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Validation of models using Chernobyl fallout data from southern Finland

Scenario S

Second report of the VAMP Multiple Pathways Assessment Working Group

Part of the IAEA/CEC Co-ordinated Research Programme on the Validation of Environmental Model Predictions (VAMP)

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FOREWORD

Following the Chernobyl accident and on the recommendation of the International Nuclear Safety Advisory Group (INSAG) in its Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident (Safety Series No. 75-INSAG-1, IAEA, Vienna, 1986), the IAEA established a Co-ordinated Research Programme on "The Validation of Models for the Transfer of Radionuclides in Terrestrial, Urban and Aquatic Environments and the Acquisition of Data for that Purpose". The programme used the information on the environmental behaviour of radionuclides which became available as a result of the measurement programmes instituted in countries of the former Soviet Union and in many European countries after April 1986 for the purpose of testing the reliability of assessment models. Such models find application in assessing the radiological impact of all parts of the nuclear fuel cycle. They are used in the planning and design stage to predict the radiological impact of nuclear facilities and in assessing the possible consequences of accidents involving releases of radioactive material to the environment and in establishing criteria for the implementation of countermeasures. In the operational phase, they are used together with the results of environmental monitoring to demonstrate compliance with regulatory requirements concerned with radiation dose limitation.

The programme, which had the short title "*Va*lidation of Environmental *M*odel *P*redictions (VAMP)", continued from 1988 to 1995; it was jointly sponsored by the Division of Nuclear Fuel Cycle and Waste Management and the Division of Nuclear Safety and is also supported by the European Commission. There were four working groups within the VAMP programme: the Terrestrial Working Group, the Urban Working Group, the Aquatic Working Group, and the Multiple Pathways Assessment Working Group.

The **VAMP Multiple Pathways Assessment Working Group** was an international forum for the testing and comparison of model predictions. The emphasis was on evaluating transfer from the environment to humans via all pathways which are relevant in the environment being considered. This Technical Document is the second report of the Group and contains the results of the second test exercise on the validation of multiple pathways assessment models using Chernobyl fallout data obtained from the southern Finland (Suomi) region (**Scenario** S).

The report is the outcome of a joint effort by the participants of Scenario S. Their names are listed at the end of the document. A special acknowledgement is due to the Chairman of the Working Group, F.O. Hoffman (USA), for directing the work of the group. He was also responsible for drafting the main text of the report and was assisted by K. Thiessen (USA). The Finnish Centre for Radiation and Nuclear Safety (STUK) provided resources for the development of the Scenario and analysis of test data (Appendix I). The work was supported by many STUK scientists and was co-ordinated by A. Rantavaara (Finland). The IAEA staff member responsible for the document was S. Hossain of the Division of Nuclear Fuel Cycle and Waste Management.

Other reports issued under the VAMP programme are:

Modelling of Resuspension, Seasonality and Losses during Food Processing. First Report of the VAMP Terrestrial Working Group, IAEA-TECDOC-647 (1992).

Assessing the Radiological Impact of Past Nuclear Activities and Events, IAEA-TECDOC-755 (1994).

Modelling the Deposition of Airborne Radionuclides into the Urban Environment. First Report of the VAMP Urban Working Group, IAEA-TECDOC-760 (1994).

Validation of Models using Chernobyl Fallout Data from the Central Bohemia Region of the Czech Republic - Scenario CB. First Report of the VAMP Multiple Pathways Assessment Working Group, IAEA-TECDOC-795 (1995).

Modelling of Radionuclide Interception and Loss Processes in Vegetation and of Transfer in Semi-natural Ecosystems. Second Report of the VAMP Terrestrial Working Group, IAEA-TECDOC-857 (1996).

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. GENERAL BACKGROUND

Evaluation of the impact of radionuclide releases on humans and on the environment is important, both to quantify the risks which arise from radionuclides present in the environment due to past human activities and to predict the possible future risks associated with planned and unplanned (accidental) releases from nuclear facilities. The risks from these releases arise as a result of the transport of radionuclides in air, water, soils, or food from their release point to humans. Evaluating the impact of releases requires understanding the processes and mechanisms by which radionuclides can reach humans. Knowledge gained over the last few decades has enabled the construction of mathematical models which express our understanding of the processes of transport from source to man (e.g. Refs [1-3]). It must be recognized that our knowledge is imperfect and that radioecological models can only simulate the actual transfer processes in an approximate way. There is, therefore, a constant need to improve the reliability of models by testing their predictions in real situations (e.g. Refs [4-7]).

1.2. BACKGROUND AND OVERALL OBJECTIVES OF VAMP

The Co-ordinated Research Programme on "The Validation of Models for the Transfer of Radionuclides in Terrestrial, Urban and Aquatic Environments and the Acquisition of Data for that Purpose" was established by the International Atomic Energy Agency in 1988. The programme, known as **VAMP** (*VA*lidation of Environmental *M*odel *P*redictions), seeks to use the information on the environmental behaviour of radionuclides which became available as a result of the measurement programmes instituted in many countries following the reactor accident at Chernobyl in 1986. This information is used to test the reliability of models used in assessing the radiological impact of all parts of the nuclear fuel cycle. Models are used in the planning and design stage to predict the radiological impact of planned nuclear facilities and in assessing the possible consequences of accidents involving releases of radioactive material to the environment. In the operational phase, models are used together with the results of environmental monitoring to demonstrate compliance with regulatory requirements concerned with radiation dose limitation.

There are four working groups within the VAMP programme: the Terrestrial Working Group, the Urban Working Group, the Aquatic Working Group, and the Multiple Pathways Assessment Working Group. The overall objectives of the VAMP programme are:

- to provide a mechanism for the validation of assessment models by using the environmental data on radionuclide transfer which have resulted from the Chernobyl release;
- to acquire data from affected countries for that purpose; and
- to produce reports on the current status of environmental modelling and the improvement achieved as a result of post-Chernobyl validation efforts.

