesium in sandy soil as a function of time. * The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.

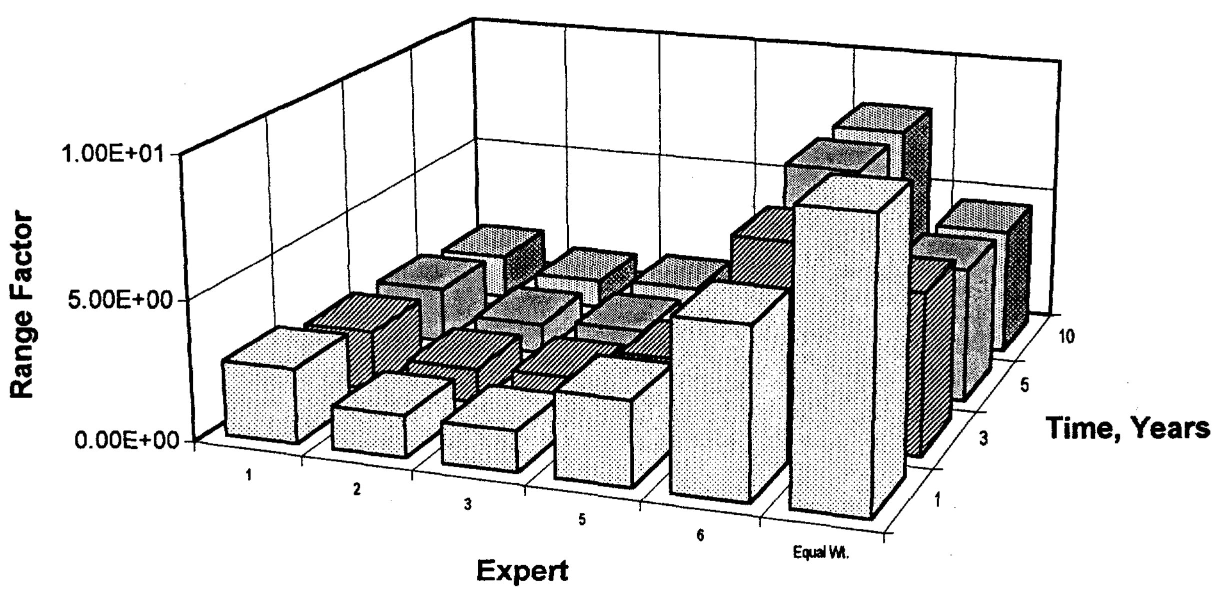

Figure G.26 Range factors (ratio of 95th/5th percentile) for fixation of cesium in sandy soil as a function of time.

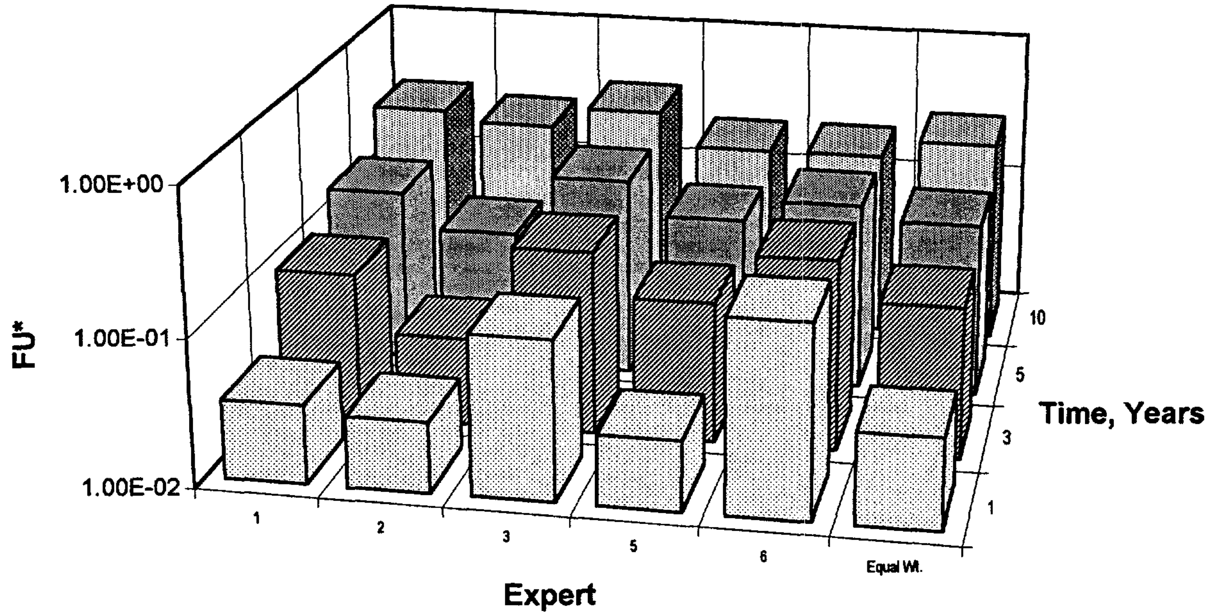

Figure G.27 Median value for fixation of strontium in sandy soil as a function of time. * The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.

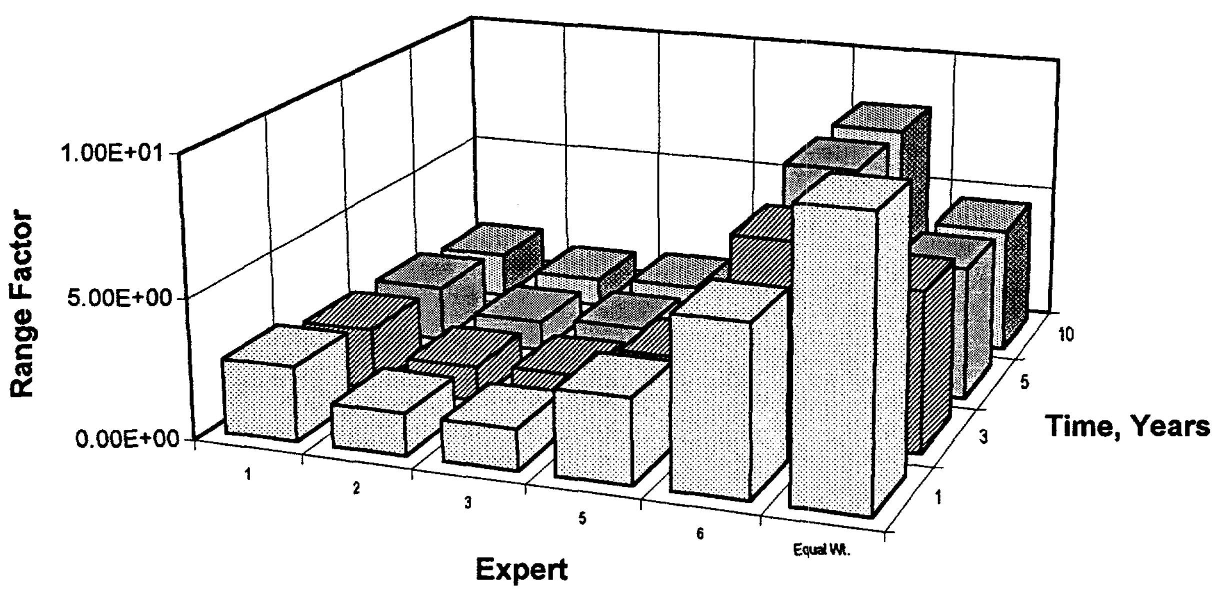

Figure G.28 Range factors (ratio of 95th/5th percentile) for fixation of strontium in sandy soil as a function of time.

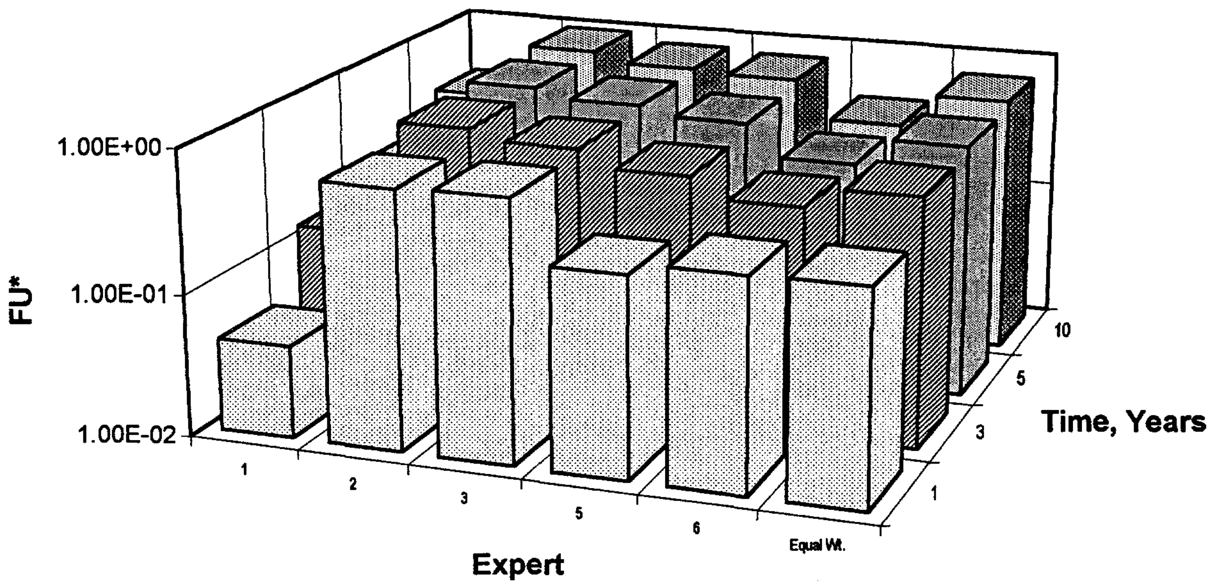

Figure G.29 Median values for fixation of cesium in highly organic soil as a function of time. * The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.

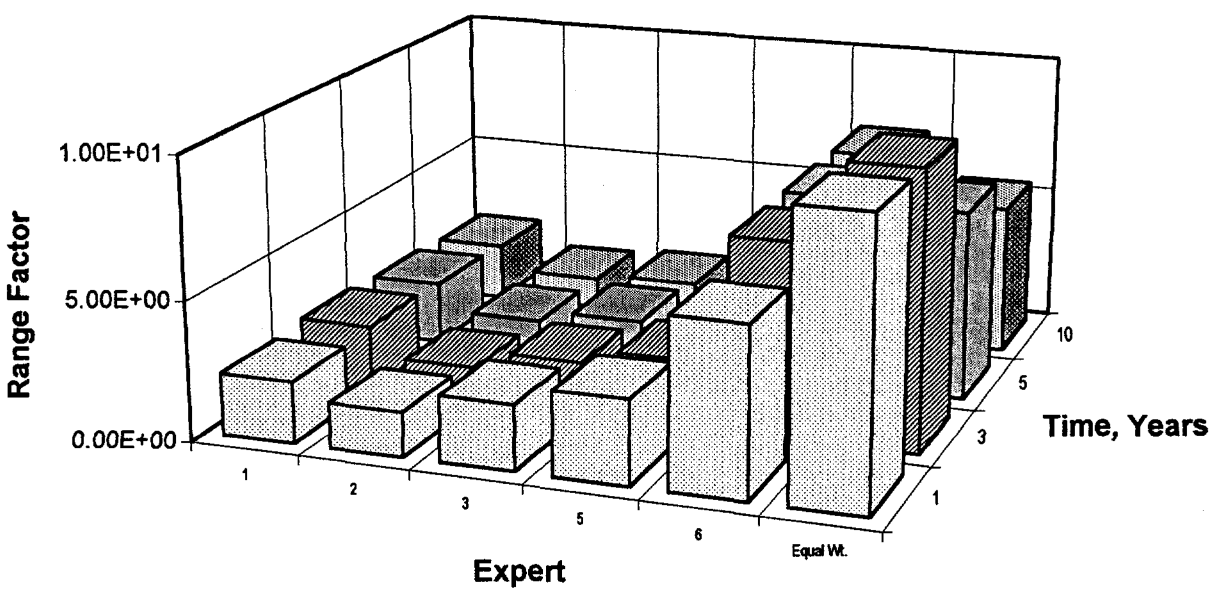

Figure G.30 Range factors (ratio of 95th/5th percentile) for fixation of cesium in highly organic soil as a function of time.

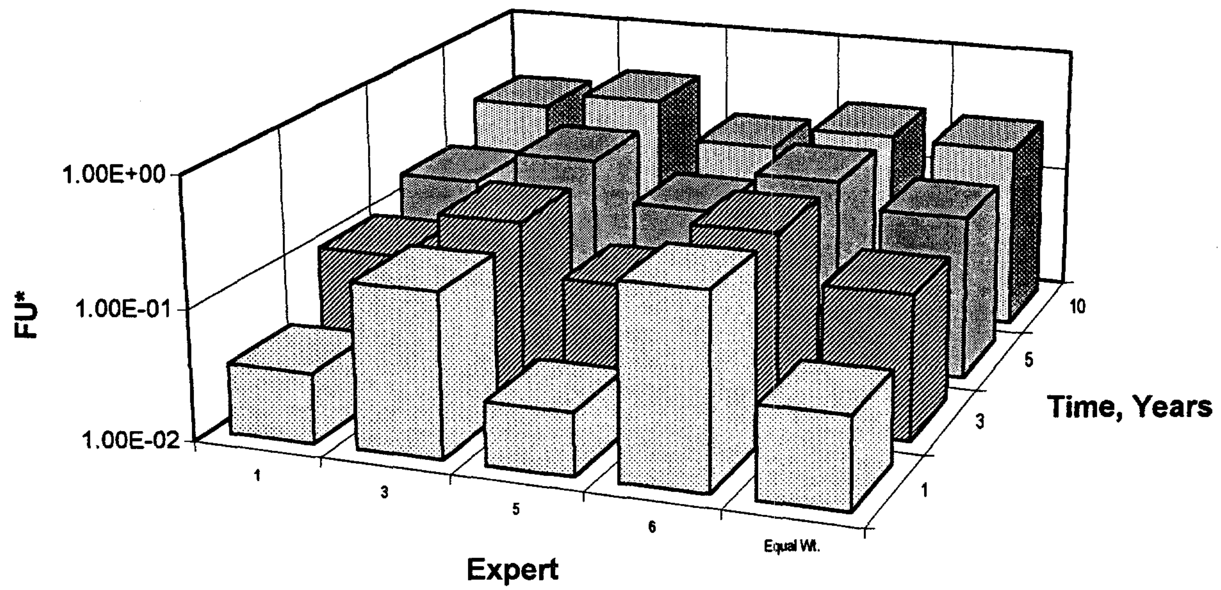

Figure G.31 Median values for fixation of strontium in highly organic soil as a function of time. * The variable representing fixation in soil is expressed as the fraction of the element that is unavailable for uptake by plant roots at the specified time following deposition.

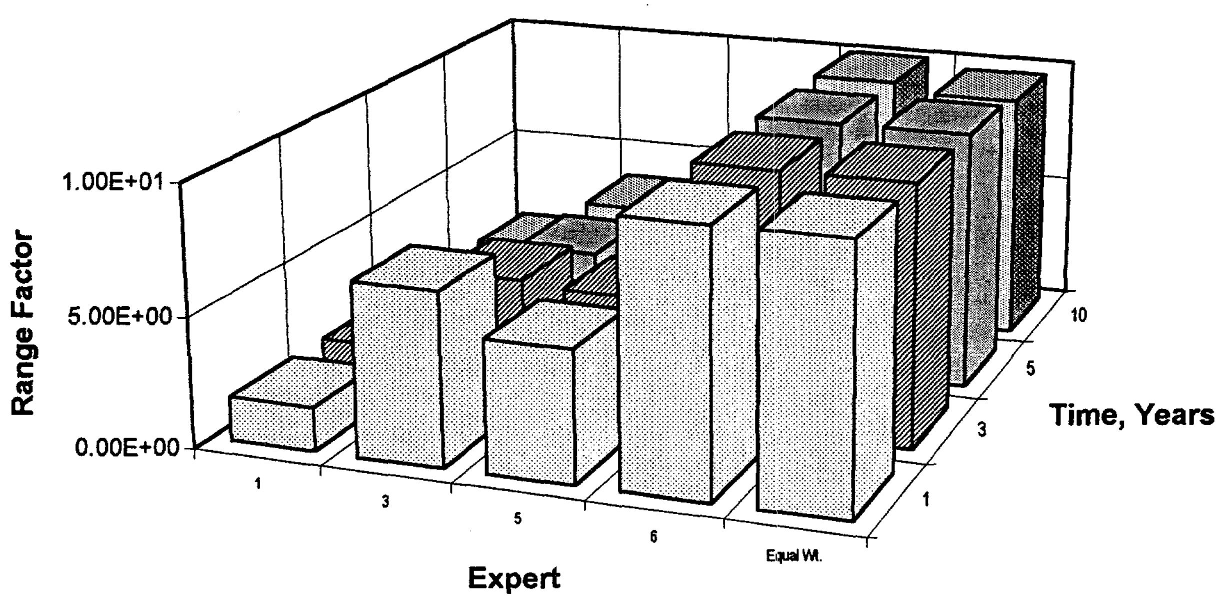

Figure G.32 Range factors (ratio of 95th/5th percentile) for fixation of strontium in highly organic soil as a function of time.

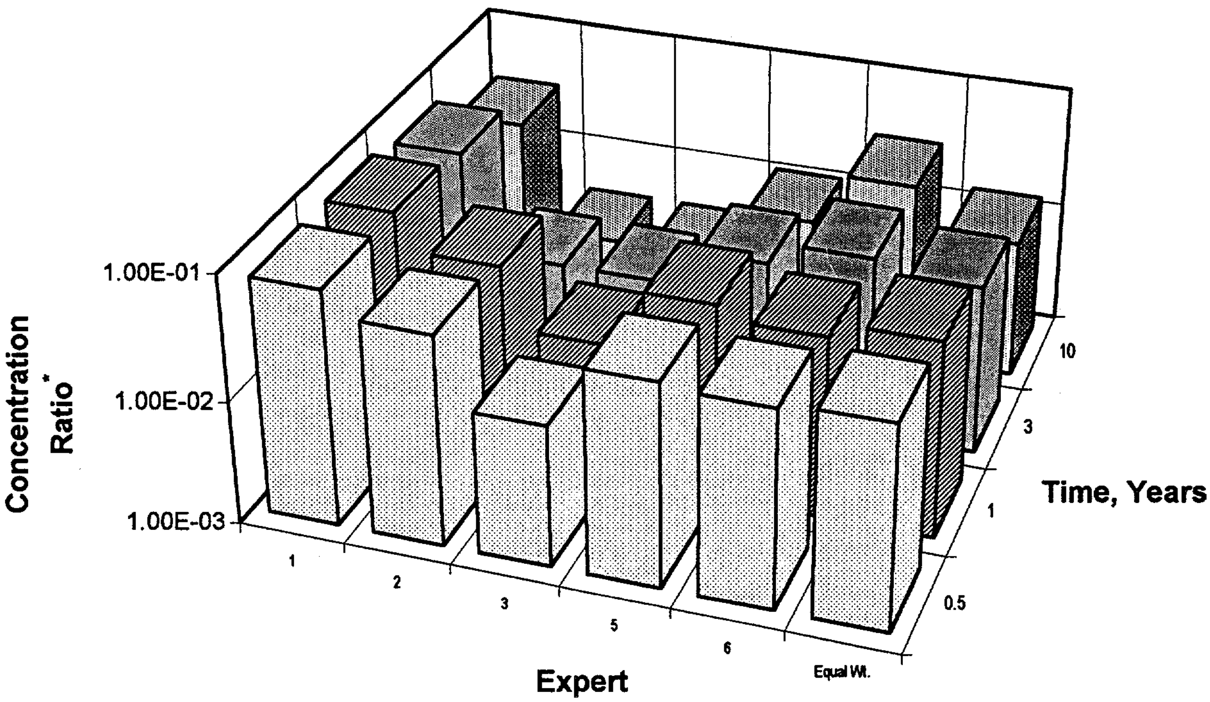

Figure G.33 Median values for soil to plant uptake of cesium in green vegetables for generic European soil as function of time. * Concentration ratio is expressed as Bq kg-1 fresh mass plant per Bq kg-1 dry mass soil.