1.3. MULTIPLE PATHWAYS ASSESSMENT WORKING GROUP

The Multiple Pathways Assessment Working Group performs biospheric model validation exercises which consider all relevant pathways leading to internal and external exposure from sources to human populations. The exercises are based on data available following the Chernobyl accident. Thus, the main objectives of this group are as follows:

- to test the predictive capability of models for multiple pathways of exposure;
- to identify the most important reasons for model misprediction; and
- to demonstrate the effect of model improvement on predicted results.

Suitable data sets for testing biospheric models exist in several countries; these are used to test a modeller's ability to predict the time variation of radionuclide concentrations in various foodstuffs and in the bodies of human populations, given, as input data, the air concentration during the deposition event. These data sets, which include both model input and observed data, represent the essential component (the test scenario) of the model testing exercise.

Input data included within a test scenario comprise:

- measurements of environmental radionuclide concentrations in air and soil samples in the region;
- environmental information such as meteorological characteristics, soil and water source characteristics, agricultural practices, and topographic and orographic features;
- population information such as residency habits and age- and sex-specific characteristics for food consumption; and
- information about food production, consumption, and distribution in the region.

Observed data are prepared by the scientists responsible for the measurement programmes from measurements taken at different intermediate steps and endpoints of the scenario. These include deposition estimates, time variation of radionuclide concentrations in ground level air, forage, vegetation, and food, and time variation of whole body concentrations in humans. To account for the variability and uncertainty of the observed data, both arithmetic mean values and 95% confidence intervals about these means are carefully prepared using statistical techniques and expert judgment, as necessary.

The exercises in this working group are carried out as so called "blind tests", i.e., the modellers receive a scenario description (input data) and are provided with the observed data only after their predictions, including uncertainty estimates, have been submitted to the Secretariat. For subsequent analysis of results, modellers are requested to submit their individual evaluation of model predictions based on comparison of predictions vs. observations, subsequent improvement of their models, and revised predictions. Because both the model predictions and observed data are associated with uncertainties, comparisons are made to arithmetic mean values as well as confidence intervals about these means for both model predictions and observed values.

The Multiple Pathways Assessment Working Group has already completed a test exercise using data from Central Bohemia in the Czech Republic [4]. This exercise examined a number of pathways and food types leading to exposure of humans. Among other things, the results showed the importance of (1) model-testing exercises to identify and correct errors in computer codes, (2) testing midpoints as well as endpoints to identify the presence of compensatory effects, (3) consideration of the influence of the model user on the results obtained from the computer code, and (4) obtaining as much detailed, site-specific information as possible. Scenarios under consideration for future exercises include sites in Russia, Ukraine, and the United States; some of the scenarios deal with Chernobyl fallout data, while others are being developed from data on historical releases of radionuclides.

1.4. SCENARIO S EXERCISE

Scenario S is the second test exercise of the Multiple Pathways Assessment Working Group. Data sets were collected in southern Finland (Suomi) for the ^{137}Cs contamination of various environmental media following the Chernobyl accident in 1986. The main purpose of the exercise and a description of the scenario are given in sections 1.4.1 and 1.4.2, below. The major differences between Scenario S and Scenario CB are (1) the inclusion of several additional midpoints and endpoints to give more detail in the food chain pathways, particularly the consideration of natural and semi-natural products (e.g. fish, game, berries, mushrooms) in the human diet; and (2) the disclosure of the test site at the beginning of the test exercise, permitting direct interaction between the modellers and the originators of the test data.

1.4.1. Purpose

The purpose of the exercise was to test model predictions against measurements for a number of test points and to intercompare estimates of doses to average members of the given population from external and internal radiation exposure. The input data for the calculations were ^{137}Cs concentrations in the air and on the ground. To enable a thorough comparison between model predictions and observations and a detailed analysis thereof, predictions were requested for average total deposition in the whole area, contamination of food and fodder, intake by humans, human whole body concentrations, and estimates of pathway-specific and total doses to humans.

The actual validation exercise was performed against the observed ^{137}Cs concentrations in food, fodder, and humans for a 5-year period following the accident. Dose estimates (for 1 year, 5 years, and 50 years) were requested within the context of radiation protection purposes only (they could be compared among modellers, but not validated).

1.4.2. Scenario description

The region of Scenario S (southern Finland) is shown in Fig. 1. Data sets (both input data and test data) were provided by the Finnish Centre for Radiation and Nuclear Safety (STUK) in Helsinki. The main features of the scenario are given below; a full description of the scenario is given in Appendix I.

Participants were provided with input data containing the following main items:

(1) Measurements of environmental ^{134}Cs and ^{137}Cs in the test area (air concentrations, ground contamination, total deposition, and soil samples/vertical profiles);
(2) Descriptions of protective measures employed;
(3) Environmental information (meteorological characteristics, topographical description, climatic conditions, descriptions of inland waters and forests);
(4) Agricultural information (practices by season, types of cultivated soils, and production and use of feeds);
(5) Information on agricultural production (foodstuffs);
(6) Information on sources of household water;
(7) Descriptions of hunting seasons and types of game;
(8) Information on the collection of natural products;
(9) Information on fishing;
(10) Information on food distribution; and
(11) Population information (age, dwelling and industrial structures, and food consumption).

This information was provided in the form of tables, most of which were also available on diskette from the IAEA Secretariat.

Predictions for the following time-dependent quantities of ^{137}Cs were requested:

(1) Total average (wet and dry) deposition and total inventory;
(2) Annual (1986-1990) average concentrations in leafy vegetables;
(3) Annual (1986-1990) average concentrations in cereals (wheat, rye);
(4) Annual (1986-1990) average concentrations in animal feeds (pasture vegetation, oats, barley);
(5) Monthly (1986) and quarterly (1987-1990) average concentrations in milk;
(6) Monthly (1986) and quarterly (1987-1990) average concentrations in beef;
(7) Monthly (1986) and quarterly (1987-1990) average concentrations in pork;
(8) Annual (1986-1990) average concentrations in small and big game;
(9) Annual (1986-1990) average concentrations in mushrooms;
(10) Annual (1986-1990) average concentrations in wild berries;
(11) Annual (1986-1990) average concentrations in freshwater fish;

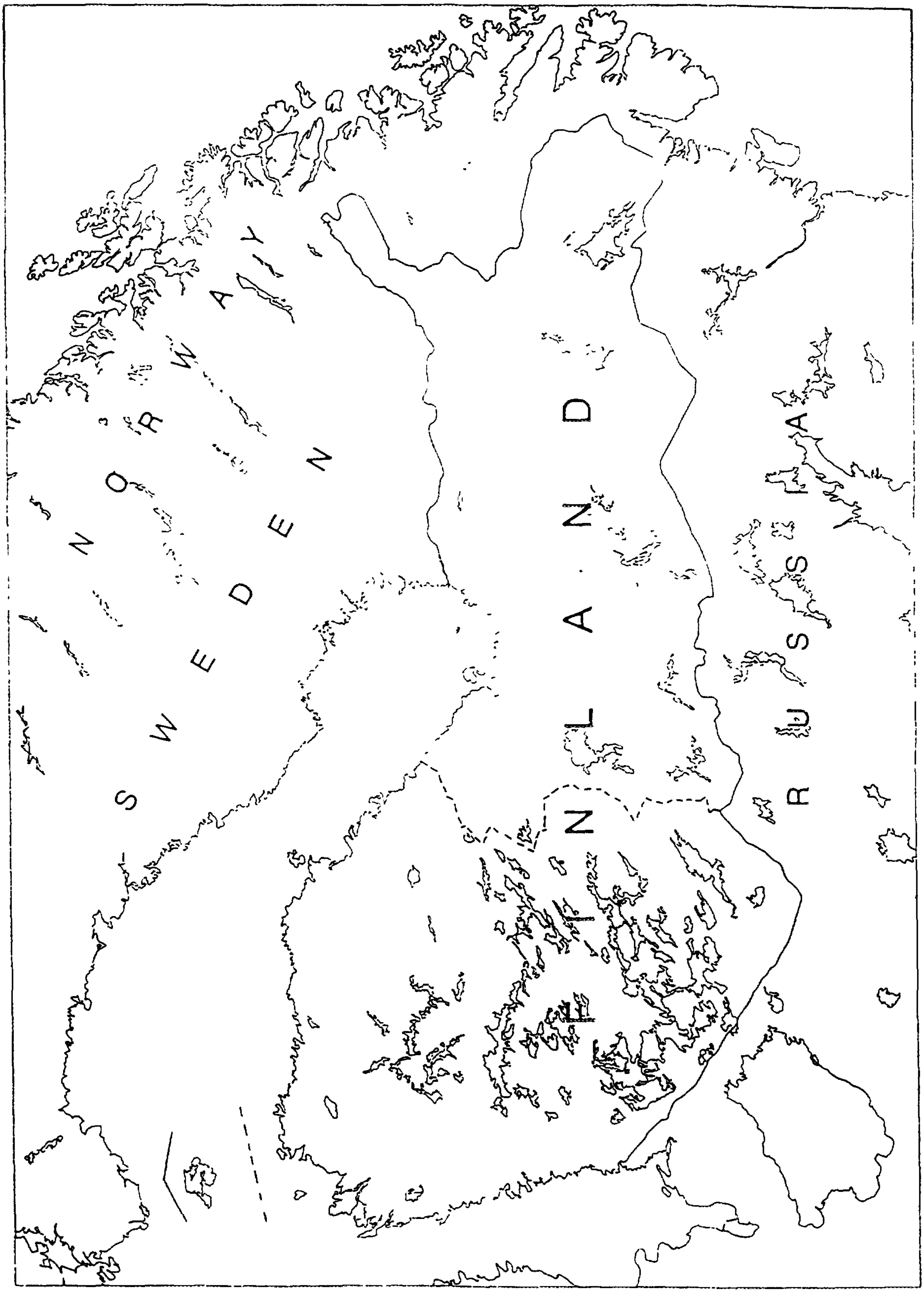


Fig. 1. Map of Finland showing the region considered in the test scenario.

(12) Average daily intake by humans (men, women, and children);
(13) Average concentrations in the whole body of humans (men, women, and children);
(14) Distributions of whole body concentrations for adult males;
(15) External dose (cloud and ground exposure);
(16) Inhalation dose (cloud and resuspension);
(17) Ingestion dose, with a summary of the three principal foods; and
(18) Total dose from all pathways.

Total deposition and total inventory were single, non-time-dependent predictions. Internal doses were time-dependent predictions, and external doses were time-averaged predictions based on time-dependent estimates. Distributions of whole body concentrations were requested for two time points, 31 December 1987 and 31 December 1990. For each quantity predicted, estimates of both the arithmetic mean and the 95% confidence interval about the mean were requested for the specified time periods.

For each of the assessment tasks listed above, observed data on Chernobyl-derived ^{137}Cs contamination of southern Finland were collected and evaluated by experts from STUK[1] for comparison with the model predictions. For those test endpoints that involved intercomparisons of dose estimates (i.e. external, inhalation, ingestion, and total doses), the STUK experts provided independent estimates based on their evaluation of the data on ^{137}Cs deposition density in soil and ^{137}Cs concentrations in soil, air, foodstuffs, and humans.

1.5. STRUCTURE OF THE REPORT

In Section 1, the introduction to VAMP and its Multiple Pathways Assessment Working Group, and the purpose and description of the second test exercise (Scenario S) are given. Section 2 summarizes the participation in the exercise and provides a description of the characteristics of the models used. A summary and discussion of the results of the test exercise is given in Section 3. Explanations for the main mispredictions described in Section 3 are provided in Section 4. In Section 5, the test data for Scenarios CB and S have been compared, followed by a discussion of uncertainty analyses in Section 6. Section 7 concludes the report with remarks from this exercise and general comments from the VAMP Multiple Pathways Assessment Working Group.