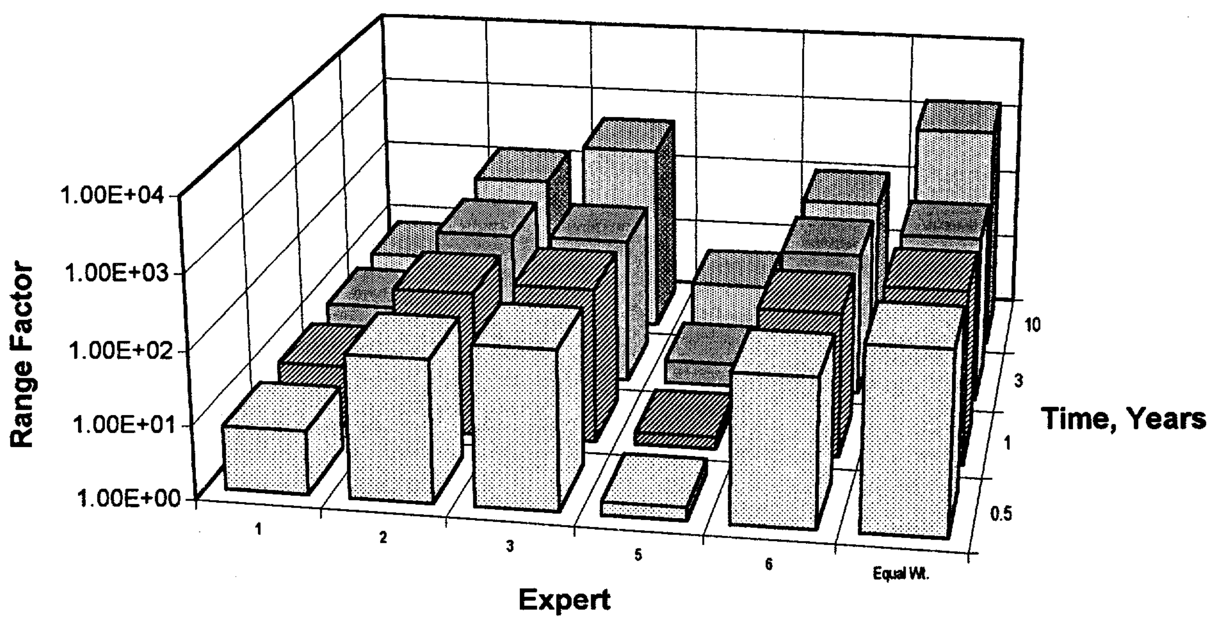

Figure G.34 Range factors (ratio of 95th/5th percentile) for soil to plant uptake of cesium in green vegetables for generic European soil as a function of time.

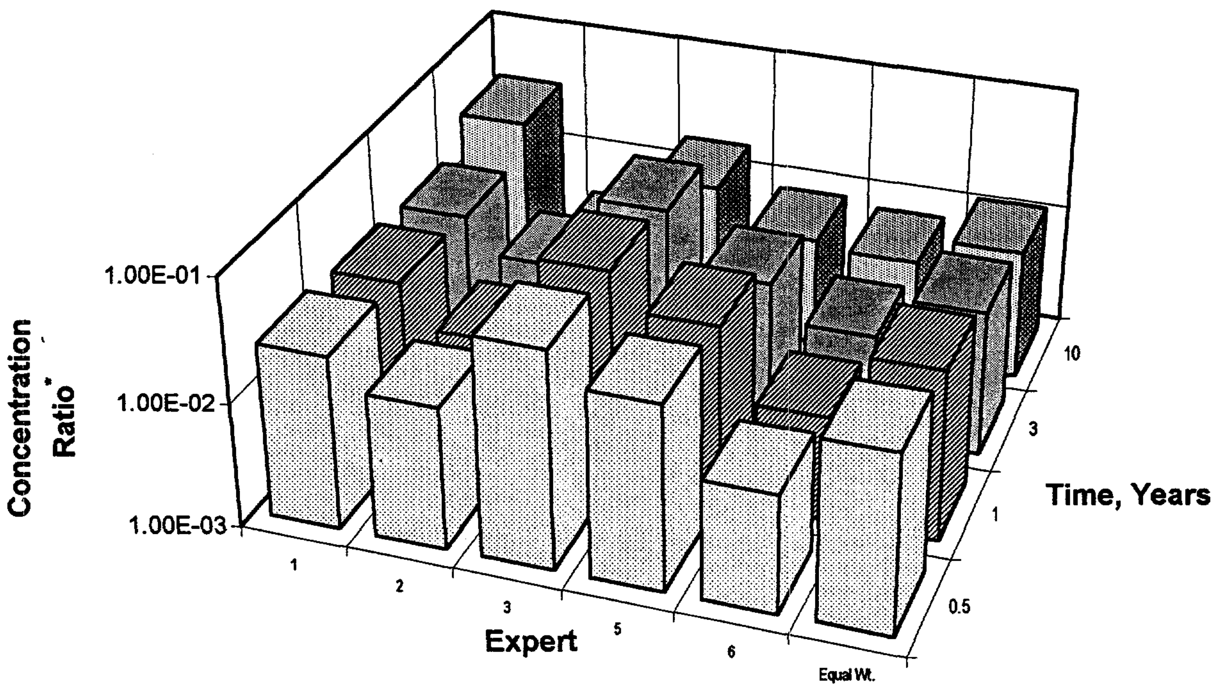

Figure G.35 Median values for soil to plant uptake of cesium in grain for generic European soil as a function of time. * Concentration ratio is expressed as Bq kg-1 fresh mass plant per Bq kg-1 dry mass soil.

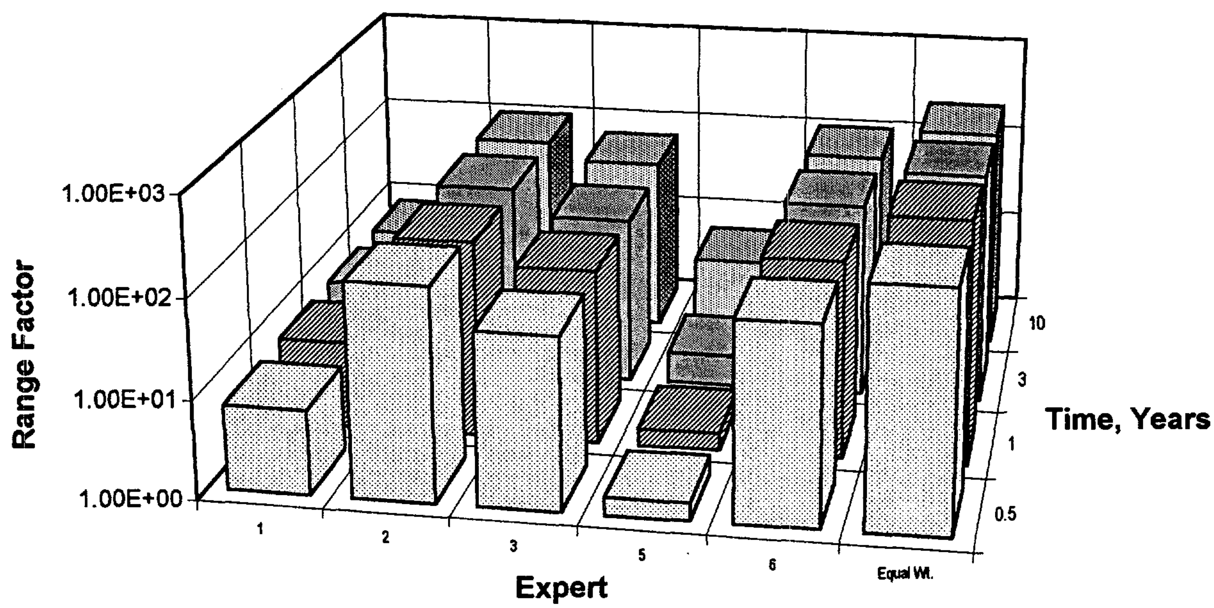

Figure G.36 Range factors (ratio of 95th/5th percentile) for soil to plant uptake of cesium in grain for generic European soil as a function of time.

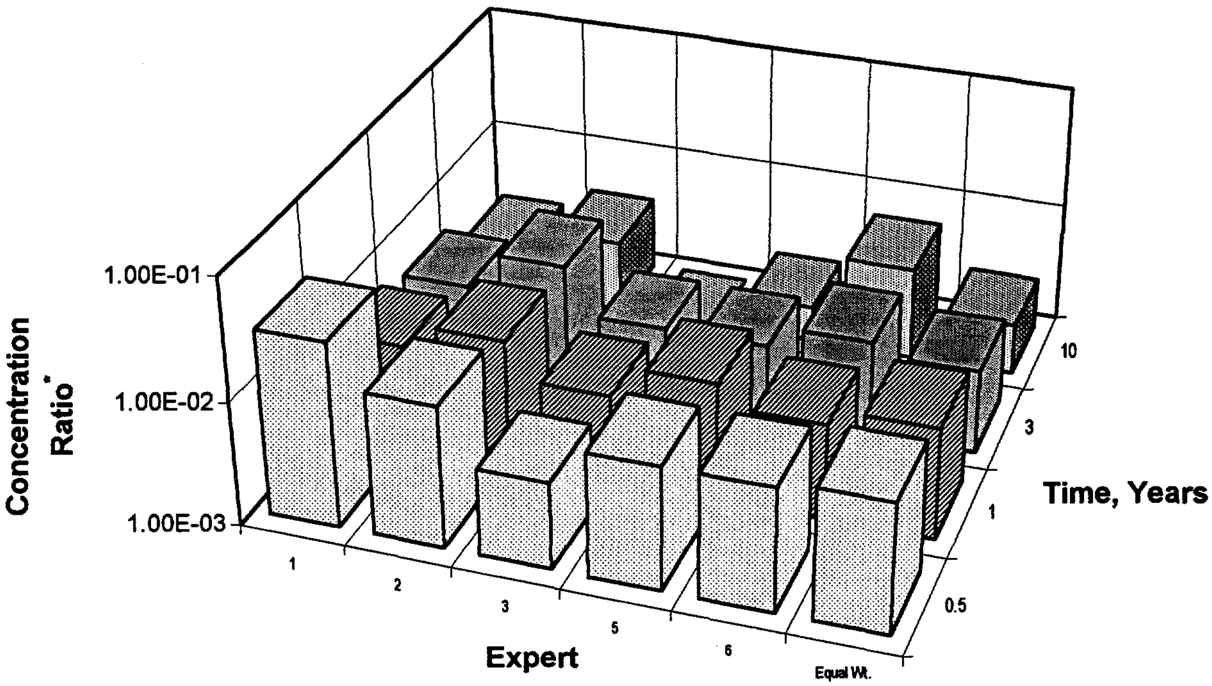

Figure G.37 Median values for soil to plant uptake of cesium in root vegetables for generic European soil as a function of time. * Concentration ratio is expressed as Bq kg-1 fresh mass plant per Bq kg-1 dry mass soil.

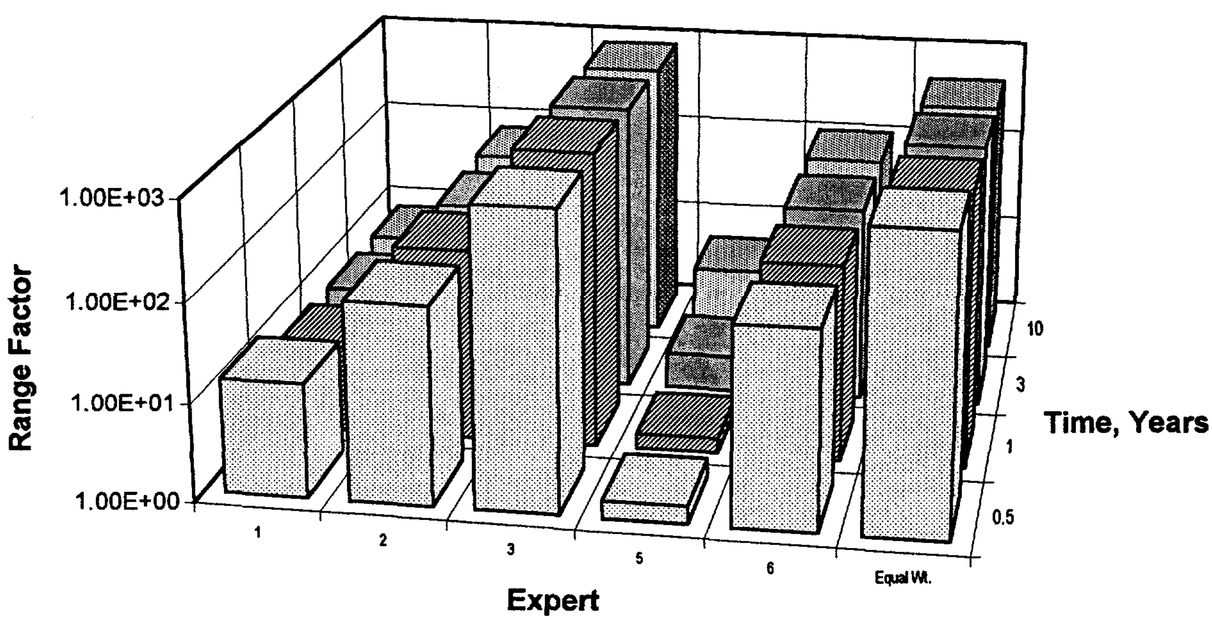

Figure G.38 Range factors (ratio of 95th/5th percentile) for soil to plant uptake of cesium in root vegetables for generic European soil as a function of time.

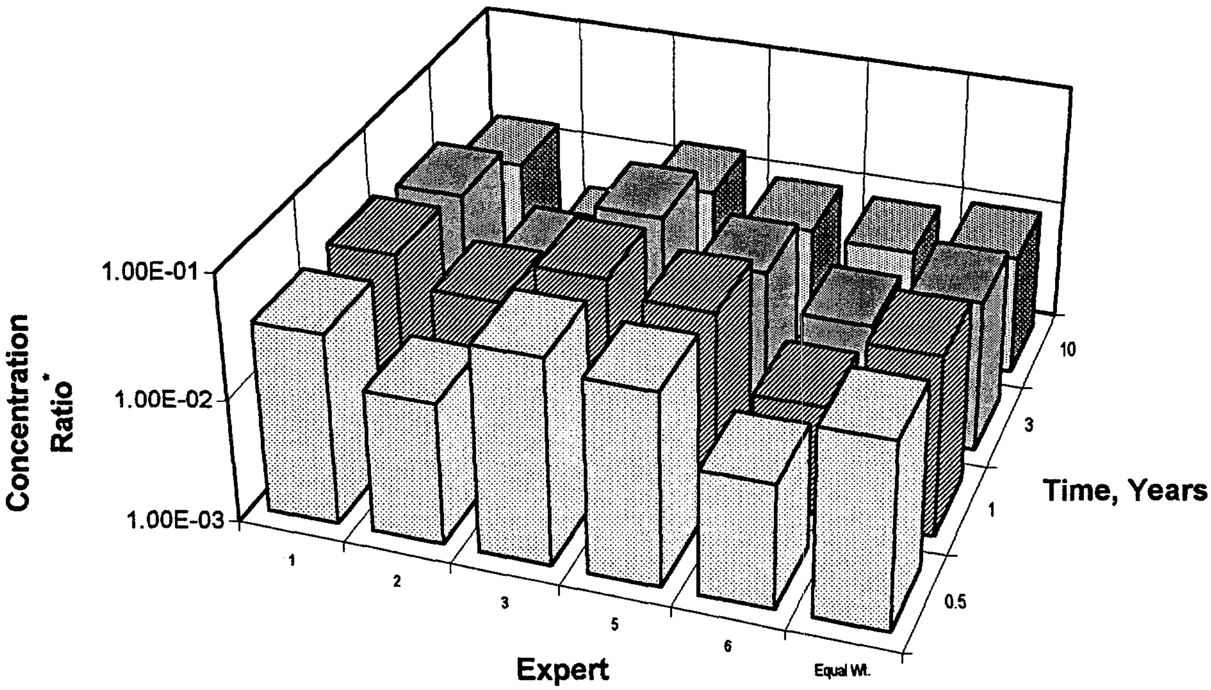

Figure G.39 Median values for soil to plant uptake of cesium in potatoes for generic European soil as a function of time. * Concentration ratio is expressed as Bq kg-1 fresh mass plant per Bq kg-1 dry mass soil.

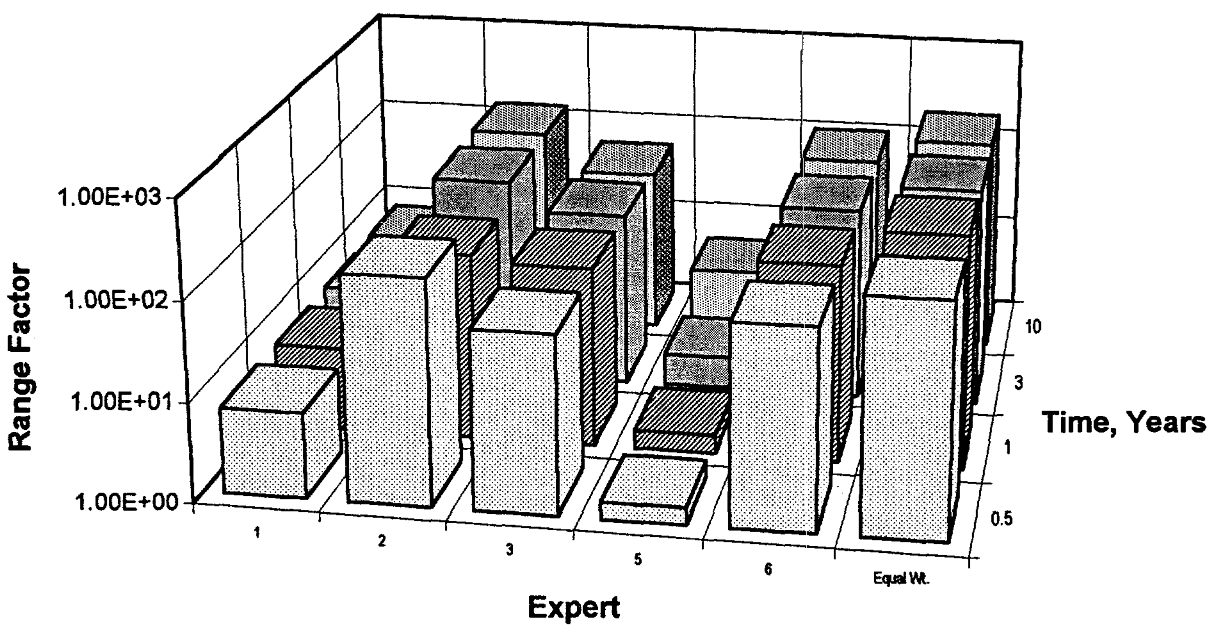

Figure G.40 Range factors (ratio of 95th/5th percentile) for soil to plant uptake of cesium in potatoes for generic European soil as a function of time.

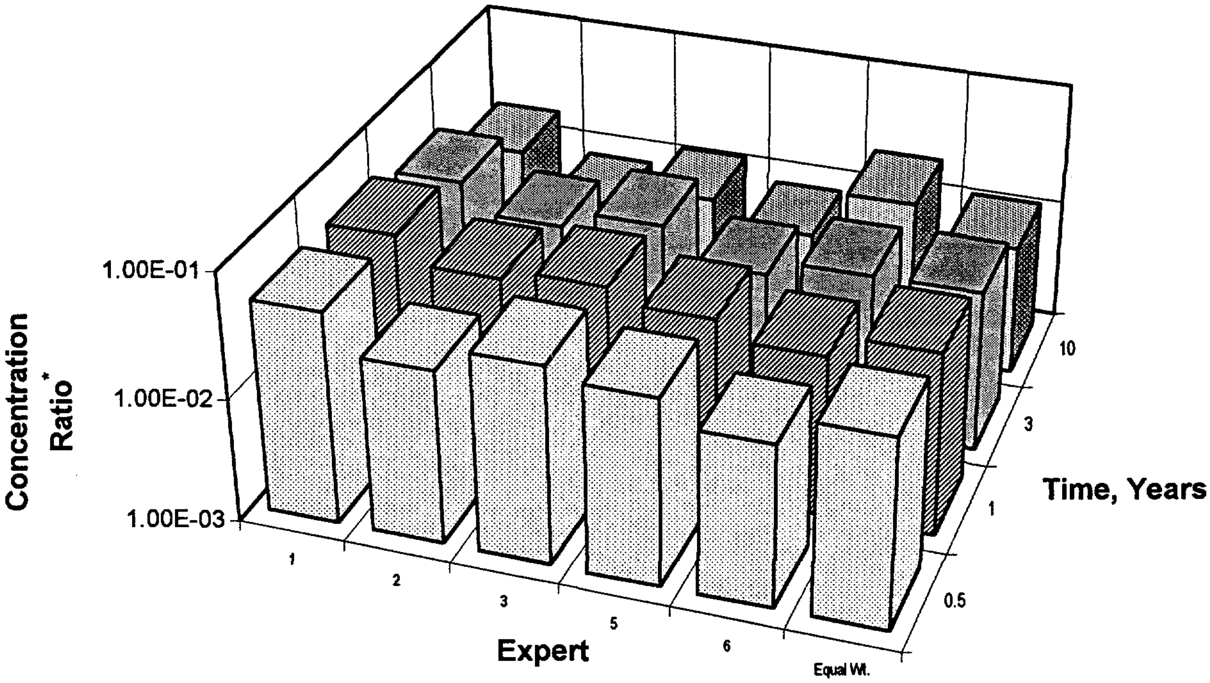

Figure G.41 Median values for soil to plant uptake of cesium in pasture grass for generic European soil as a function of time. * Concentration ratio is expressed as Bq kg-1 fresh mass plant per Bq kg-1 dry mass soil.