The main text of this report is supplemented by three appendices. Appendix I contains a detailed description of Scenario S, including both input and observed data. Appendix III contains description of models and the individual evaluations of model predictions by the participants in the exercise. Detailed documentation of model predictions is given in Appendix III.

2. PARTICIPANTS AND MODELS

In this model-testing exercise, model predictions were contributed by eleven participants. Participants and their models are listed in Table I, together with important characteristics of the models. Most of the models tested in the Scenario S exercise were developed over several years, and many have already been tested in previous international exercises, including the Scenario CB exercise recently completed by this working group [4] and the A4 and A5 scenarios of BIOMOVS [5,7] (participation in these exercises is indicated in Table I). Model documentation is provided in Appendix II. Ten of the eleven participants performed uncertainty analyses on some or all of their predictions; at least six of these used some form of Monte Carlo analysis.

[1]Here and in the subsequent text the references to STUK mean the small group of experts involved in the VAMP project located at STUK rather than STUK the national organization.

TABLE I. SUMMARY OF PARTICIPANTS AND MODELS IN THE SCENARIO S EXERCISE

Participant/MODEL	Country	Dynamic or equilibrium	Best estimate or conservative estimate	Method used for uncertainty propagation
Attwood/FARMLAND [a]	United Kingdom	dynamic	best estimate (but conservatively biased, uncertain to within a factor of 10-20)	judgment
Bergström/ECOPATH [b]	Sweden	dynamic	conservative	Monte Carlo (LHS)
Galeriu/LINDOZ [b,c]	Romania	dynamic	best estimate	Monte Carlo/judgment [e]
Horyna/SCHRAADLO [b,c]	Czech Republic	dynamic	best estimate	Monte Carlo
Kanyar/TERNIRBU [b,c]	Hungary	dynamic	best estimate	Monte Carlo
Krajewski/CLRP [c]	Poland	dynamic	best estimate (uncertain to within a factor of 3)	analytical error propagation/ judgment [e]
Peterson/CHERPAC [b,c]	Canada	dynamic	best estimate (uncertain to within a factor of 5)	Monte Carlo (LHS)
Sazykina/ECOMOD	Russia	dynamic	best estimate	parameter perturbation
Suolanen/DETRA [a]	Finland	dynamic	best estimate (uncertain to within a factor of 10)	Monte Carlo/deterministic
Yu/RESRAD	USA	quasi-equilibrium	best estimate	Monte Carlo (LHS)
Zeevaert/DOSDIM [b,d]	Belgium	dynamic	conservative, but to a reduced degree	Monte Carlo (LHS)

[a] Code was used in the A4 and/or A5 exercises of BIOMOVS by a different user.
[b] Assessor participated in the A4 and/or A5 exercises of BIOMOVS with the same code or its predecessor.
[c] Assessor participated in the Scenario CB exercise with the same code.
[d] Code was used in the Scenario CB exercise by a different user.
[e] "Judgment" refers to judgment applied to uncertainty on the results, as opposed to judgment on estimates of uncertainty in the input data.

It must be emphasized that this exercise tested the performance of models and model users for one region as the result of contamination from a single event. A number of the computer codes had to be modified for this exercise, particularly with respect to use of site-specific information or for the addition of new pathways. These codes may well be changed again in the future. In addition, some models were used by their developers; others were used by new individuals who may have been less experienced either with the model or with the processes being modelled. In some cases, models were run to test their performance with default parameter values; in other cases, participants made extensive use of site-specific information.

In this report we have preserved the names of the models and the model users to indicate the fact that the accuracy of the model is a function of the assumptions of the model user, the structure of the code, and the suite of parameter values used. These in turn may reflect the purpose for which the model was developed, the experience of the model user, the individual's goals in participating in the model testing exercise, and the level of effort expended by the model user. Accordingly, the reader is encouraged to exercise caution in evaluating models based on their performance in a single test exercise. The reader is also encouraged to make use of Appendix II, which contains detailed descriptions of participating models and evaluations of model performance by the individual participants.

3. SUMMARY AND DISCUSSION OF RESULTS

The comparison of model predictions with observations for Scenario S is summarized in this section. Results are presented for the primary starting points, midpoints, and endpoints of the multiple pathways considered in this study: the average deposition of ^{137}Cs on the ground surface; the average concentrations of ^{137}Cs in animal feeds, in foodstuffs, and in the human body; and the estimates of the internal and external effective dose equivalents. Results are also shown for four models that attempted a simulation of the variability of ^{137}Cs whole body concentrations among individuals.

For predictions of time-variant quantities such as ^{137}Cs concentrations in various foods and human daily intake of ^{137}Cs, the results are presented as composite graphs showing each modeller's predictions of the quantities compared to the observed or estimated quantities. Distributions of human whole body concentrations are also shown as composite graphs. Predictions for total deposition, total inventory, and internal and external doses are shown for specified time points, together with the measured or estimated quantities. The graphical presentation permits easy comparison of predictions with observations, both in terms of the values at any time point and also with respect to the dynamic behavior of a time series or the location of a peak value. In addition, the uncertainty ranges of both the observations and the model predictions can be readily compared in the graphs.

Due to the range of test questions and the sheer volume of predictions, especially for time-variant quantities, it has not been considered satisfactory to use a single numerical index (e.g. P/O ratios) for comparison of model predictions and observed data. The values for the test data (observations or estimates) and the model predictions, with their associated uncertainties, are given in tables in Appendix III. Readers desiring to perform additional quantitative analyses for selected endpoints may make use of these tables. In addition, readers are strongly encouraged to read Appendix II, in which modellers present detailed evaluations of their own modelling performance.