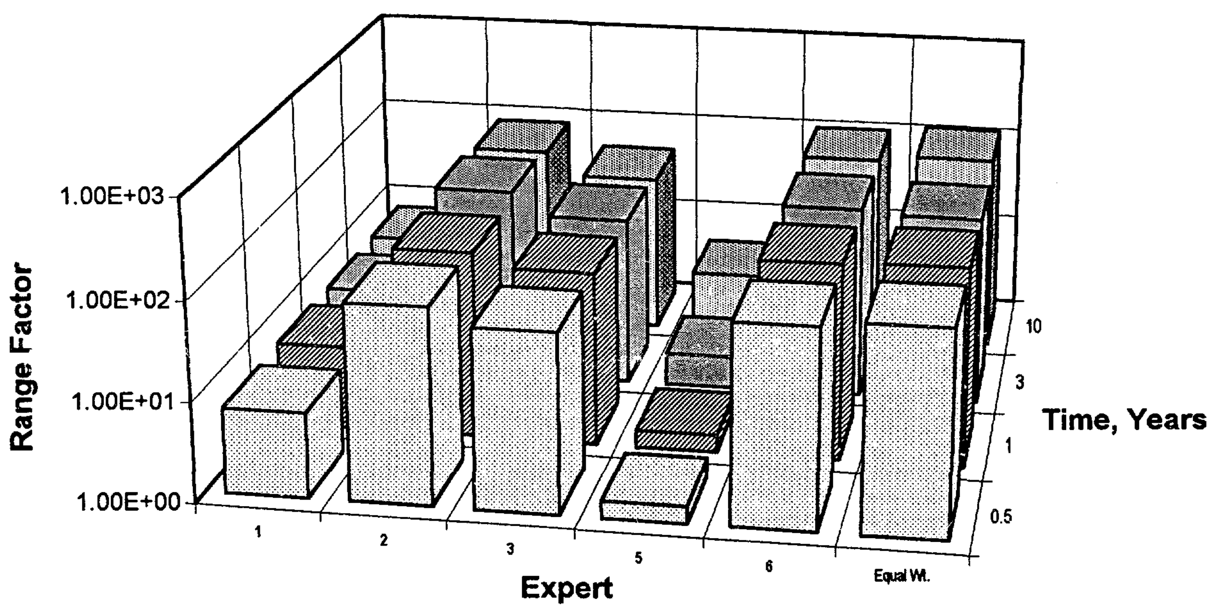

Figure G.42 Range factors (ratio of 95th/5th percentile) for soil to plant uptake of cesium in pasture grass for generic European soil as a function of time.

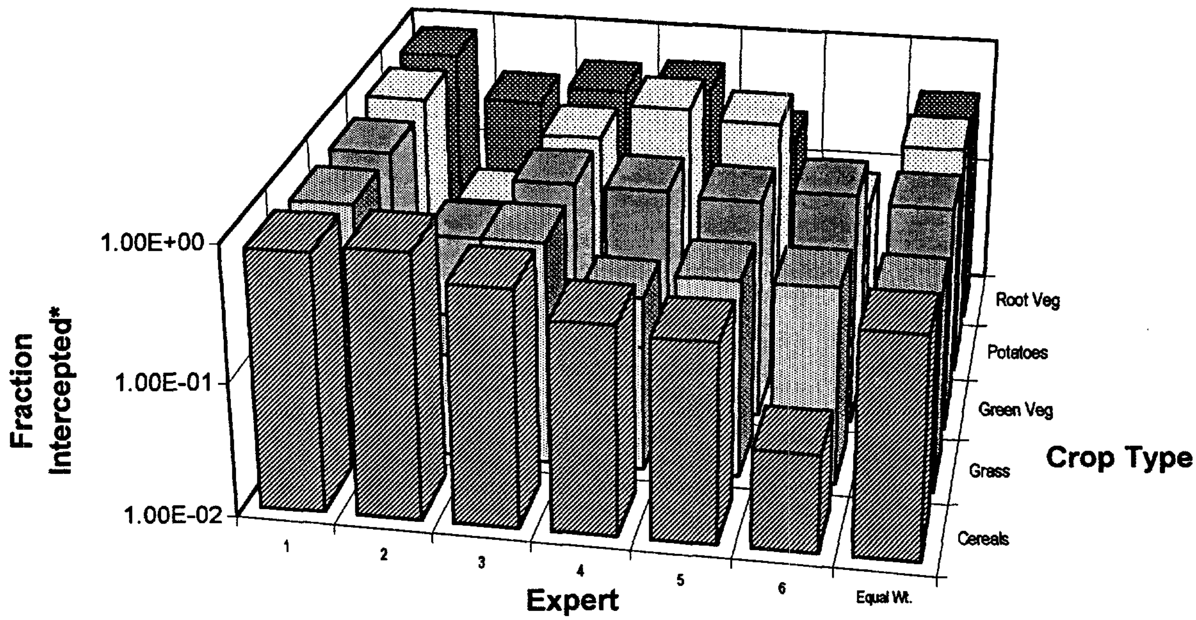

Figure G.43 Median values for element independent interception factors for five crops. * The interception factor is the fraction of the ground deposit that is intercepted by the plant at maturity.

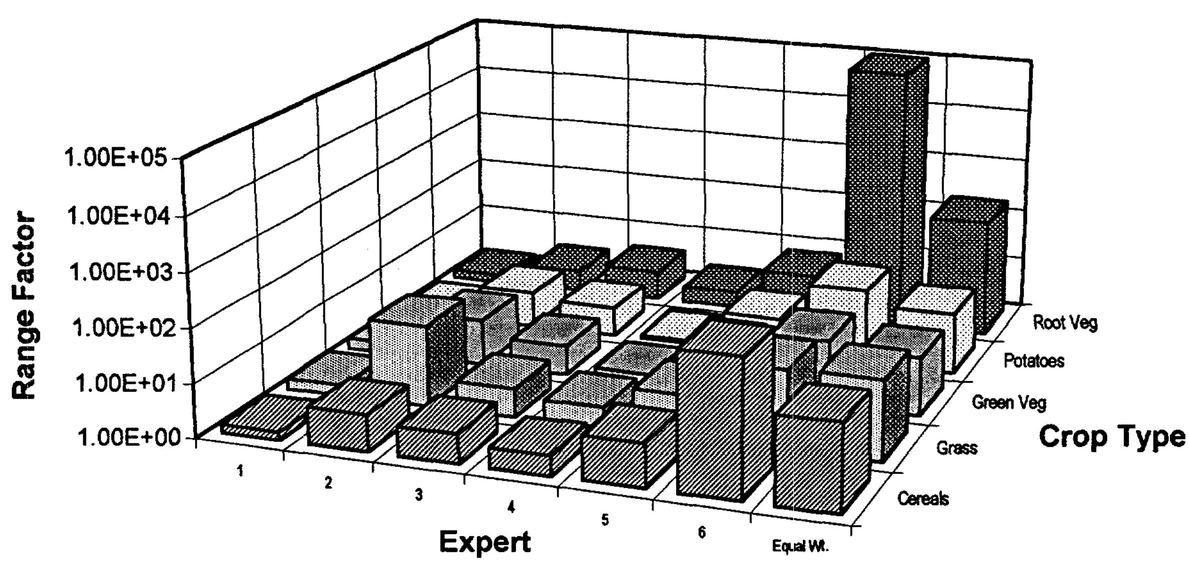

Figure G.44 Range factors (ratio of 95th/5th percentile) for element independent interception factors for five crops.

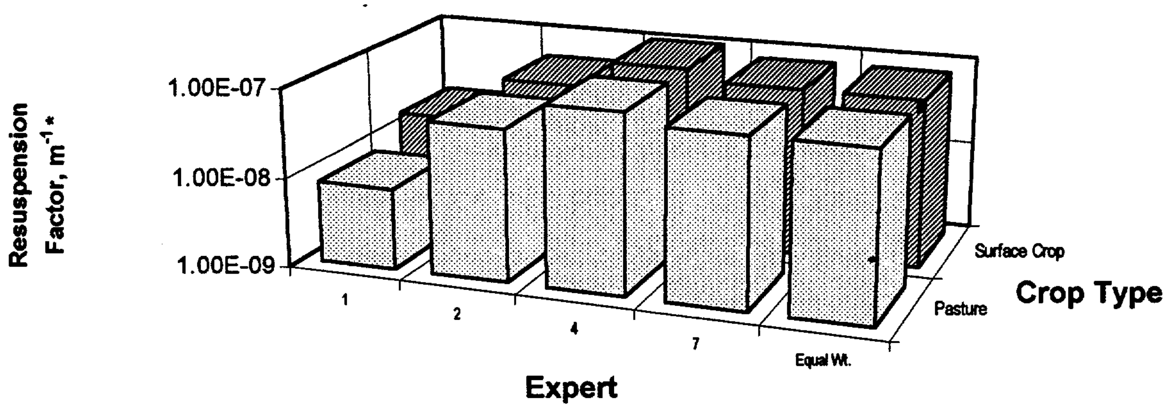

Figure G.45 Median values for resuspension factors for surface crops and pasture. * Resuspension factor is the ratio of the concentration in air (Bq/M3) 1 m above ground surface to the concentration deposited on the ground (Bq/m2).

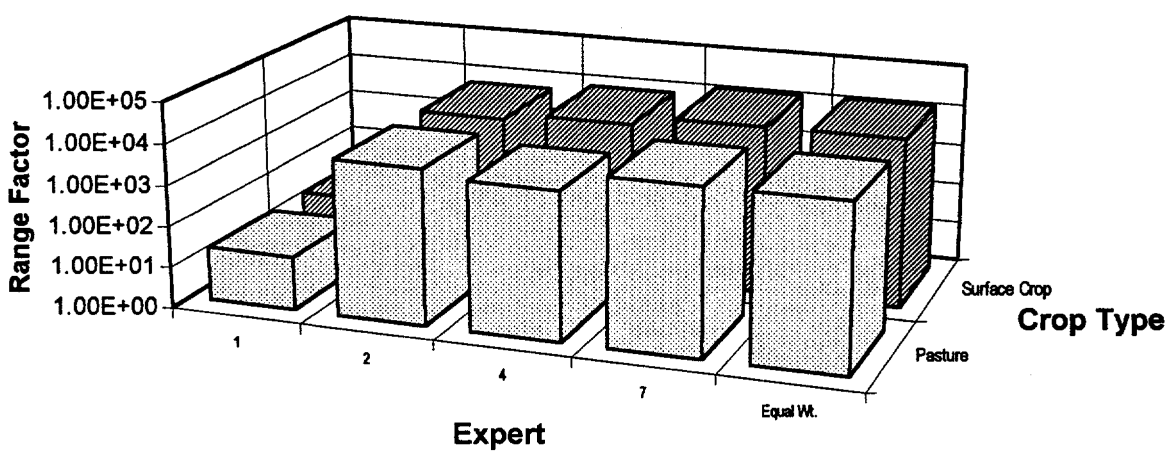

Figure G.46 Range factors (ratio of 95th/5th percentile) for resuspension factors for surface crops and pasture.

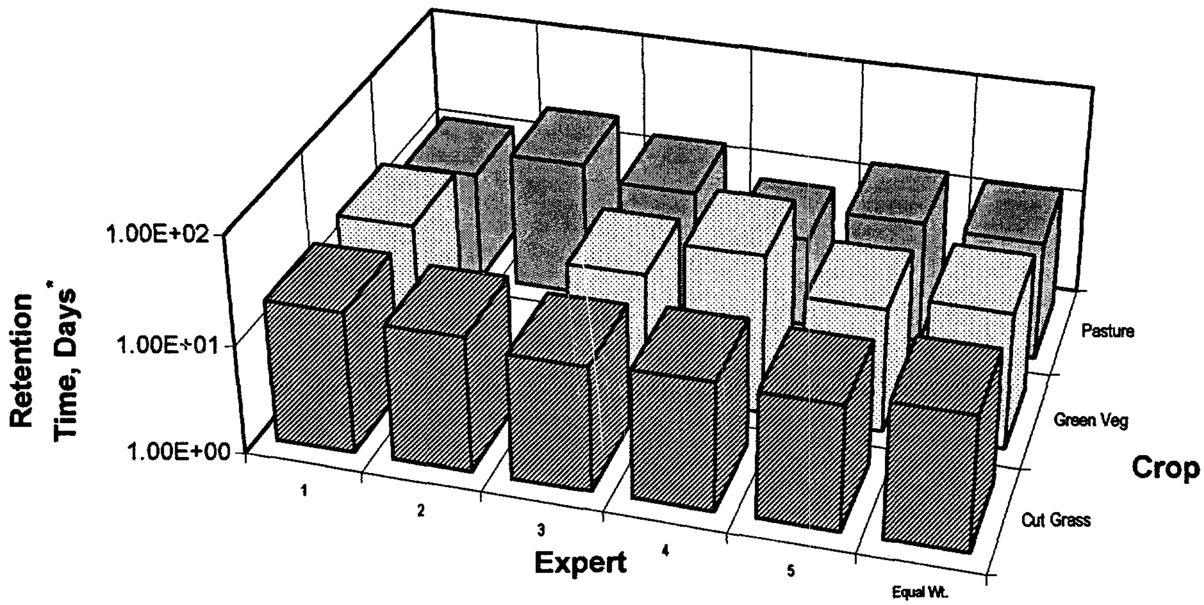

Figure G.47 Median values for element dependent retention times on three crops. *Retention time is expressed as the time taken for half the activity on the surface of the plant to be reduced to half of its original value.

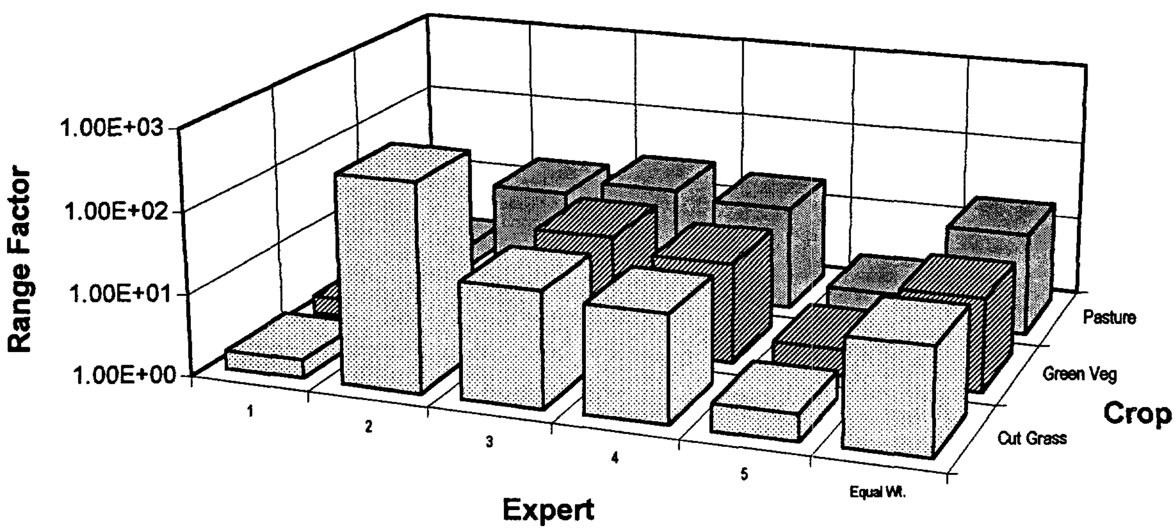

Figure G.48 Range factors (ratio of 95th/5th percentile) for element dependent retention times on three crops.

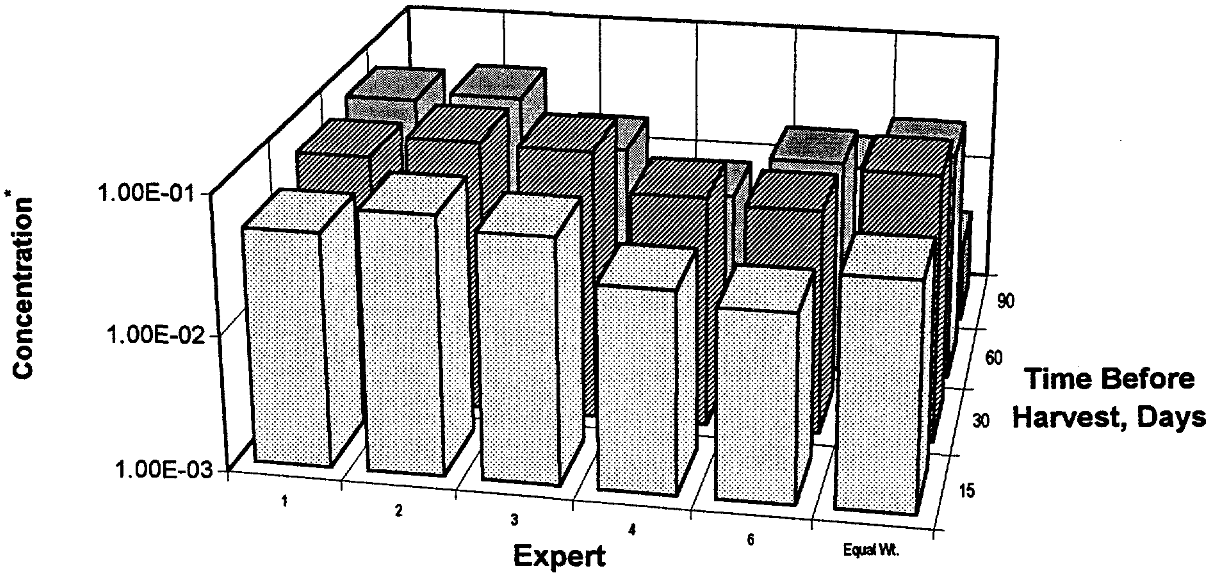

Figure G.49 Median values for the concentration of cesium in grain at harvest from direct contamination of the crop at specified times before harvest. * The concentration is expressed as Bq kg-1 fresh mass of edible grain at harvest per Bq m-2 deposited on the ground.

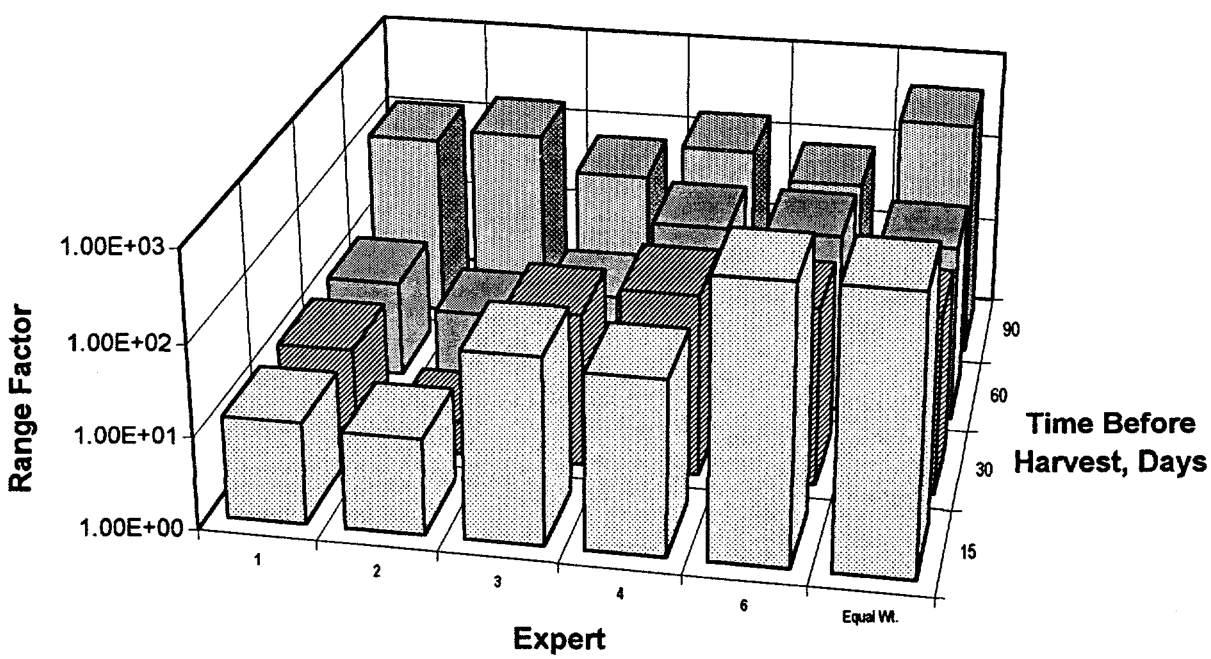

Figure G.50 Range factors (ratio of 95th/5th percentile) for the concentration of cesium in grain from direct contamination of the crop at specified times before harvest.