Unless otherwise noted, the predictions presented in the graphs are those which were initially submitted. Following evaluation of the predictions, some participants submitted revised predictions. These revisions are discussed at appropriate places in this report; in particular, examples of revised predictions are discussed in Section 4.6 and in the participants' write-ups in Appendix II. Revised predictions for doses are discussed in Section 3.8.

3.1. TOTAL DEPOSITION AND TOTAL INVENTORY

The average deposition density for the region of southern Finland was 19 900 Bq m^{-2} with an uncertainty of 13 900 to 25 900 Bq m^{-2}. Almost all participants produced estimates that fell within this range (Fig. 2, top) despite the use of different sources of data for the starting point of their calculations. Most participants relied on deposition measurements and soil data reported for individual sampling stations and for all the subregions of S, but some (Galeriu/LINDOZ, Peterson/CHERPAC, Krajewski/CLRP) used measurements of radiocaesium in air and rain to produce similar results. Attwood/FARMLAND used only deposition measurements from individual sampling stations, neglecting information reported on subregion averages. This subset of information was chosen to simulate the types of raw data available at the time of an accident. However, for the calculation of activity concentrations in food and doses from ingestion, a deposition of 19 500 Bq m^{-2} (inventory of 3.05×10^{15} Bq) was used.

Differences in uncertainty estimates produced by the modellers reflected differences in interpretation of the representativeness of the reported data given in the scenario. The large uncertainty estimates given by Peterson/CHERPAC are due to the large distributions on dry deposition velocity and washout ratios, because air was used as the starting point. The initial prediction by Suolanen/DETRA included an uncertainty estimate of about 2 orders of magnitude; this estimate, which was not carried through to subsequent calculations, was later revised (the revised prediction is shown in Fig. 2).

The total inventory of ^{137}Cs deposited in southern Finland, 3.5×10^{15} Bq, is the simple product of the average deposition density and the area of the region. Nevertheless, substantial mispredictions occurred initially due to unit-conversion errors. Fig. 2 (bottom) shows the results for the deposition inventory after correction for this common source of error.

3.2. ANIMAL FEEDS

3.2.1. Pasture vegetation

Pasture vegetation in southern Finland is composed mostly of timothy (*Phleum pratense*), meadow grass (*Festuca pratensis*) and clovers (*Trifolium sp.*). The average concentration of ^{137}Cs in pasture varied from 1500 Bq kg^{-1} fresh wt. in May of 1986 to 2 Bq kg^{-1} during the summer of 1990. A tendency to overestimate was exhibited by some models (Bergström/ECOPATH and Krajewski/CLRP) due to the reporting of results on a dry instead of wet weight basis. Although this could make a difference by as much as a factor of five, the predictions were still within the confidence intervals given for the observed values (Fig. 3). The tendency to underestimate exhibited by other models was due to the assumption of a faster rate of fixation of cesium in the root zone of soil than actually occurred. The strong seasonal dynamics predicted by Suolanen/DETRA were due to his assumption that the transfer of cesium from soil to plants is affected by the growth rate of pasture vegetation.

Most pasture samples were taken from the southern part of southern Finland, which is known to have different soil characteristics than the areas where most dairy cows and beef cattle are raised. For this reason, it is difficult to use the pasture data in the validation of models for the rest of the food chain or for testing for compensatory effects in the milk and meat pathways. However, it was known in advance that the available pasture data for 1987-1990 were not representative of the areas where cattle were raised.

3.2.2. Barley and oats

Barley and oats are produced mainly for feeding cattle, pigs, and poultry. The delay between harvesting and distribution of cereals in feed mixtures varies from a few months to about a year. The mean values of observed data show a substantial increase in cesium during 1989, with concentrations being within a factor of two of the observed average values for 1986 (Figs 4 and 5). None of the participants reproduced this effect, although the confidence intervals presented by four were sufficiently wide to contain all observed mean values. The annual fluctuations in cesium concentrations observed for barley and oats probably reflect the fact that they are grown on varying soil types, including organic (peat) soils and coarse mineral soils as well as clay soils. This effect is not observed for grains such as wheat and rye, which are uniformly sown on clay soils (see Section 3.3.2, Figs 7 and 8). The ^{137}Cs remains bioavailable longer in organic and coarse mineral soils than in soils with considerable fraction of clay. Cesium uptake may also be affected by annual differences in summer climate. The low values for 1987, for example, coincide with a summer of low mean temperatures and high precipitation during which considerable crop failure occurred.

The absence of dynamic trends for predictions given by Attwood/FARMLAND for barley and oats is due to the assumption that no cereals were sown until 20 May - after the deposition occurred - and therefore the effects of direct deposition and translocation were not seen. Similarly, the absence of dynamic trends for predictions given by Yu/RESRAD and Zeevaert/DOSDIM is due to the assumption that no significant contamination resulted from direct deposition onto plant surfaces, as well as the assumptions that these grains are in equilibrium with the soil and that soil concentrations are being maintained by ploughing. The very large confidence bounds presented by Zeevaert/DOSDIM reflect uncertainty due to the grouping of all grains (except rye) into a single model compartment. A similar assumption is made by Yu/RESRAD, but the confidence bounds for the predictions for grains for this model are relatively small.

3.3. FOODSTUFFS

3.3.1. Leafy vegetables

The observations for leafy vegetables include cabbage (93%) and lettuce (7%). The annual mean concentrations are somewhat comparable from year to year, with 1989 being about the same as 1986 (3 Bq $kg^{-1}_{fresh\ wt.}$) (Fig. 6). Because most of the vegetables (all of the lettuce) were grown in greenhouses, direct deposition of ^{137}Cs on plant surfaces from ventilation air was only significant pathway during 1986, when growing media were uncontaminated. Some uptake of ^{137}Cs into the vegetables occurred later (1987-1990) from use of contaminated peat as a growing medium.

The effect of direct deposition during 1986 is overestimated by five participants because of assumptions that the contamination of leafy vegetables would be similar to that of pasture vegetation located outdoors. Successful results for the period 1987 through 1990 are due to the method used for modelling root uptake and the correct assumption about the slow rate of fixation of ^{137}Cs in peat soil. Noticeable underestimations are produced by three participants and overestimations by two. These are primarily the result of misestimation of the uptake of ^{137}Cs from peat soil. The large underestimation by Zeevaert/DOSDIM, however, was the result of misreading the output of the code. Despite small estimates of uncertainty, the confidence intervals associated with model predictions of Krajewski/CLRP, Kanyar/TERNIRBU, Bergström/ECOPATH, and Sazykina/ECOMOD encompassed most of the observed annual mean values. Peterson/CHERPAC was the only participant to encompass all observations within the confidence bounds of the model predictions.

3.3.2. Cereals (wheat and rye)

Wheat and rye are uniformly sown on fine mineral soils. For 1986, ^{137}Cs concentrations were about 5 Bq kg^{-1} for wheat and 30 Bq kg^{-1} for rye (Figs 7 and 8). By 1987 the mean concentrations of ^{137}Cs for both plant species dropped about one order of magnitude; thereafter annual mean concentrations decreased only marginally (to about 0.3 Bq kg^{-1} for wheat and 1 Bq kg^{-1} for rye by 1990). The observed annual mean concentrations for rye and wheat after 1986 are more constant than they are for barley and oats.

Six of the 11 participants reproduced the general trends in the annual mean concentrations for both rye and wheat. Five participants included all mean observations for wheat within the confidence intervals of their predictions, while only three were similarly successful for rye. The large overestimates produced by Bergström/ECOPATH were due primarily to the use of a conservatively biased soil-to-plant transfer coefficient for these grains. Two participants (Sazykina/ECOMOD and Yu/RESRAD) used averaged values for soil-to-plant transfer for grains obtained from a draft version of a recent IAEA Handbook [8]. This produced relatively accurate results for rye but led to large overestimates of the observed mean annual concentrations in wheat after 1986. A comparable overestimate for wheat was produced by Zeevaert/DOSDIM, but because of the large uncertainty assigned to the model predictions, the observed mean values were within the confidence bounds of the model predictions. The predictions produced by Attwood/FARMLAND were expected to be within a factor of 20 of the observed values and to be biased on the conservative side. These expectations were not met for rye or for the 1986 observations for wheat, due to the assumption that no cereals were sown until 20 May and therefore the effects of direct deposition and translocation were not seen.

3.3.3. Milk

Concentrations of ^{137}Cs in milk did not rise immediately after the initial deposition of ^{137}Cs because dairy cows were still on a diet of stored feed. Mean concentrations were about 2 Bq L^{-1} in May of 1986, rising to 30 Bq L^{-1} by June 1986 (Fig. 9) after cows were released from their stables and put out on pasture. Weathering of ^{137}Cs from the surfaces of pasture vegetation accounted for the observed decline in the mean concentration of ^{137}Cs during the summer of 1986, but the introduction of hay and silage harvested after midsummer 1986, when ^{137}Cs content higher than in July and in August 1986, increased the concentration during the last quarter of 1986. After 1986, a slight decline in milk concentrations was observed each succeeding summer when the cows were put out on fresh pasture. The rate of decline of concentrations in milk was relatively slow, with the concentrations at the end of 1990 being still slightly higher than the concentrations in May of 1986 and about 10% of the peak concentrations of June 1986 and the winter of 1986-1987.

Most models underestimated the concentrations of ^{137}Cs after 1987. The only participant to include all observed mean values within the confidence bounds of the predicted values was Suolanen/DETRA. A direct explanation of the reasons for underestimation is difficult to obtain since the observed values available for this exercise for pasture were known not to be underestimated, although the upper confidence limit was expected to be realistic for the region. Underestimation of the milk concentrations may be due to overestimation of the rate of ^{137}Cs fixation in soil, underestimation of the soil uptake by pasture vegetation, and underestimation of the fraction of the animal's diet composed of contaminated grain.

Some participants have suggested that the milk transfer coefficient for ^{137}Cs may have been underestimated; however, this coefficient has been fairly well established in the literature and is probably not the cause for the general underestimation produced by most participants for the years after 1987. For example, Galeriu/LINDOZ assumed that the milk transfer coefficient would increase after the summer of 1986. Despite this assumption, substantial underestimation was made of the observed mean concentrations after 1987. Galeriu/LINDOZ later matched the observed values by using soil-to-plant uptake coefficients that were specific to each of the regional soil types used to produce pasture, hay, and silage.

Attwood/FARMLAND and Sazykina/ECOMOD overstated the effect of seasonal variability in the mean milk concentrations. The underestimate produced by Attwood/FARMLAND during 1986 was due to errors made in a parameter value and in the modelling of winter feeding. The apparent accuracy of Attwood/FARMLAND after 1987 is the result of compensatory effects.

3.3.4. Beef

The observed mean ^{137}Cs concentrations for beef exhibited similar trends to those for milk, except that concentrations in beef were generally a factor of four higher (Fig. 10). Concentrations increased rapidly to over 100 Bq kg^{-1} by June of 1986 from an initial observed mean value of about 10 Bq kg^{-1} for May of 1986. After 1986, a decrease in ^{137}Cs concentrations in beef was observed during the third and fourth quarters of each year. By the fourth quarter of 1990, the concentrations in beef were almost equal to those measured in May 1986.

As was the case with milk, most participants underestimated concentrations in beef after 1987; these underestimates are probably due to underestimation of the uptake of ^{137}Cs from soil to grain and pasture and overestimation of the rate of ^{137}Cs fixation in surface soil. The most accurate predictions were produced by Krajewski/CLRP and Suolanen/DETRA. The predictions of Krajewski/CLRP are suspected to have been the result of compensatory effects. As with milk, direct determination of compensatory effects is difficult without detailed measurements of the animals' diet.