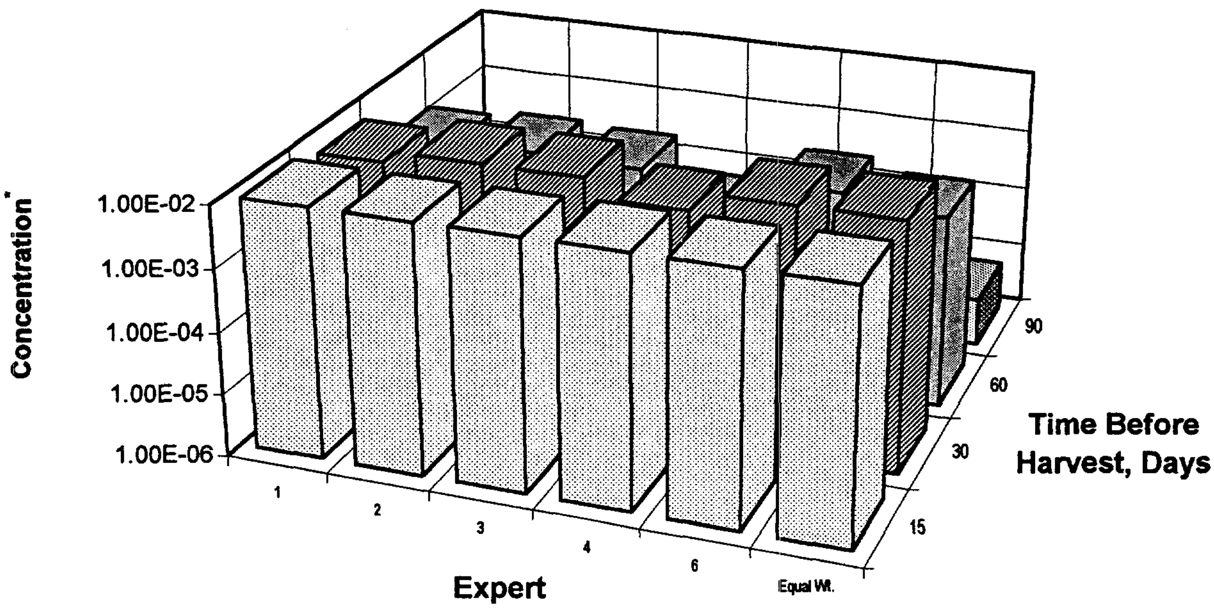

Figure G.51 Median values for the concentration of strontium in grain at harvest from direct contamination of the crop at specified times before harvest. * The concentration is expressed as Bq kg-1 fresh mass of edible grain at harvest per Bq m-2 deposited on the ground.

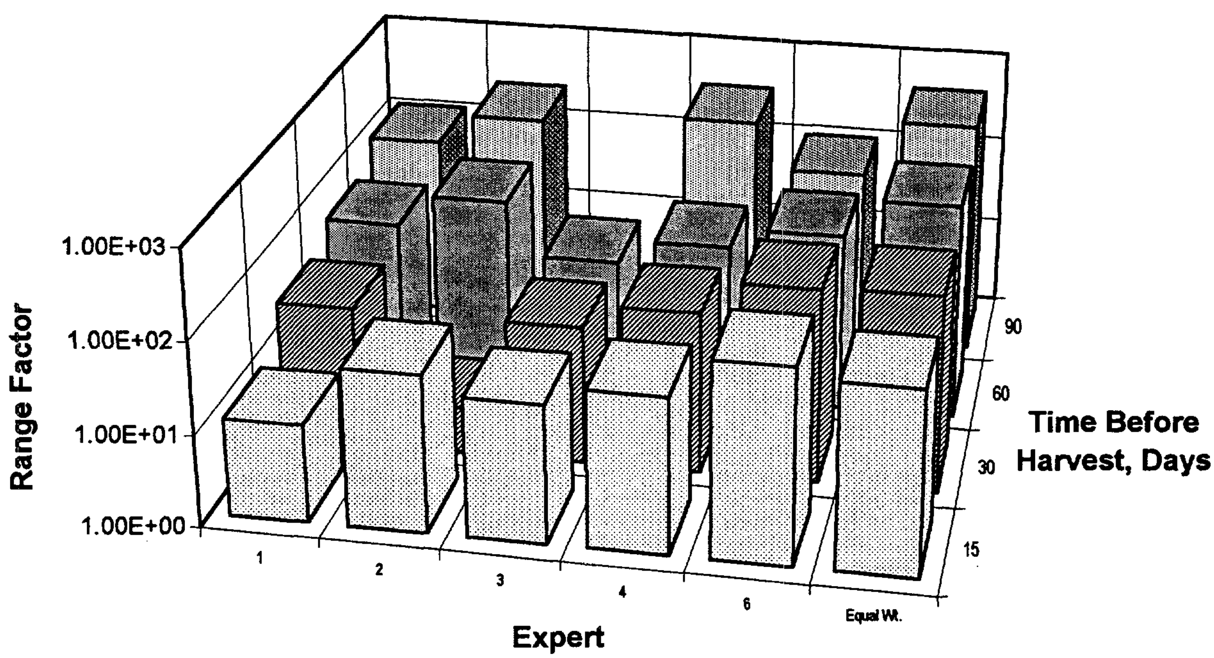

Figure G.52 Range factors (ratio of 95th/5th percentile) for the concentration of strontium in grain at harvest from direct contamination of the crop at specified times before harvest.

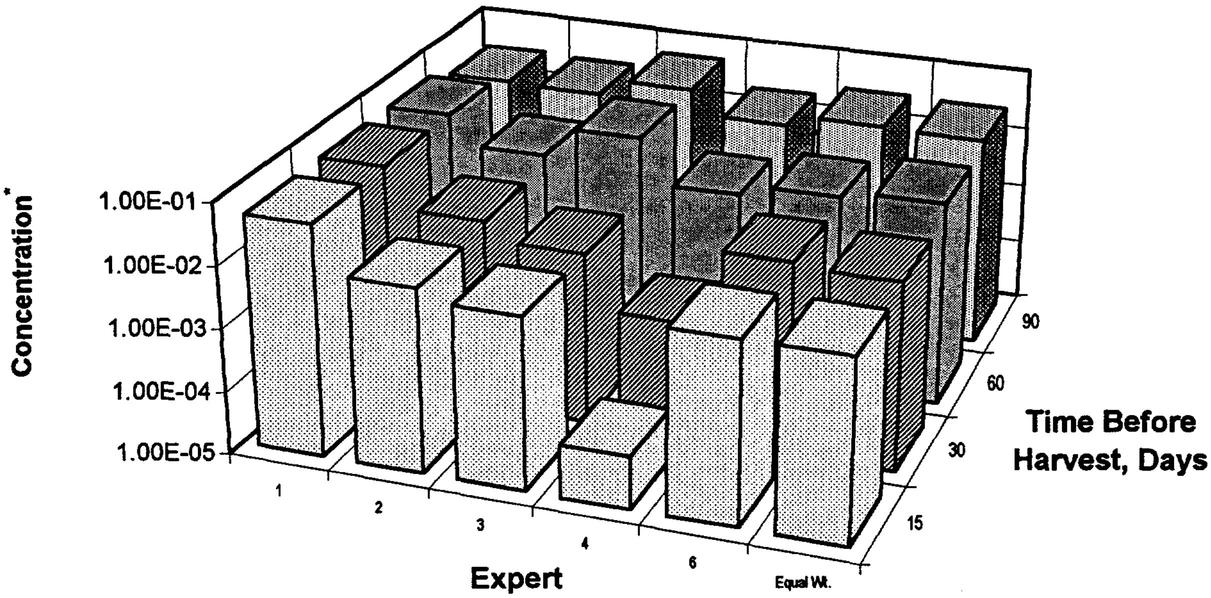

Figure G.53 Median values for the concentration of cesium in root vegetables at harvest from direct contamination of the crop at specified times before harvest. * The concentration is expressed as Bq kg-1 fresh mass of edible root vegetables at harvest per Bq m-2 deposited on the ground.

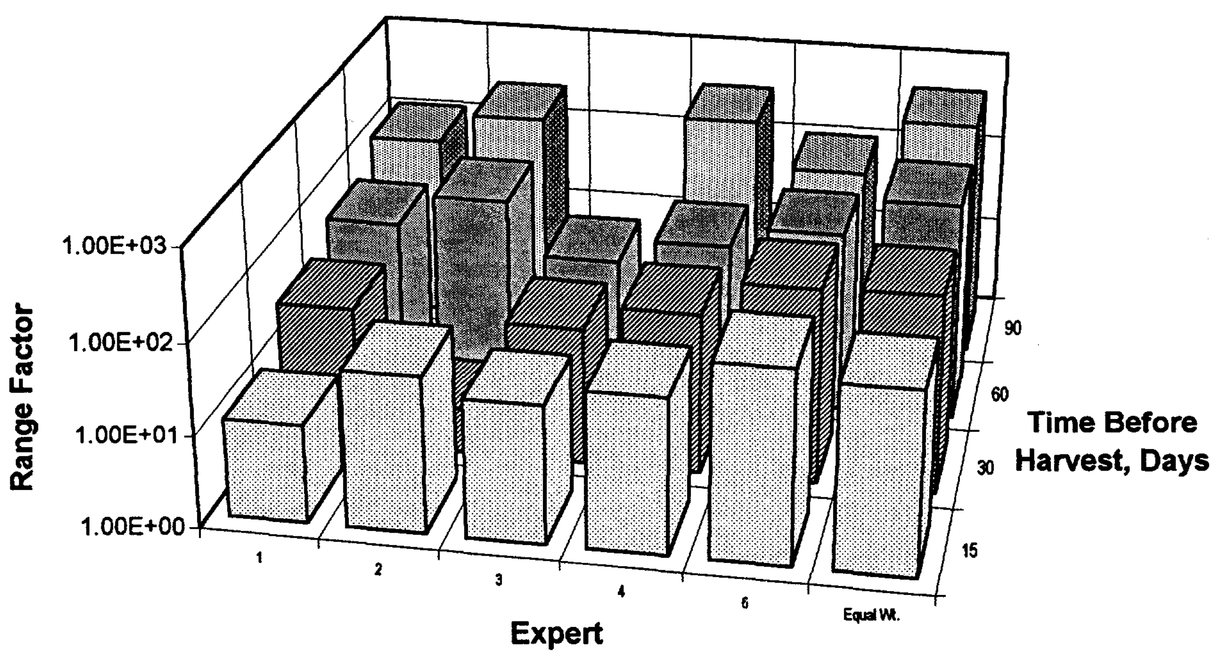

Figure G.54 Range factors (ratio of 95th/5th percentile) for the concentration of cesium in root vegetables at harvest from direct contamination of the crop at specified times before harvest.

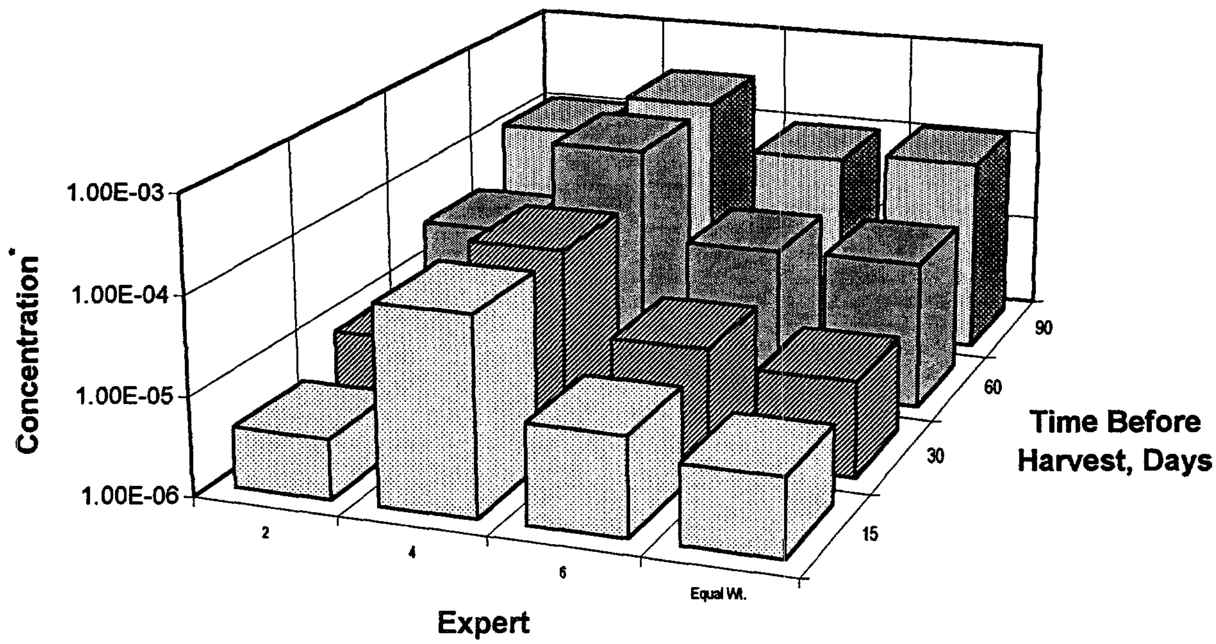

Figure G.55 Median values for the concentration of strontium in root vegetables at harvest from direct contamination of the crop at specified times before harvest. * The concentration is expressed as Bq kg-1 fresh mass of edible root vegetables at harvest per Bq m-2 deposited on the ground.

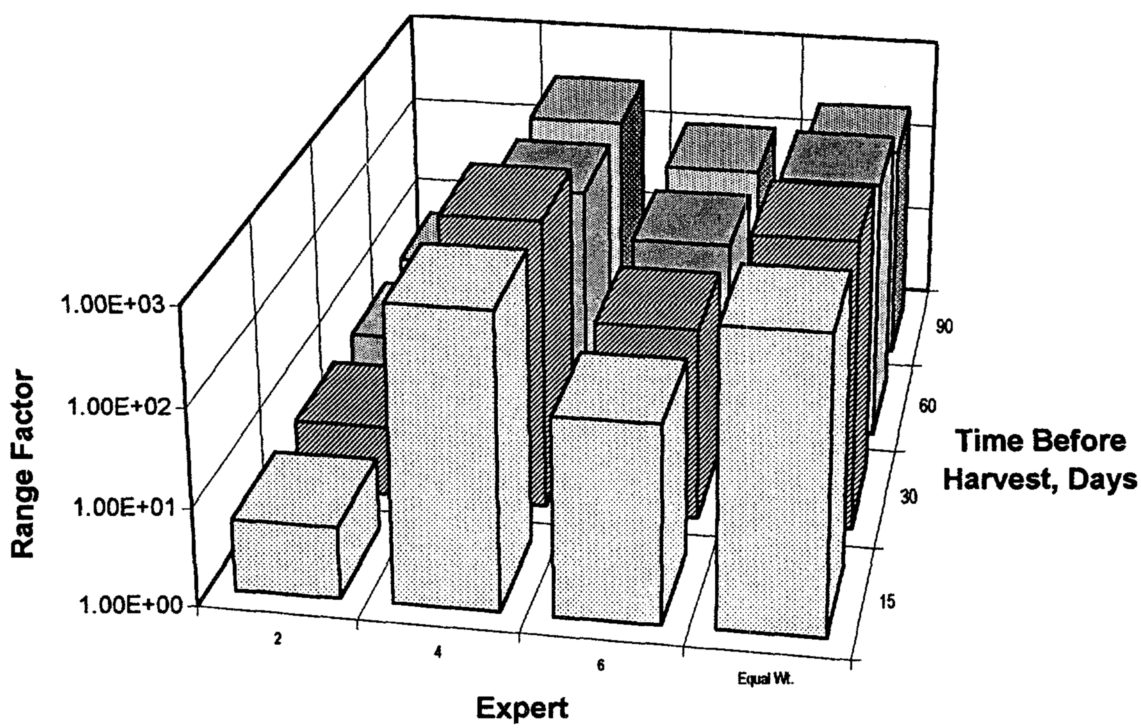

Figure G.56 Range factors (ratio of 95th/5th percentile) for the concentration of strontium in root vegetables at harvest from direct contamination of the crop at specified times before harvest.

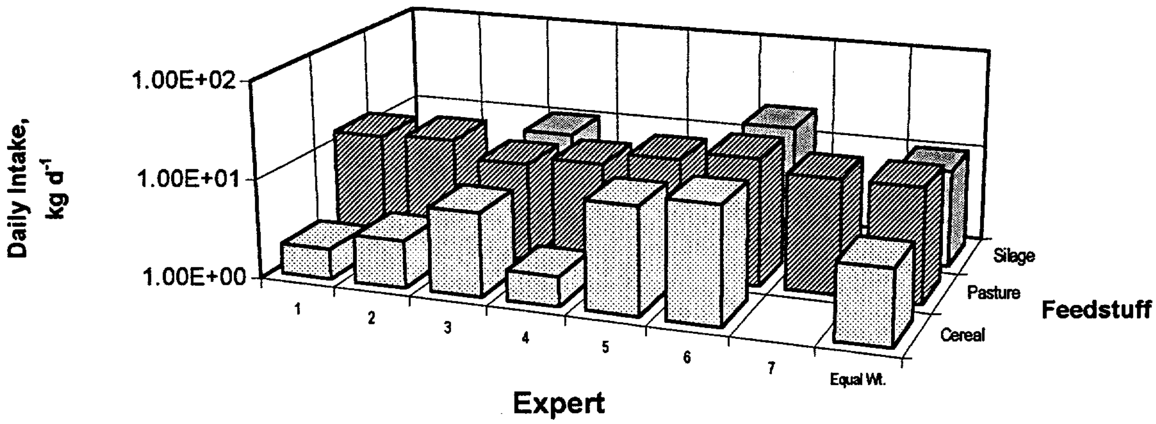

Figure G.57 Median values for daily intake of dairy cows for different feedstuff eaten outdoors.

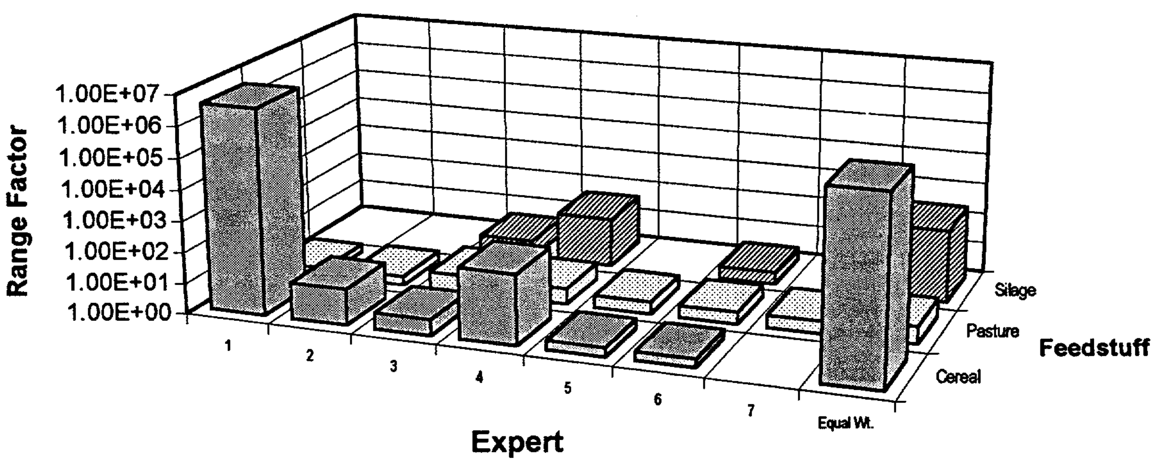

Figure G.58 Range factors (ratio of 95th/5th percentile) for daily intake of dairy cows for different feedstuff eaten outdoors.

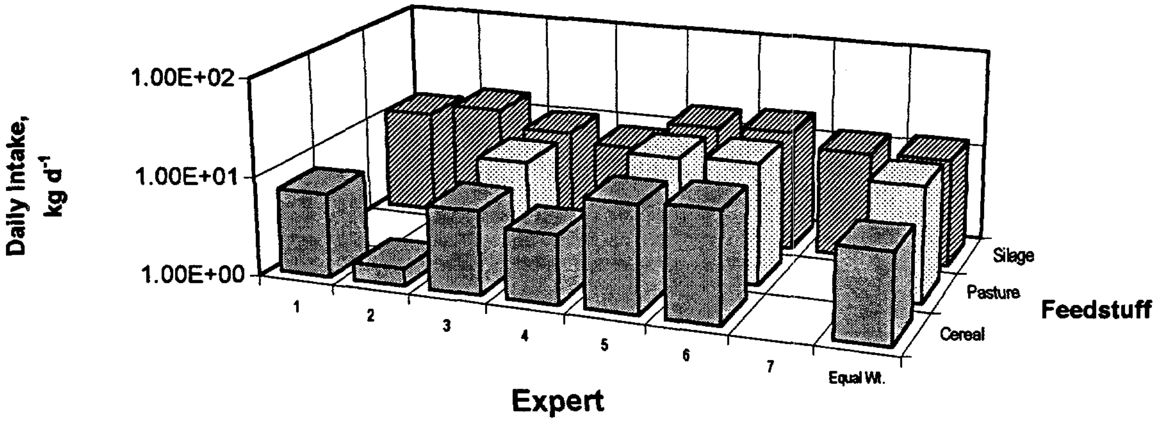

Figure G.59 Median values for daily intake of dairy cows for different feedstuff eaten indoors.