Underestimates of the observed concentrations during 1986 were made by five participants. These participants assumed that cattle did not receive much contaminated fresh feed during the summer of 1986; however, the scenario description stated that although beef cattle in southern Finland did not graze, they are fed fresh grass. The large underestimate produced by Attwood/FARMLAND during 1986 was due to errors in a parameter value and in the modelling of winter feeding. In addition, the fraction of the diet which was contaminated was substantially overestimated due to the use of default consumption habits.

3.3.5. Pork

The mean observed concentrations of ^{137}Cs in pork began at about 0.8 Bq kg^{-1} in May of 1986, peaked at about 15 Bq kg^{-1} during the summer of 1987, and remained at about 6 to 7 Bq kg^{-1} from 1988 through 1990 (Fig. 11). The peak concentrations in pork were about 10 to 12 times below those for beef. Unlike concentrations in milk and beef, however, ^{137}Cs concentrations in pork did not decrease after 1988, reflecting a diet dominated by grain.

Most participants underestimated concentrations in pork after 1988 by assuming that ^{137}Cs in the diet of pigs would decrease with time in a manner similar to that seen for pasture vegetation. Suolanen/DETRA suggested that the primary reasons for misprediction of the concentration in pork were inaccurate predictions of the concentration of ^{137}Cs in mixed grains and underestimation of the importance of mixed grain in the diet of pigs from this region.

Accurate estimates were produced only by the quasi-steady-state calculations of Yu/RESRAD, who made no estimates for 1986. The results by Yu/RESRAD were partially due to compensatory effects from overestimation of the concentration in the diet of pigs and underestimation of the diet-to-pork transfer.

With the exception of May 1986, the observed values were underestimated by Zeevaert/DOSDIM by about one order of magnitude due to incorrect assumptions about the amount and sources of ^{137}Cs in the diet of pigs; nevertheless, the relative dynamics of ^{137}Cs concentrations in pork were closely simulated. Large underestimates produced by Attwood/FARMLAND were due to an error in the calculations and also to assumptions made about the agricultural practices for cereals and pigs.

3.4. FOOD PRODUCTS FROM THE NATURAL ECOSYSTEM

This model testing scenario is the first to consider food products from natural ecosystems in addition to agricultural products. Most participants had to adjust parameter values and make structural changes to their models to predict concentrations of ^{137}Cs in food types obtained from the natural ecosystem. Many participants who submitted accurate predictions used published bulk transfer coefficients for specific food types and assumed that ^{137}Cs is located primarily in the uppermost surface (top 2 cm) of the soil of natural ecosystems and that irreversible fixation to clay minerals is negligible. Some models, e.g. FARMLAND, do not consider foods from semi-natural environments; estimates were made for these foods based on rapid reviews of the literature rather than an experienced knowledge base.

3.4.1. Wild berries

The annual mean observed values for wild berries in southern Finland remained relatively constant at about 100 Bq $kg^{-1}_{fresh\ wt.}$, with the lowest values occurring in 1987 and the highest in 1988 (Fig. 12). Those participants using published transfer coefficients on wild berries for Nordic countries or semi-arctic environments performed extremely well. Suolanen/DETRA used a generic soil-to-plant transfer factor for berries of 0.1 Bq $kg^{-1}_{berries}$ per Bq $kg^{-1}_{forest\ soil}$ and assumed that most of the ^{137}Cs would be distributed in the top 1.5 cm of soil. Bergström/ECOPATH, however, used a dry-weight transfer factor; the observations were reported on a fresh weight basis. Thus, the results of Bergström/ECOPATH are partially due to compensatory effects. Peterson/CHERPAC used empirical bulk transfer factors (Bq kg^{-1} per Bq m^{-2}) published for Nordic countries including Finland, and Sazykina/ECOMOD used data for the region of the Leningrad Nuclear Power Plant for each year after the Chernobyl event. The large underestimates produced by Yu/RESRAD were partially due to the use of soil-to-plant transfer factors published for fruit and to the assumption that ^{137}Cs in the soils of natural ecosystems is uniformly mixed to a depth of 20 cm.

3.4.2. Mushrooms

Mushrooms had the highest ^{137}Cs concentrations reported for southern Finland for food products derived from the terrestrial environment. The peak annual mean concentration observed for mushrooms was about 700 Bq $kg^{-1}_{fresh\ wt.}$ in 1989 (Fig. 13). Five participants produced confidence bounds for their predictions that encompassed the observed annual mean values.

Suolanen/DETRA used assumptions similar to those used for wild berries, but the soil-to-plant uptake factor was increased to 0.5 Bq $kg^{-1}_{mushrooms}$ per Bq $kg^{-1}_{forest\ soil}$. The overestimates produced by Bergström/ECOPATH are due to the selection of a high value of soil-to-plant transfer for Swedish mushrooms and to reporting the results on a dry-weight basis. The slight overestimates given by Sazykina/ECOMOD are due to the use of bulk transfer coefficients for forest mushrooms in the vicinity of the Leningrad Nuclear Power Station.

Peterson/CHERPAC used averages of empirical bulk transfer coefficients from the literature to produce best-estimate predictions for mushrooms that were within the confidence bounds of all observed annual mean values; the large confidence bound on the prediction for 1988 was due to an input error on the parameter distributions.

Galeriu/LINDOZ assumed that a given mushroom species has its mycelium at a certain depth in the forest soil. Using literature data for this depth, he derived species-specific transfer factors. The time-dependent concentrations of ^{137}Cs in mushrooms was calculated using a simple model of radionuclide migration in forest soil and the vertical soil profiles of ^{137}Cs concentrations given in the scenario descriptions.