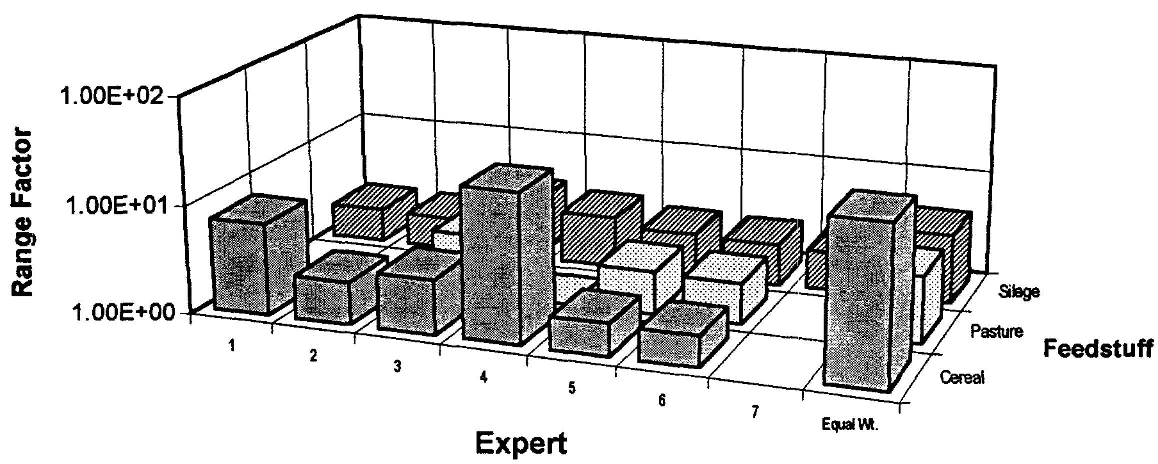

Figure G.60 Range factors (ratio of 95th/5th percentile) for daily intake of dairy cows for different feedstuff eaten indoors.

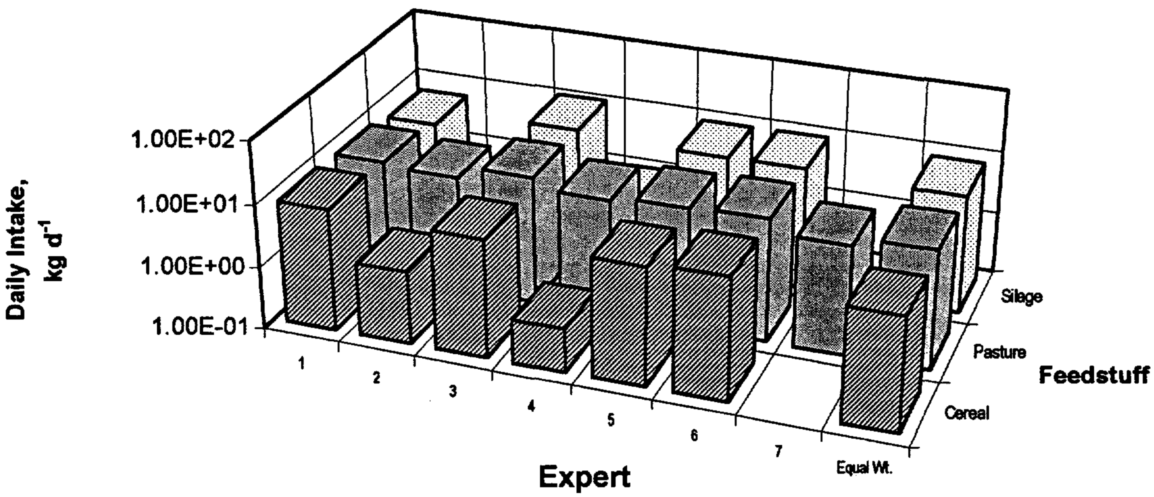

Figure G.61 Median values for daily intake of beef cattle for different feedstuff eaten outdoors.

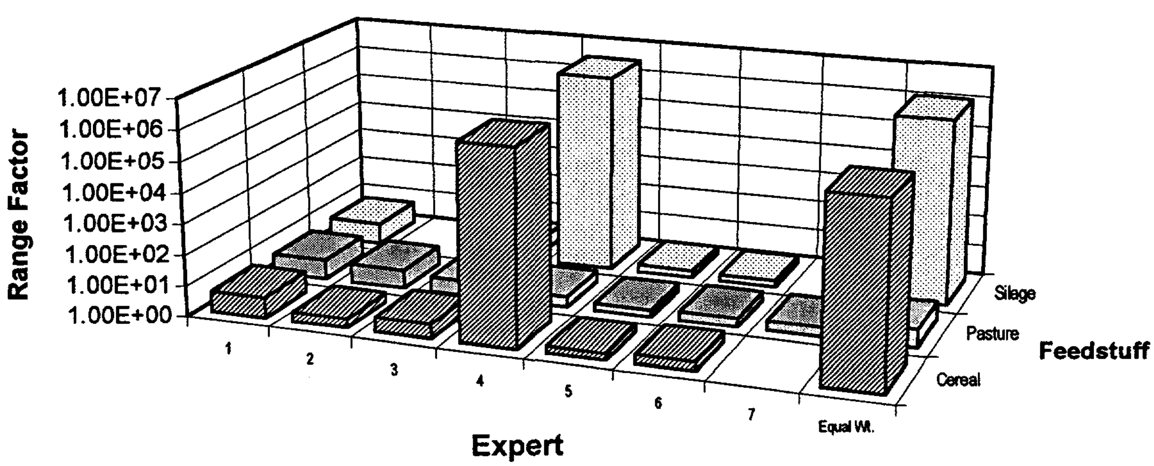

Figure G.62 Range factors (ratio of 95th/5th percentile) for daily intake of beef cattle for different feedstuff eaten outdoors.

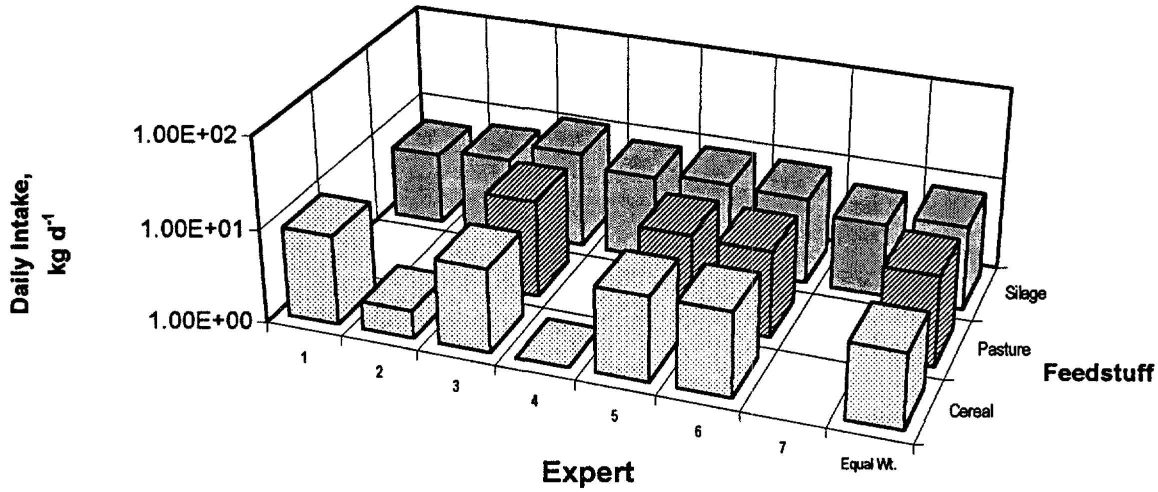

Figure G.63 Median values for daily intake of beef cattle for different feedstuff eaten indoors.

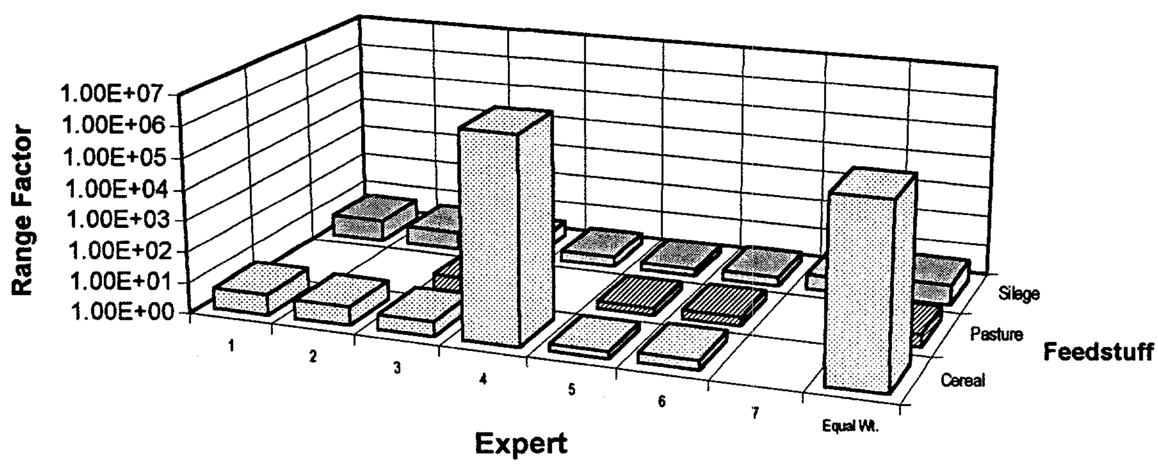

Figure G.64 Range factors (ratio of 95th/5th percentile) for daily intake of beef cattle for different feedstuff eaten indoors.

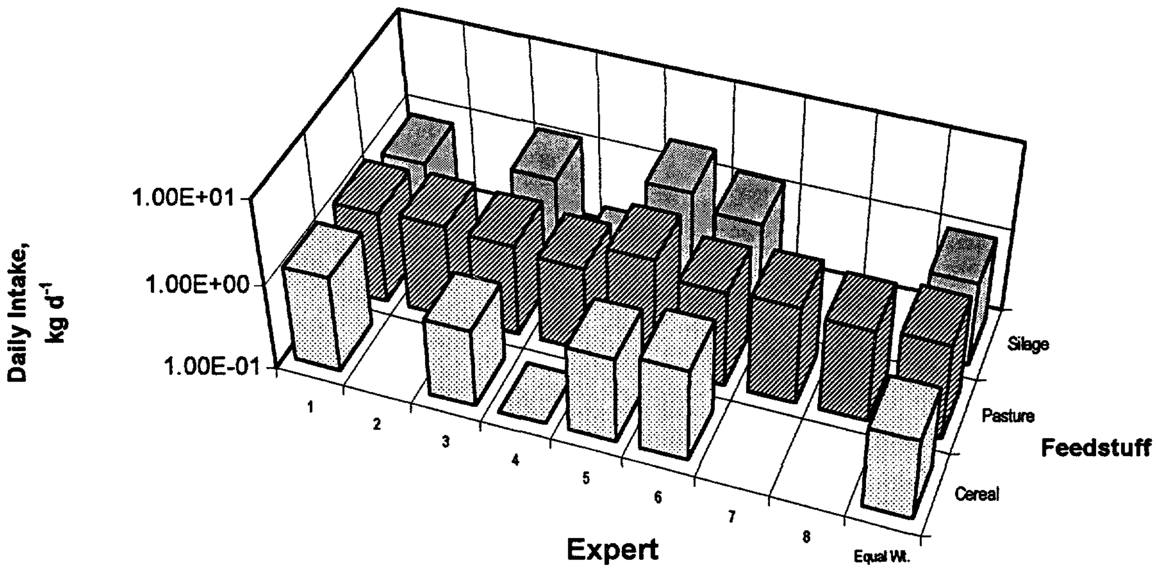

Figure G.65 Median values for daily intake of sheep for different feedstuff eaten outdoors.

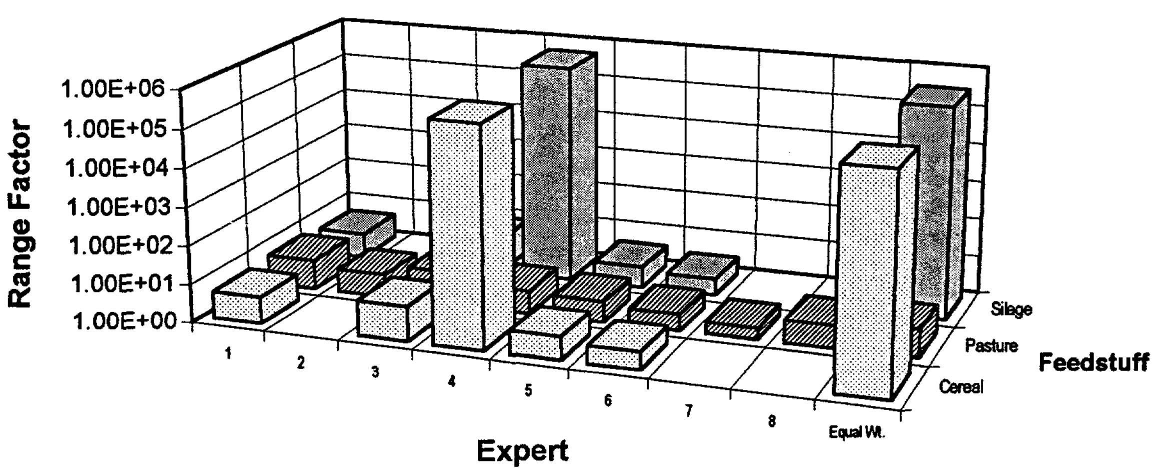

Figure G.66 Range factors (ratio of 95th/5th percentile) for daily intake of sheep for different feedstuff eaten outdoors.

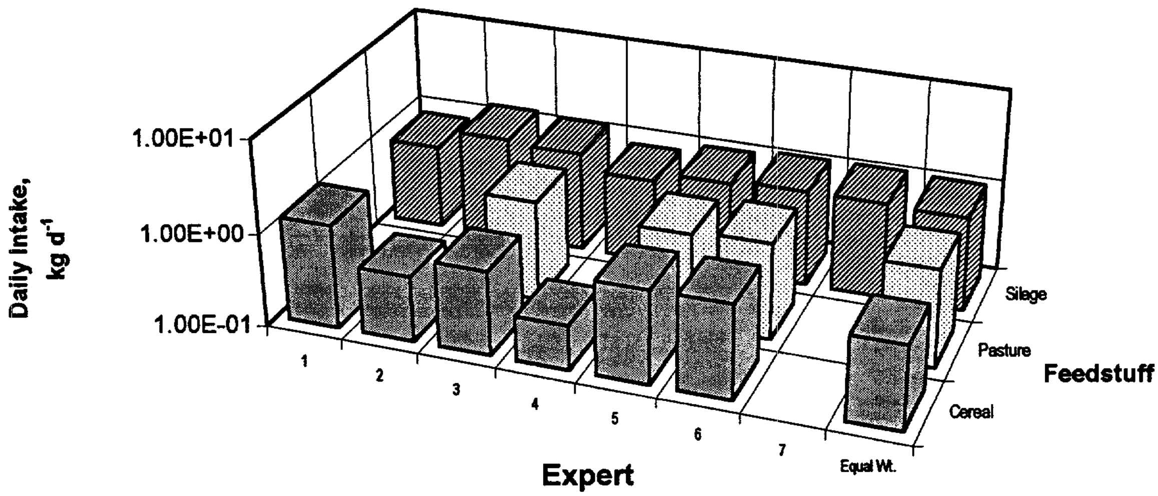

Figure G.67 Median values for daily intake of sheep for different feedstuff eaten indoors.

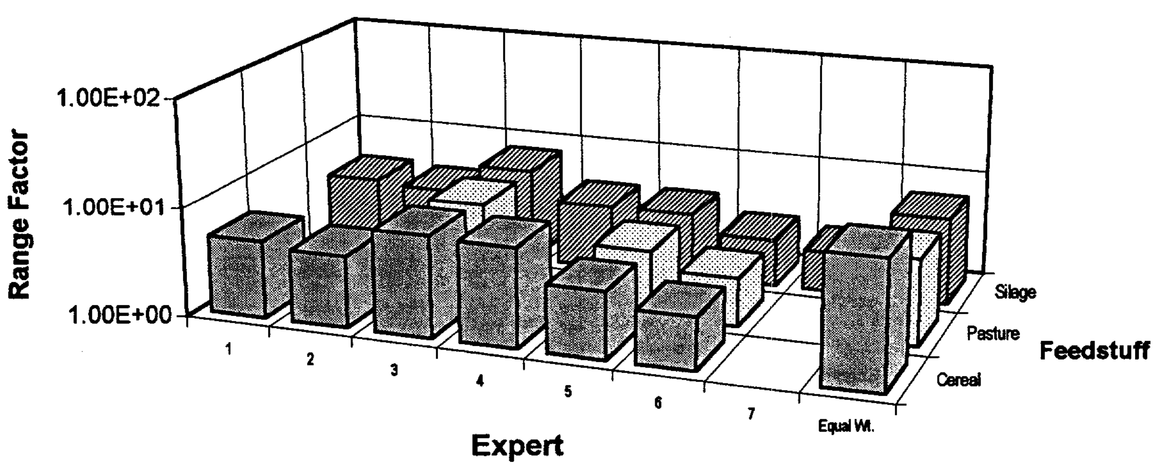

Figure G.68 Range factors (ratio of 95th/5th percentile) for daily intake of sheep for different feedstuff eaten indoors.

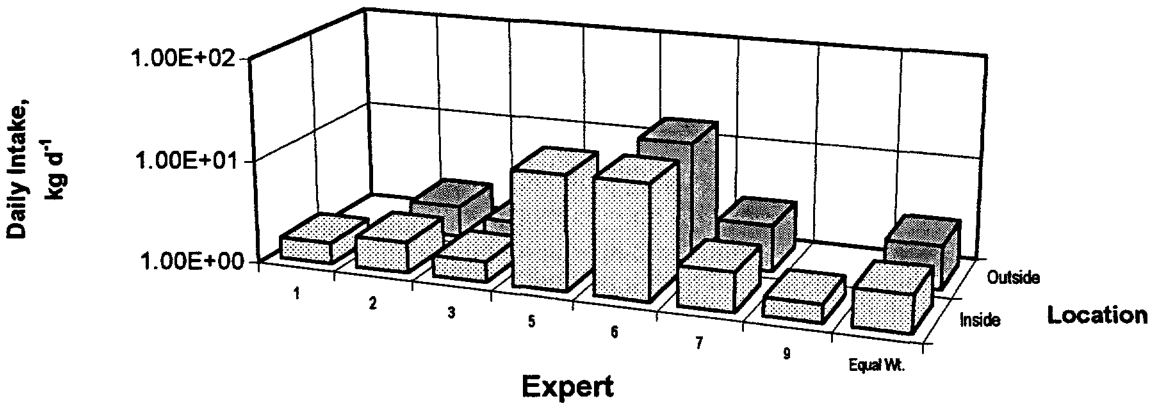

Figure G.69 Median values for daily intake of cereal by pigs eaten at different locations.

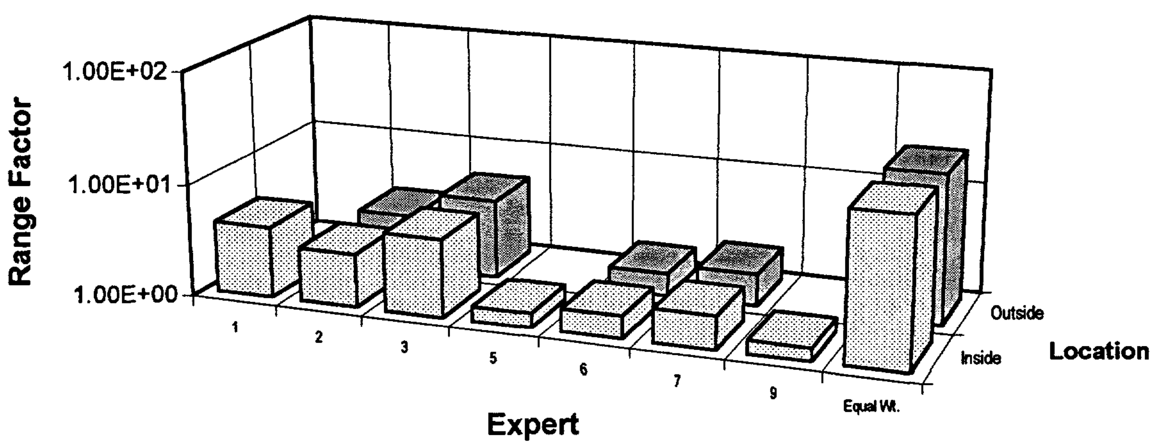

Figure G.70 Range factors (ratio of 95th/5th percentile) for daily intake of cereal by pigs eaten at different locations.

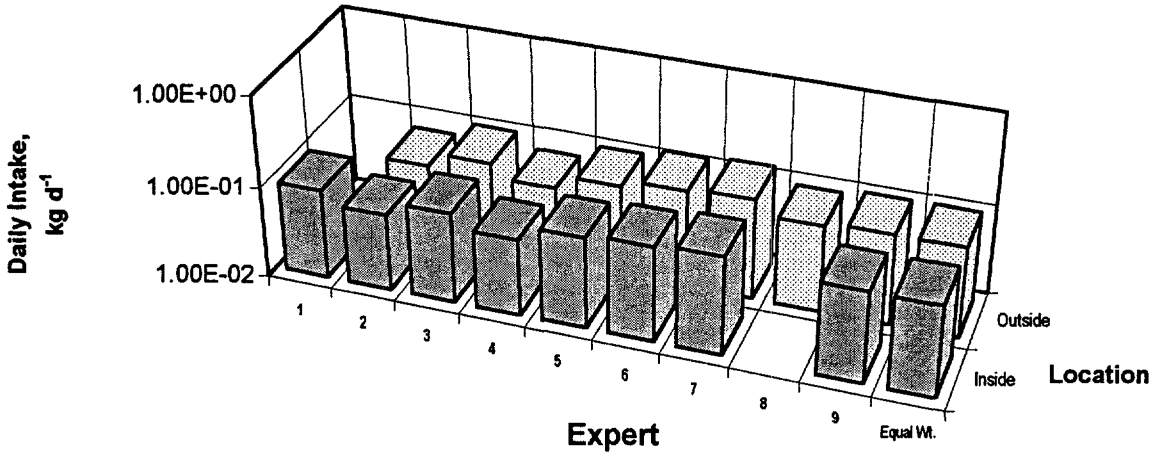

Figure G.71 Median values for daily intake of cereal by poultry eaten at different locations.

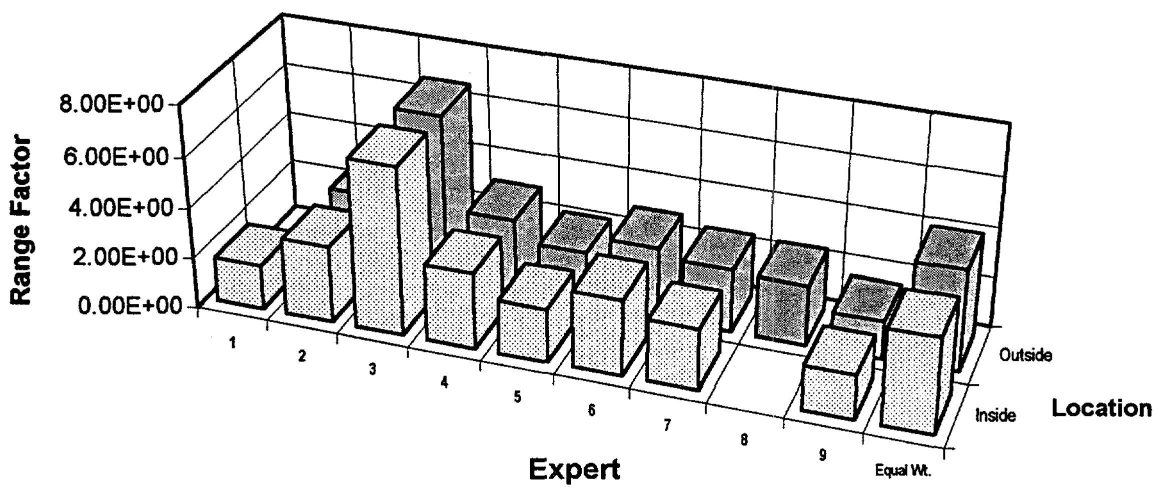

Figure G.72 Range factors (ratio of 95th/5th percentile) for daily intake of cereal by poultry eaten at different locations.

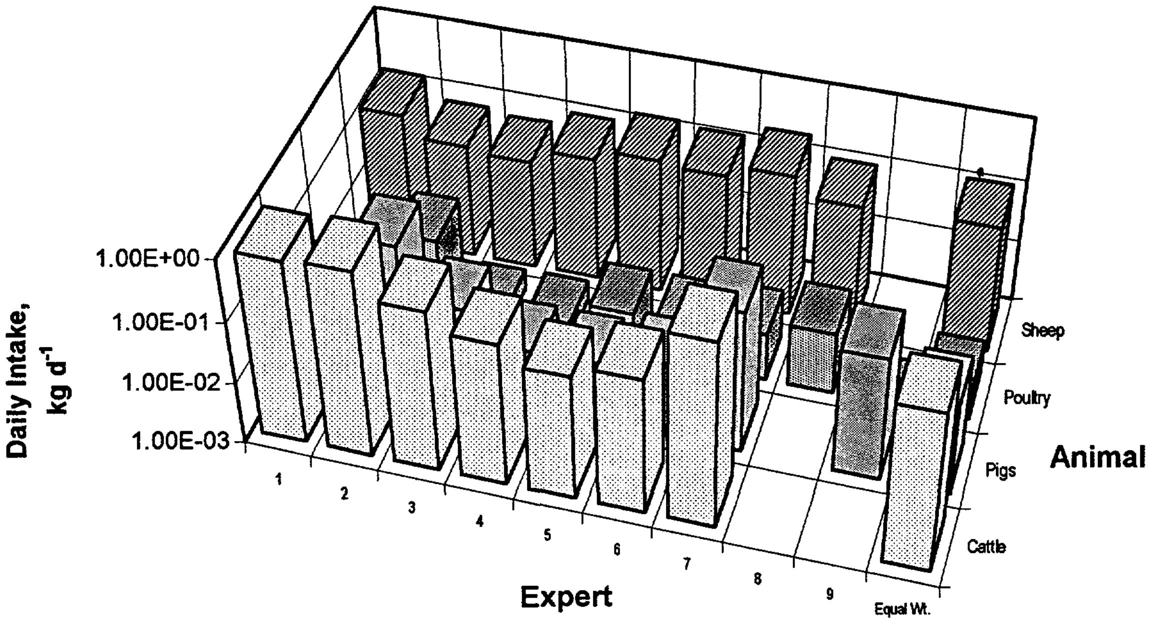

Figure G.73 Median values for daily soil consumption for different animals.

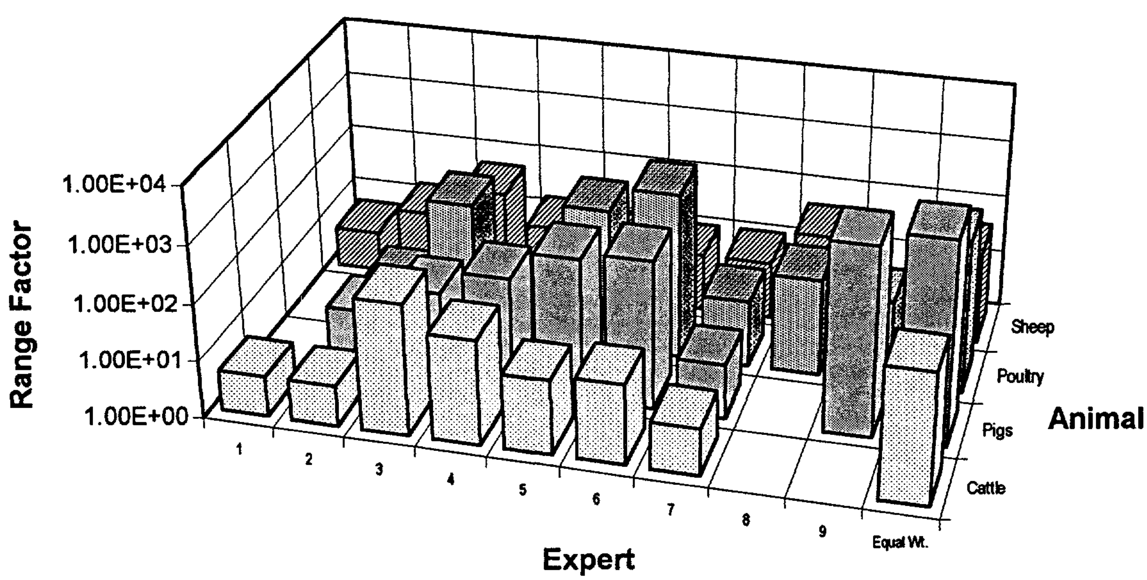

Figure G.74 Range factors (ratio of 95th/5th percentile) for daily soil consumption for different animals.

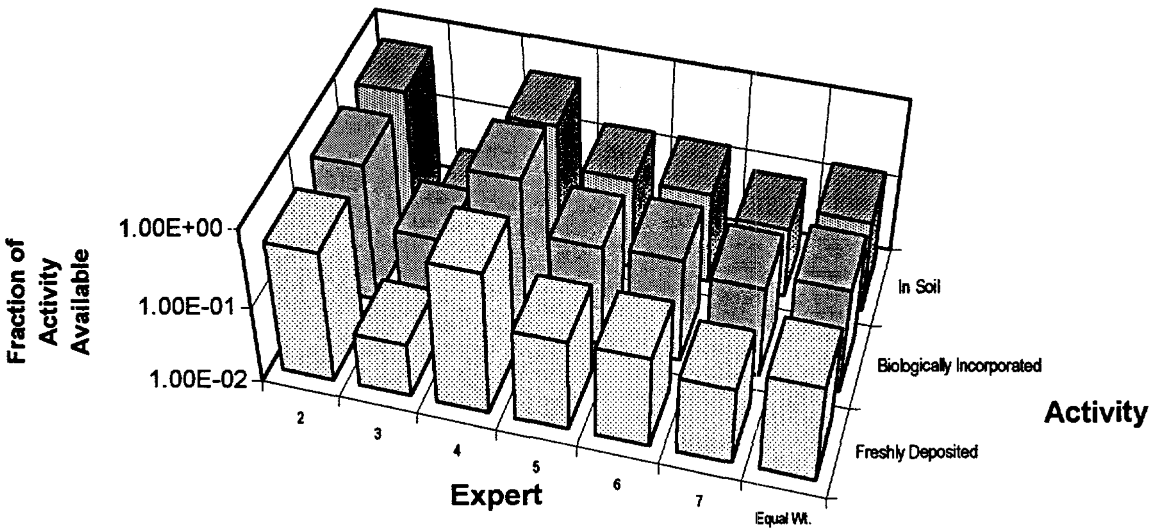

Figure G.75 Median values for fraction of strontium activity associated with consumed pasture grass that is available for transfer across the gut.

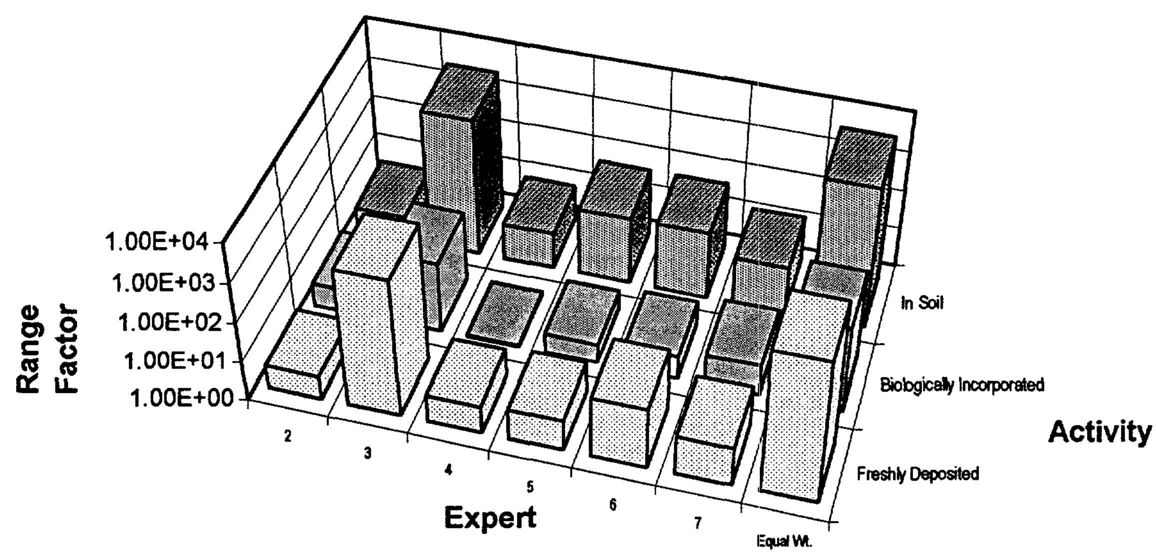

Figure G.76 Range factors (ratio of 95th/5th percentile) for fraction of strontium activity associated with consumed pasture grass that is available for transfer across the gut.

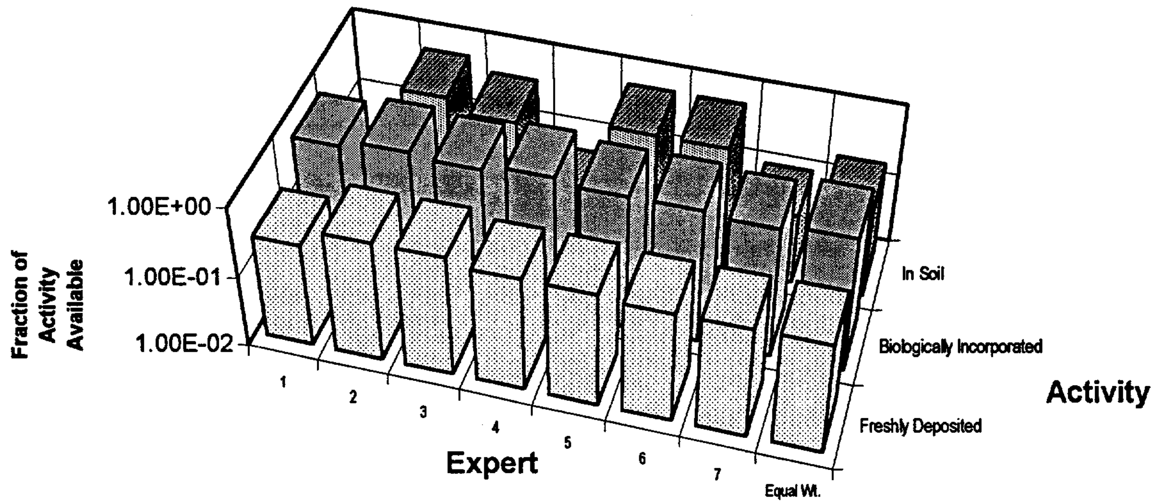

Figure G.77 Median values for fraction of cesium activity associated with consumed pasture grass that is available for transfer across the gut.

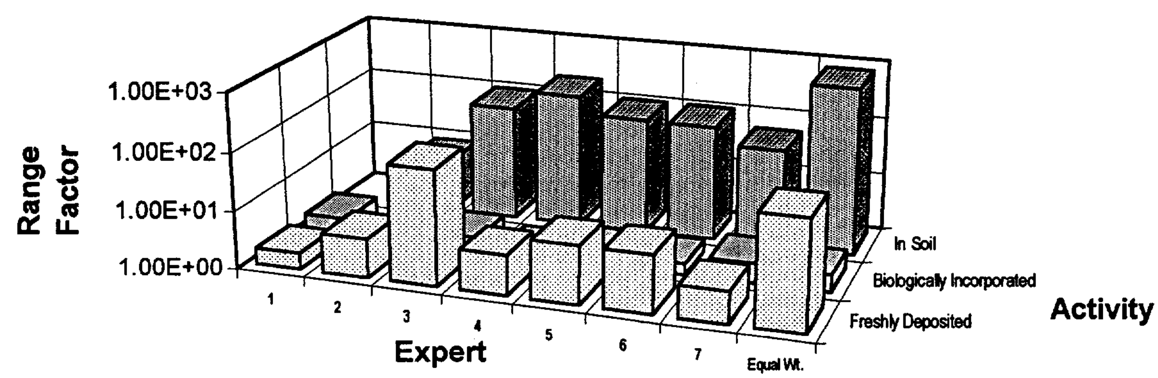

Figure G.78 Range factors (ratio of 95th/5th percentile) for fraction of cesium activity associated with consumed pasture grass that is available for transfer across the gut.

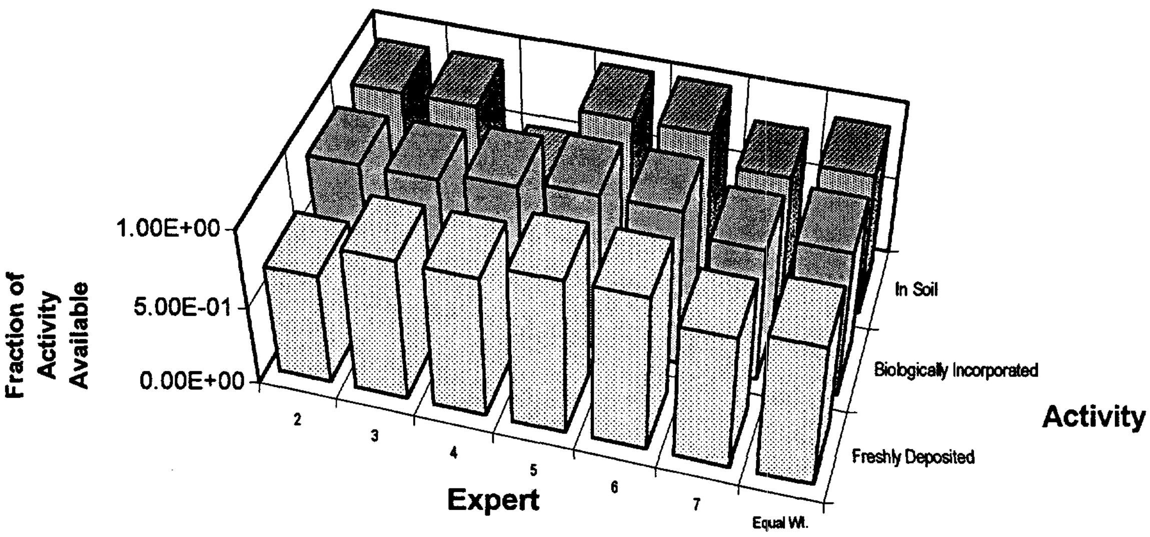

Figure G.79 Median values for fraction of iodine activity associated with consumed pasture grass that is available for transfer across the gut.

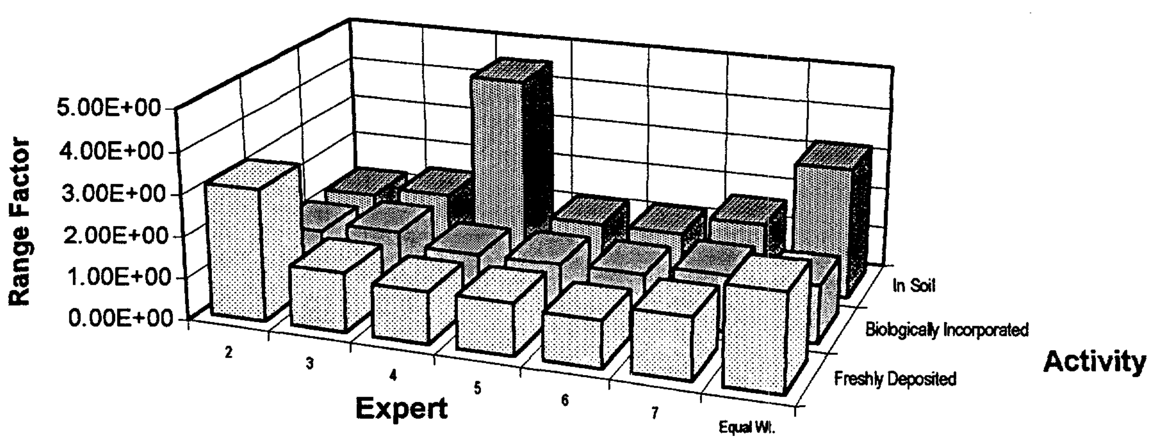

Figure G.80 Range factors (ratio of 95th/5th percentile) for fraction of iodine activity associated with consumed pasture grass that is available for transfer across the gut.

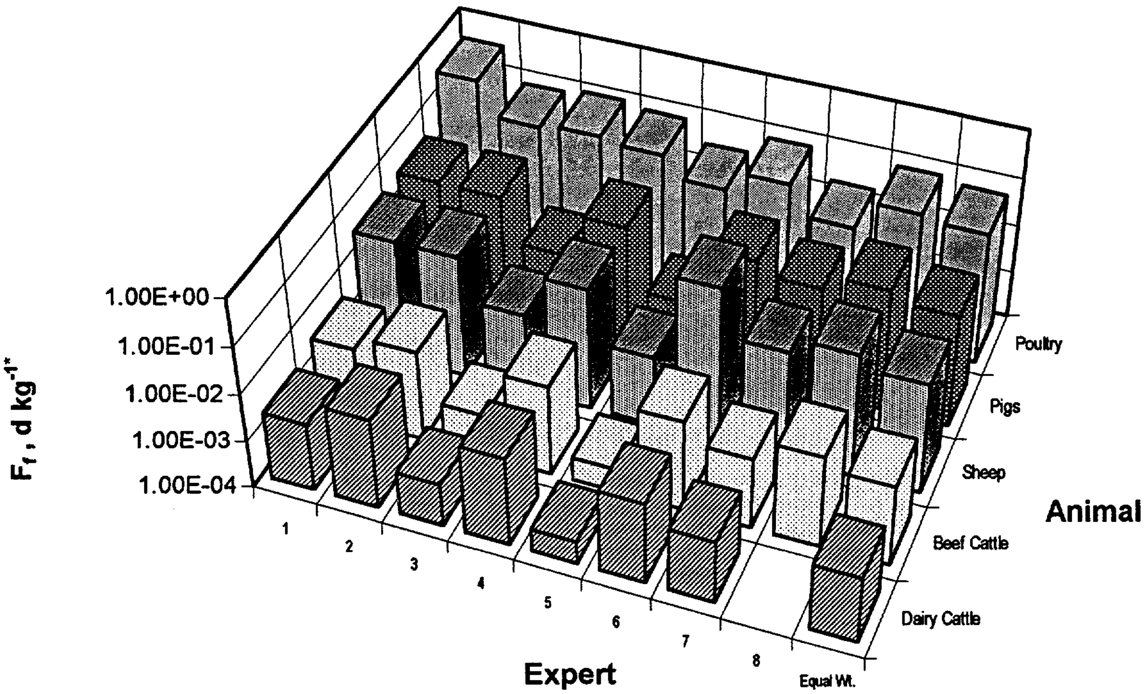

Figure G.81 Median values for the equilibrium transfer to meat (Ff) for strontium for different animals.
*** Ff is the fraction of the daily intake that is transferred to 1 kg of meat at equilibrium.**

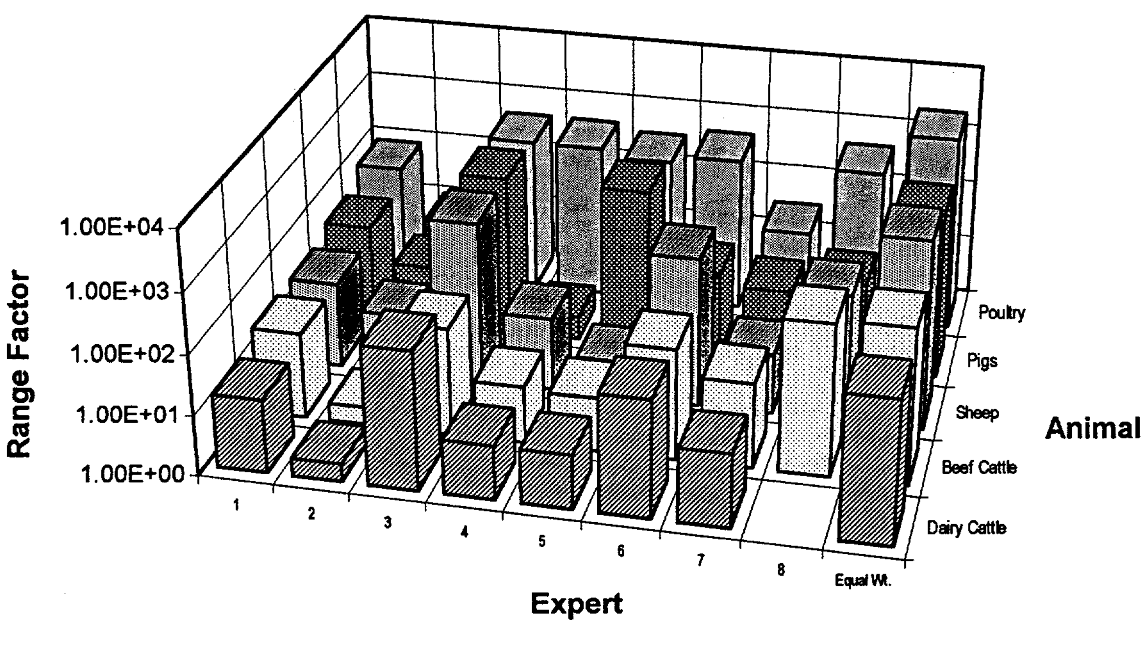

Figure G.82 Range factors (ratio of 95th/5th percentile) for the equilibrium transfer to meat (Ff) for strontium for different animals.

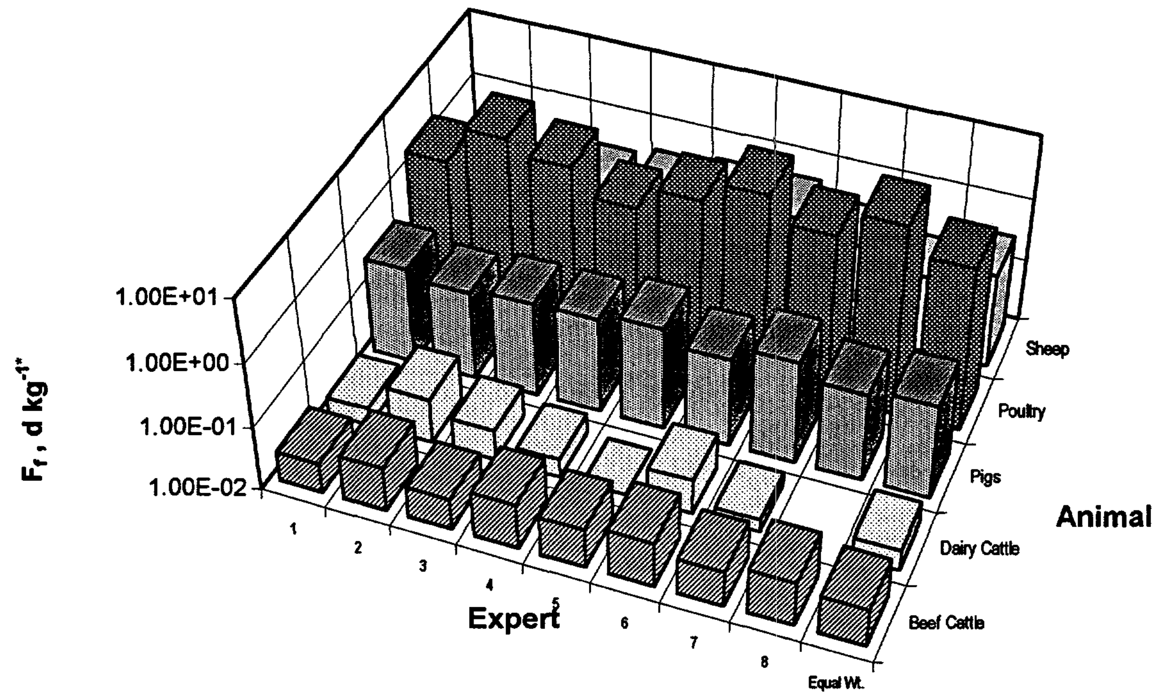

Figure G.83 Median values for the equilibrium transfer to meat (Ff) for cesium for different animals.
*** F_f is the fraction of the daily intake that is transferred to 1 kg of meat at equilibrium.**

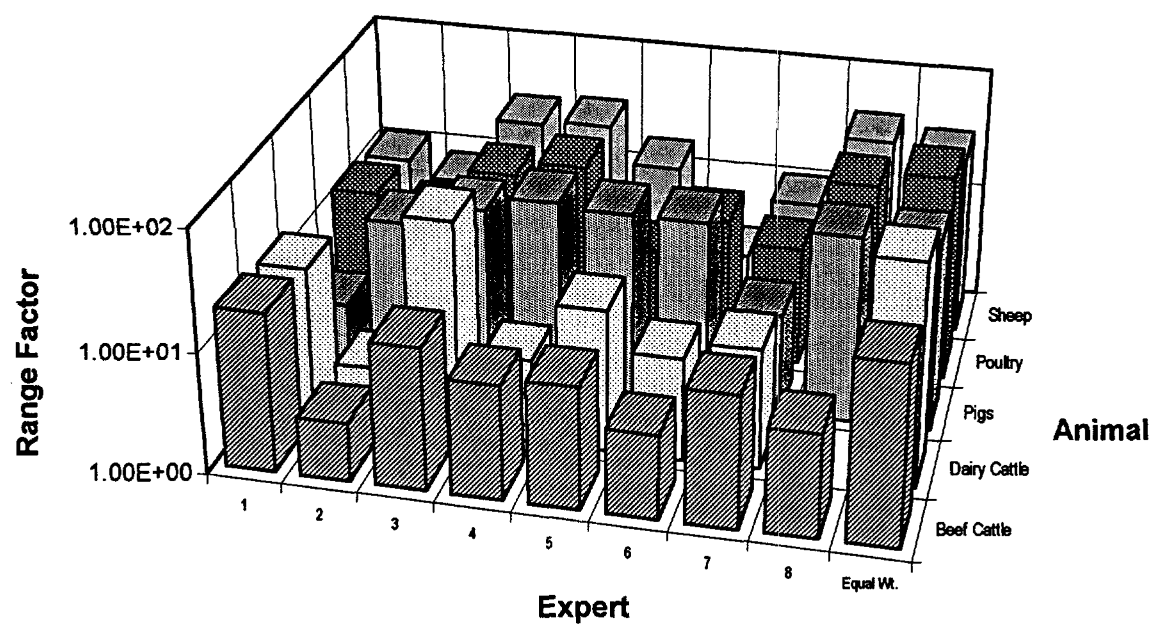

Figure G.84 Range factors (ratio of 95th/5th percentile) for the equilibrium transfer to meat (Ff) for cesium for different animals.

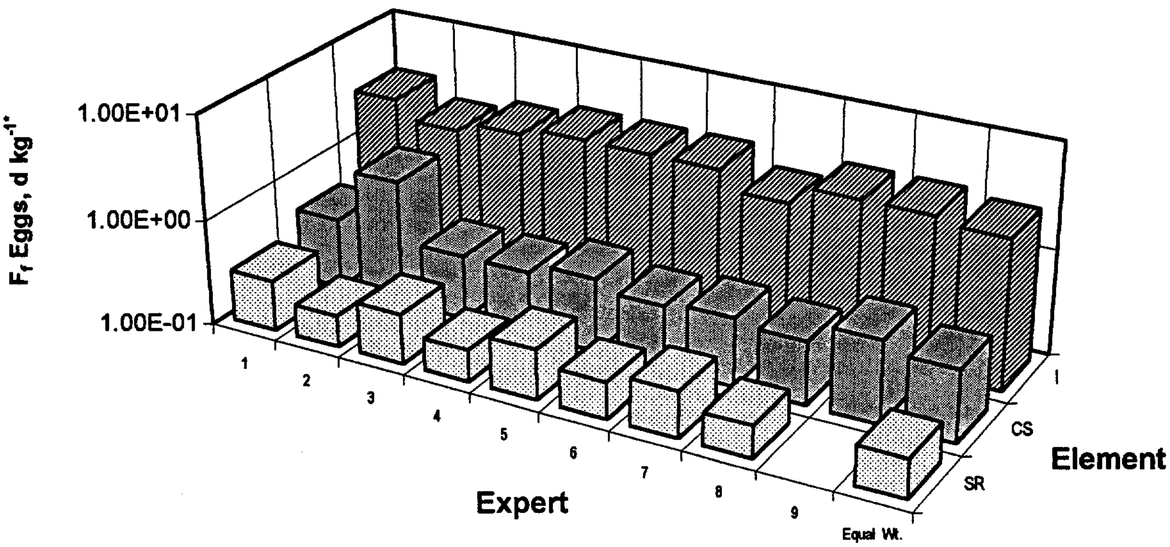

Figure G.85 Median values for the equilibrium transfer to eggs as a function of element. * Ff is the fraction of the daily intake that is transferred to 1 kg of eggs at equilibrium.

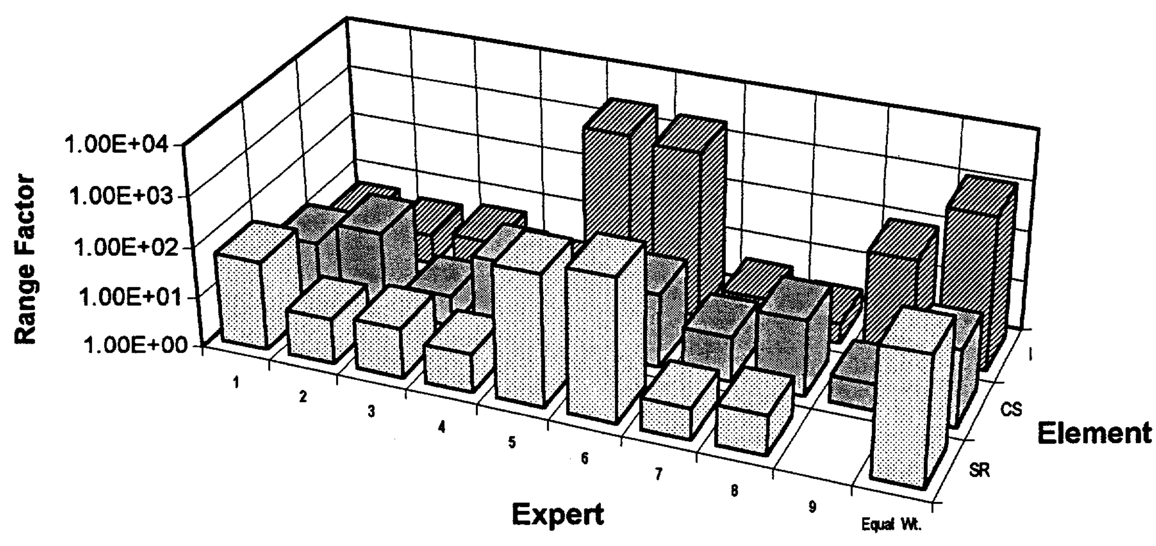

Figure G.86 Range factors (ratio of 95th/5th percentile) for the equilibrium transfer to eggs as a function of element.

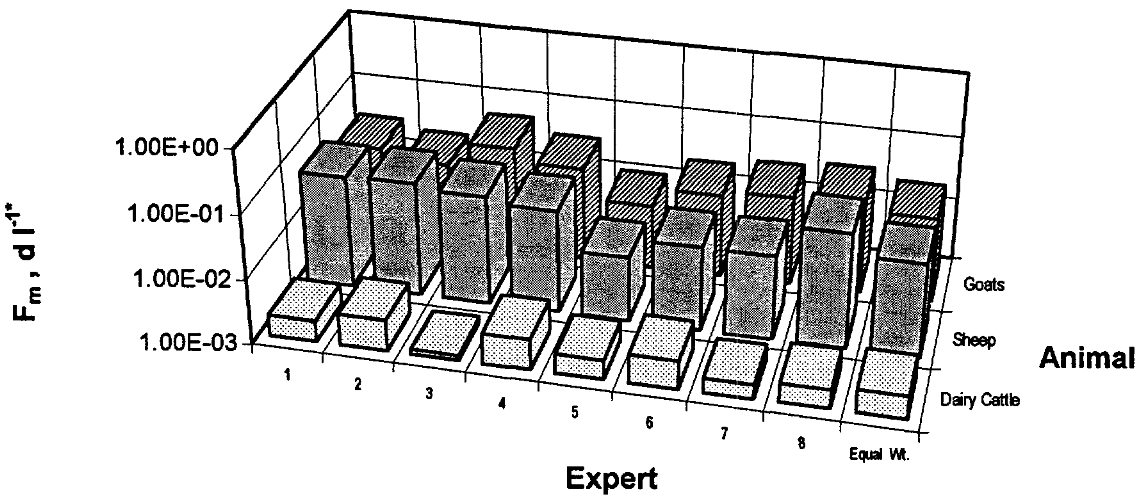

Figure G.87 Median values for the equilibrium transfer to milk (Fm) for strontium for different animals.
*** F_m is the fraction of the daily intake that is transferred to 1 liter of milk at equilibrium.**

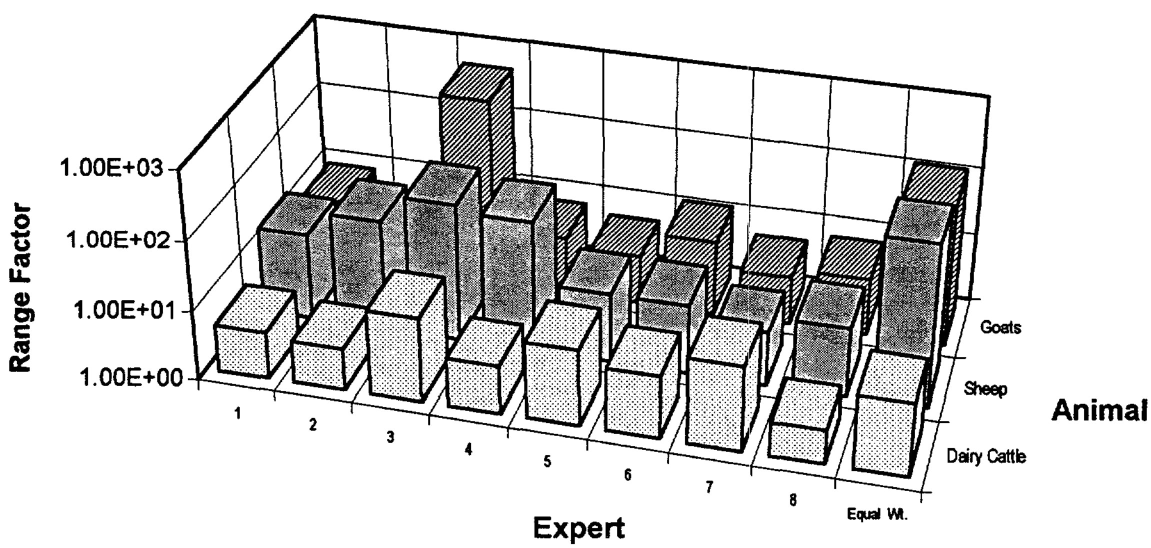

Figure G.88 Range factors (ratio of 95th/5th percentile) for the equilibrium transfer to milk (Fm) for strontium for different animals.

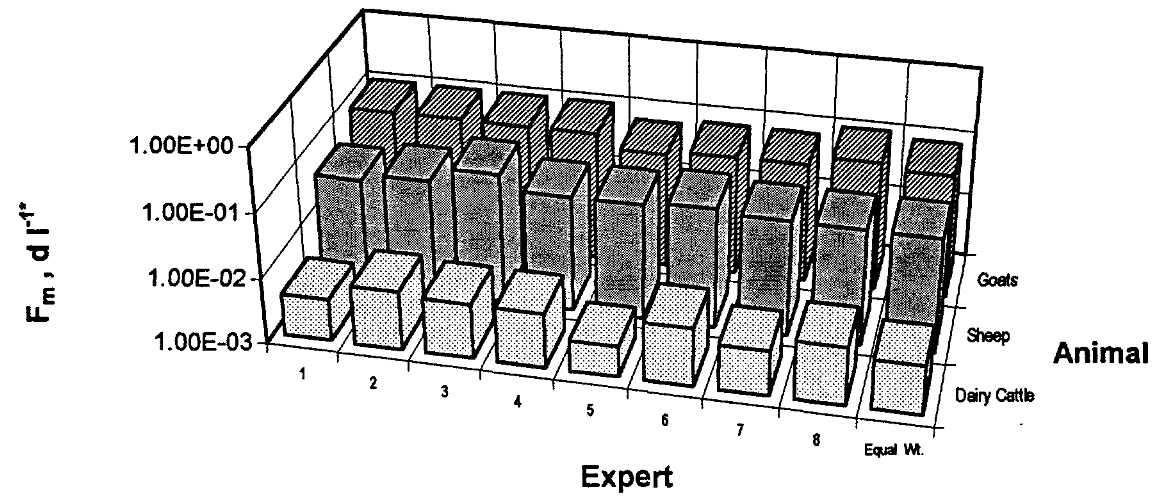

Figure G.89 Median values for the equilibrium transfer to milk (Fm) for cesium for different animals. * F_m is the fraction of the daily intake that is transferred to 1 liter of milk at equilibrium.

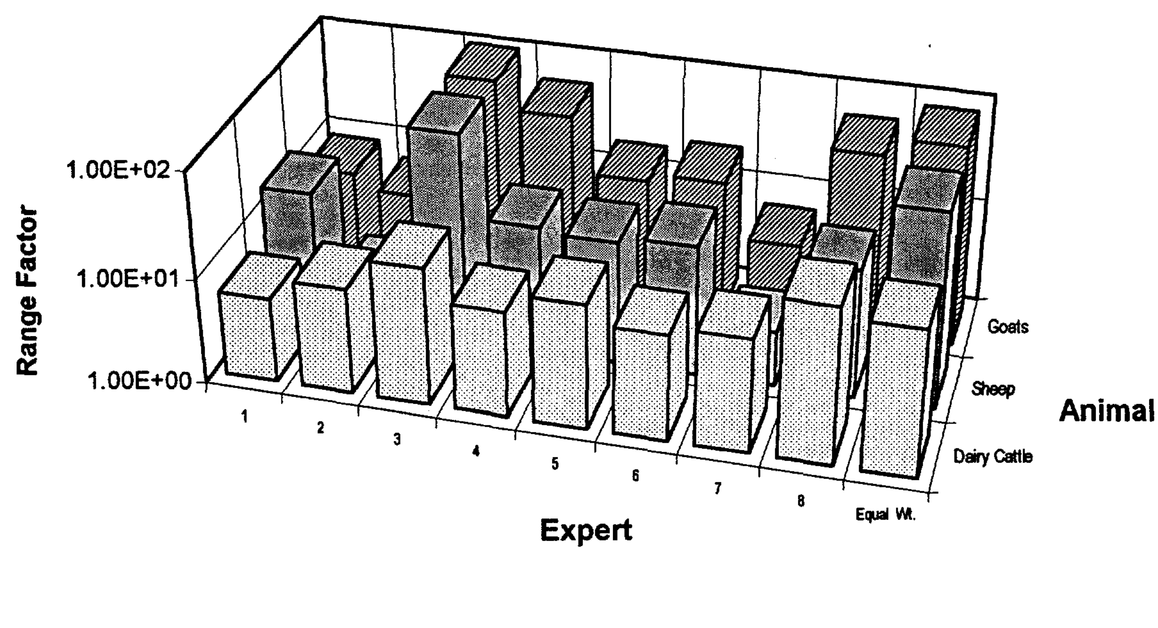

Figure G.90 Range factors (ratio of 95th/5th percentile) for the equilibrium transfer to milk (Fm) for cesium for different animals.

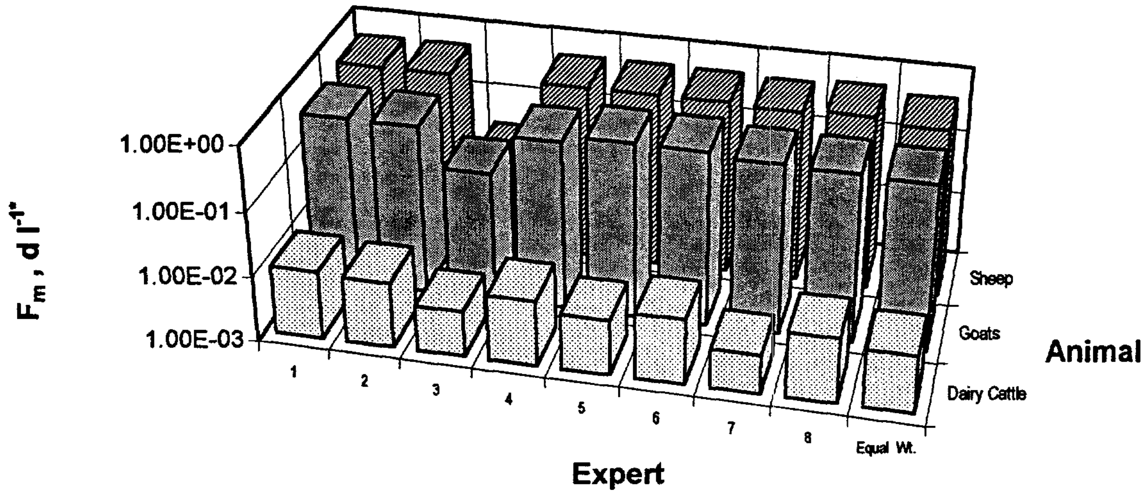

Figure G.91 Median values for the equilibrium transfer to milk (Fm) for iodine for different animals.
*** F_m is the fraction of the daily intake that is transferred to 1 liter of milk at equilibrium.**

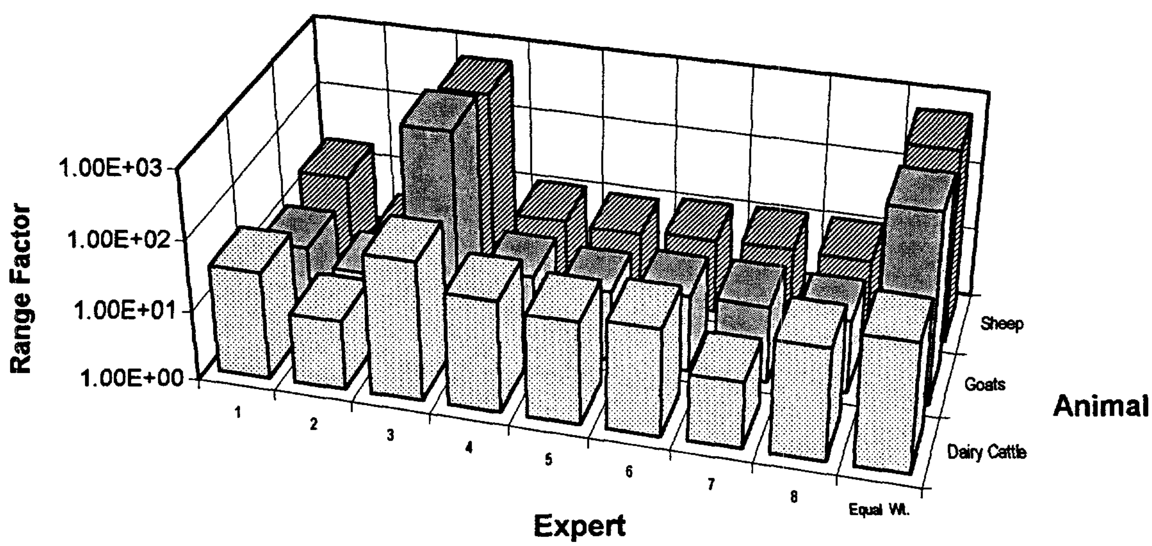

Figure G.92 Range factors (ratio of 95th/5th percentile) for the equilibrium transfer to milk (Fm) for iodine for different animals.

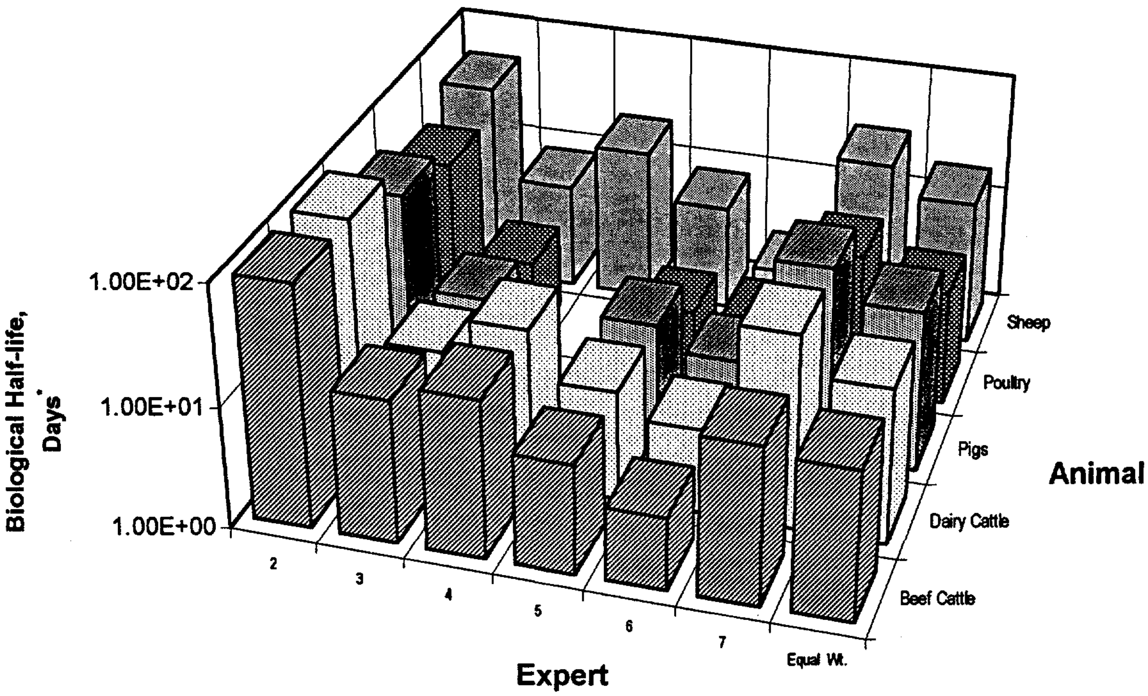

Figure G.93 Median values for the biological half-life of strontium in the meat of different animals.
*** Biological half-life is the weighted average residence time of the activity in the meat of the animal in terms of half-life.**

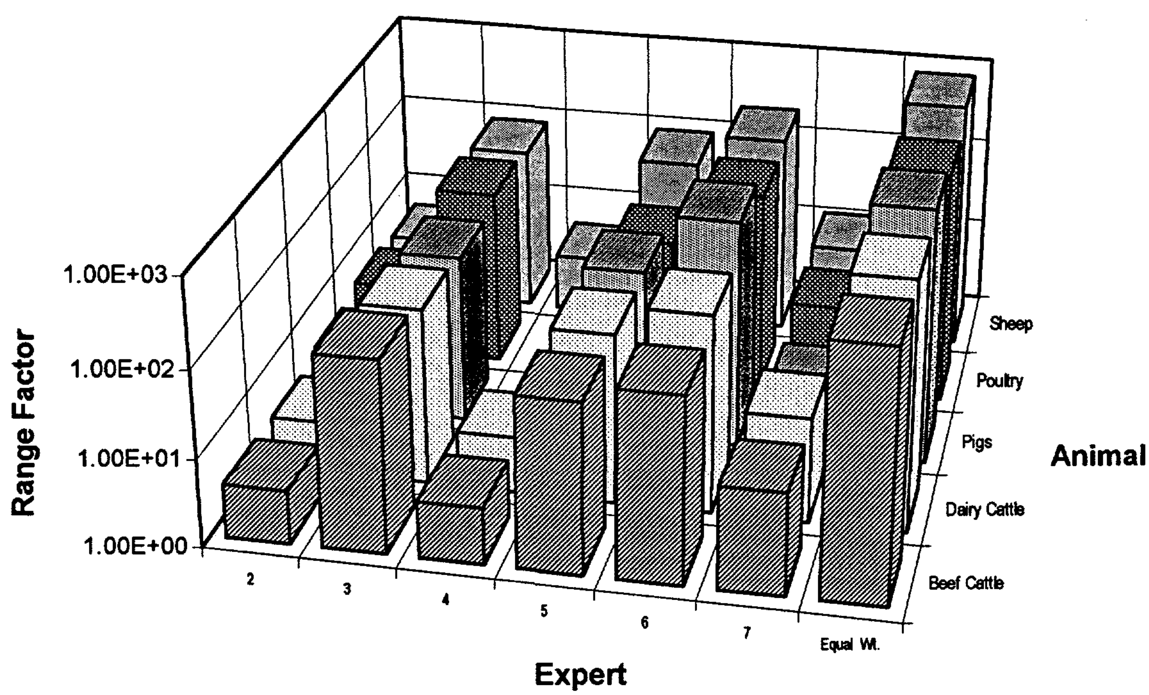

Figure G.94 Range factors (ratio of 95th/5th percentile) for the biological half-life of strontium in the meat of different animals.

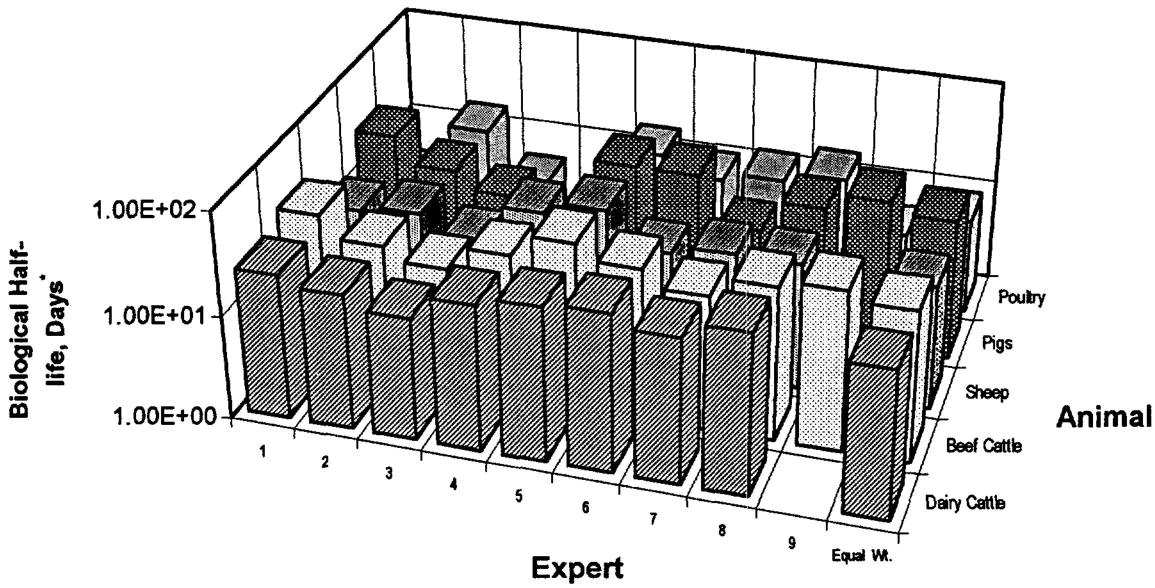

Figure G.95 Median values for the biological half-life of cesium in the meat of different animals.
*** Biological half-life is the weighted average residence time of the activity in the meat of the animal in terms of half-life.**

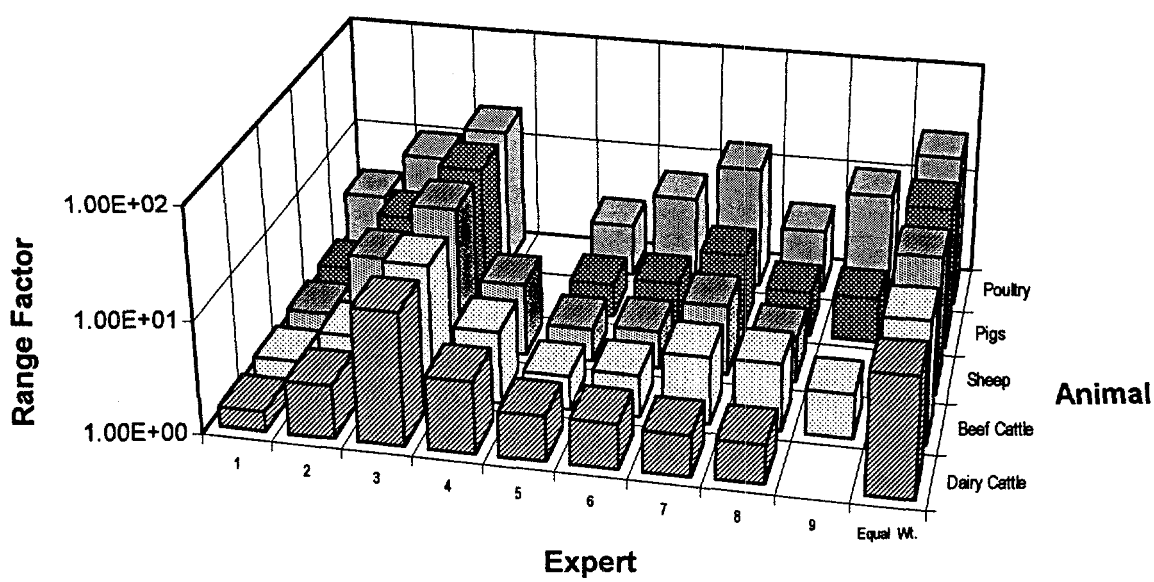

Figure G.96 Range factors (ratio of 95th/5th percentile) for the biological half-life of cesium in the meat of different animals.

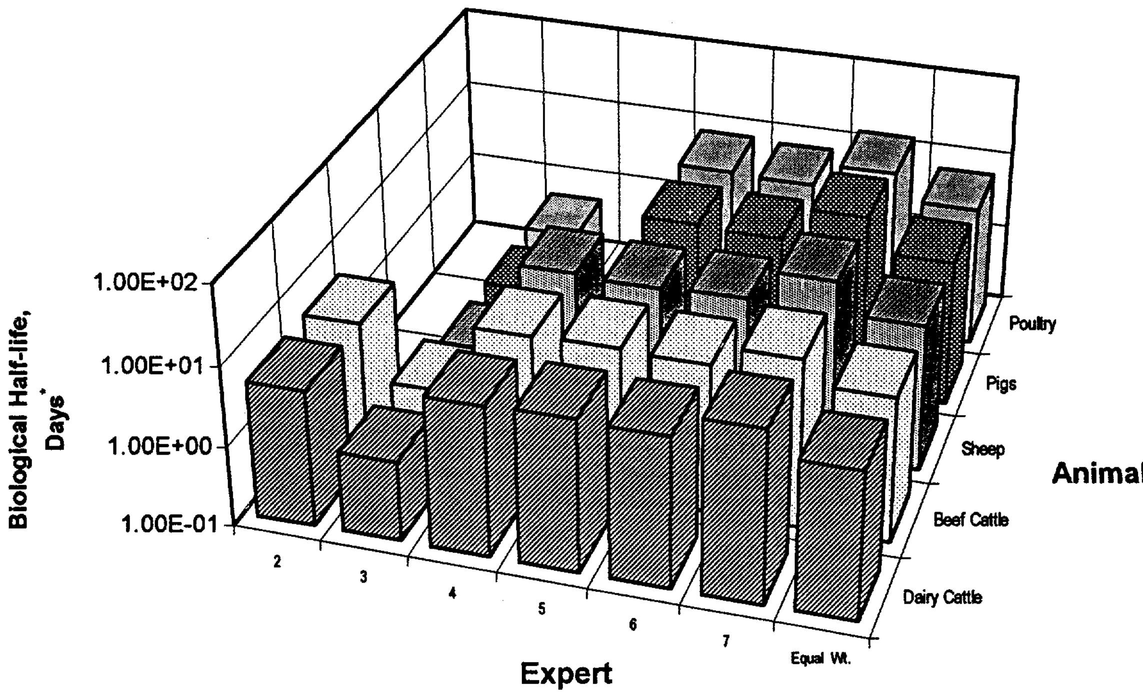

Figure G.97 Median values for the biological half-life of iodine in the meat of different animals.
*** Biological half-life is the weighted average residence time of the activity in the meat of the animal in terms of half-life.**

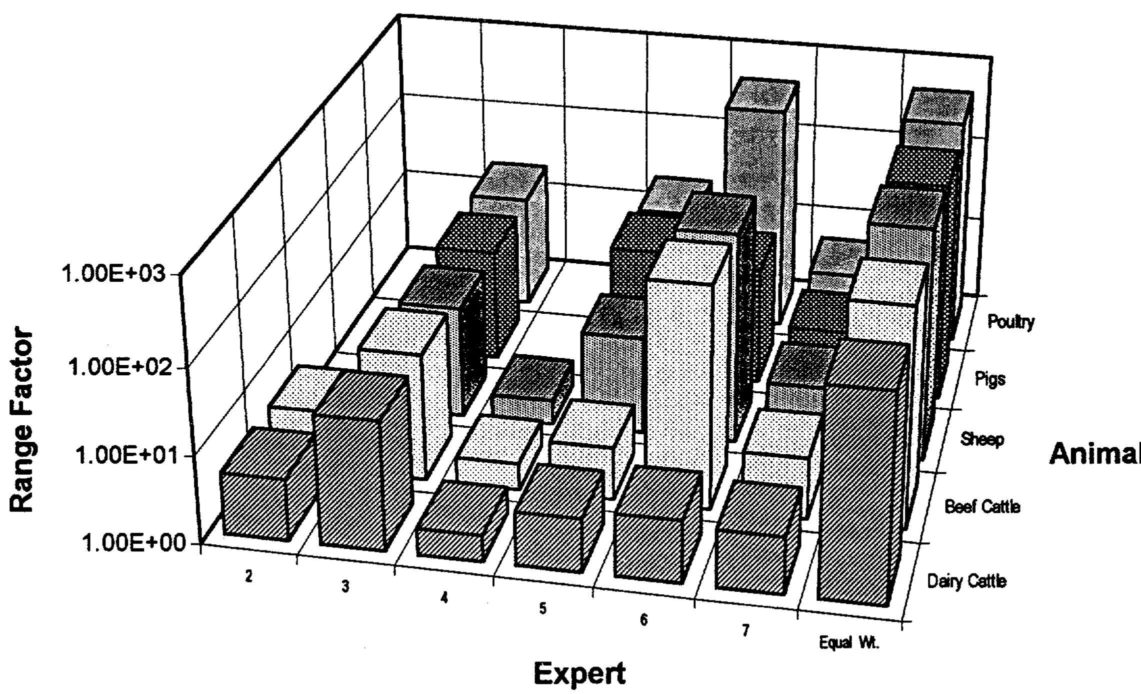

Figure G.98 Range factors (ratio of 95th/5th percentile) for the biological half-life of iodine in the meat of different animals.

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10. SUPPLEMENTARY NOTES

J. Randall, NRC Project Manager

11. ABSTRACT *(200 words or less)*

The development of two new probabilistic accident consequence codes, MACCS and COSYMA, was completed in 1990. These codes estimate the consequence from the accidental releases of radiological material from hypothesized accidents at nuclear installations. In 1991, the U.S. Nuclear Regulatory Commission and the Commission of the European Communities began cosponsoring a joint uncertainty analysis of the two codes. The ultimate objective of this joint effort was to systematically develop credible and traceable uncertainty distributions for the respective code input variables. A formal expert judgment elicitation and evaluation process was identified as the best technology available for developing a library of uncertainty distributions for these consequence parameters. This report focuses on the results of the study to develop distribution for variables related to the MACCS and COSYMA food chain models. Both soil/plant transfer processes and radionuclide transport in animals were assessed.

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