3.4.3. Small and big game

Small game in southern Finland is made up of several species, including Arctic and European hare, waterfowl, and terrestrial birds. Big game is made up of moose (*Alces*) and deer (*Odocoileus virginianus*). The observed annual mean concentrations of ^{137}Cs between 1986 and 1990 for both small and big game animals were nearly equal (approximately 230 Bq kg^{-1}). Likewise, the sets of predictions were consistent among both food types for those participants who submitted results (Figs 14 and 15).

Five participants presented results for small game and seven for big game. Of these, three produced results with confidence bounds encompassing the observed values for small game, and four encompassed the observed values for big game. Only one participant (Attwood/FARMLAND) substantially underestimated the observed values in game. For big game, this was due to an error in the transfer factor used; the corrected results are within a factor of two of the observed values. For small game, the predictions were based solely on wildfowl, while the observed values included measurements for additional species such as hare.

Successful predictions were based on an abundance of published values in the radioecological literature for transfer coefficients for the uptake of radiocaesium into game animals of arctic and subarctic regions. Although both Bergström/ECOPATH and Sazykina/ECOMOD relied on published Swedish data to parameterize their models, they produced slightly different results. In general, for these examples, an averaged annual bulk transfer factor of about 0.012 Bq kg^{-1} per Bq m^{-2} was sufficient to produce accurate estimates for both small and big game.

3.4.4. Freshwater fish

This was the first test scenario to combine predictions of human exposure from both terrestrial and aquatic sources. Freshwater fish differed from the food types derived from the terrestrial components of the natural ecosystem, in that the mean concentrations of ^{137}Cs in freshwater fish showed definite trends with time. Concentrations started at about 900 Bq kg^{-1} in 1986, peaked at 1600 Bq kg^{-1} in 1987, and then decreased gradually with time to a low of 600 Bq kg^{-1} in 1990 (Fig. 16). Freshwater fish had the highest mean concentrations of ^{137}Cs of all food types examined in this study.

Five of nine participants encompassed the mean observed values within the confidence bounds of their predictions. Of these, the most accurate predictions were by Bergström/ECOPATH, who used a simple food chain model that had been tested in previous model validation studies using data on ^{137}Cs in the fish of Nordic lakes. This model and that of Suolanen/DETRA used the deposition by area as a starting point. Suolanen/DETRA used a detailed model for fish with coefficients derived specifically for fish of Finnish lakes. Other models used the reported concentrations of ^{137}Cs in water as the starting point for their calculations. Peterson/CHERPAC estimated the uptake and retention of ^{137}Cs in fish according to trophic level and the amount of dissolved potassium and suspended sediment in water [9]. Galeriu/LINDOZ used general information on bioaccumulation of ^{137}Cs in fish. Sazykina/ECOMOD used bioaccumulation data obtained for river fish near the Leningrad Nuclear Power Station, resulting in underestimates by a factor of about two.

The underestimates by Yu/RESRAD were due to the assumption that the fish would be in equilibrium with the concentrations in water. In addition, Yu/RESRAD used an averaged bioaccumulation factor for all species of fish and did not adjust it for trophic level or for the potassium content of the water. Attwood/FARMLAND also used an equilibrium model; the results, while underestimating the measured concentrations, were within a factor of two of the observations. The results of Zeevaert/DOSDIM were influenced by the selection of a bioaccumulation factor that was low by a factor of three and which did not take into account the dissolved potassium concentrations in the water [9].

3.5. AVERAGE DAILY INTAKE OF ^{137}Cs BY HUMANS

Daily intakes of ^{137}Cs for adult males, adult females, and children (10 years of age) were estimated by STUK experts from dietary survey information (Figs 17-19). In general, the estimated daily intakes for adult males are higher than for adult females and children. For males, the peak intakes were estimated in 1987 at 50 Bq d^{-1}; the lowest value (about 13 Bq d^{-1}) was estimated for the end of 1990. For adult females and children, the peak estimated daily intakes were about 30 to 35 Bq

d^{-1}, with the 1990 low about 10 Bq d^{-1} for females and 7 Bq d^{-1} for children. For 1989 and 1990, food products from the natural environment were important contributors to the total estimated intake of ^{137}Cs.

The only participants with confidence bounds that overlap the entire time series of estimated intakes are Galeriu/LINDOZ, Peterson/CHERPAC, and Suolanen/DETRA. Of these, Suolanen/DETRA slightly overestimated the intakes for females. Substantial overestimates are produced by Attwood/FARMLAND for all ages and sexes; this could be largely due to the errors made in the food concentrations and also to the use of FARMLAND default assumptions. Large underestimates were produced after 1987 by Kanyar/TERNIRBU, Krajewski/CLRP, and Zeevaert/DOSDIM. The confidence bounds given by Zeevaert/DOSDIM, however, were sufficiently wide to include the majority of the estimated intake values.

The STUK estimates for the dietary intake of adult males may have been overestimated, based on a comparison of measured whole body concentrations of ^{137}Cs with the concentration estimated from the total diet (Fig. 20). Differences in the estimated and measured results could be due to differences in the assumed diet and metabolism and the actual diets and metabolism of the measured individuals; measured individuals probably altered their diets in response to being told their measured concentrations. If the estimated average daily intakes are biased high, then predictions made by Yu/RESRAD, Sazykina/ECOMOD, and Bergström/ECOPATH may be more nearly accurate than indicated in Figs 17-19.

3.6. AVERAGE ^{137}Cs CONCENTRATIONS IN HUMANS

Whole body concentrations of ^{137}Cs were measured in adult males, adult females, and children. From 1986 to 1990, the observed mean ^{137}Cs whole body concentrations for adult males were consistently about 1.5 times higher than for females (Figs 21-22). For 10-year old children, the mean whole body concentrations (Fig. 23) were nearly the same as the means for adult females, with the exception of 1986, when the concentrations in children were nearly equal to those for adult males. In general, the diets of women and children are similar; the consumption of milk may have been the most important factor contributing to the concentration of ^{137}Cs in the whole body. For men in general, milk and fish may have been the most important contributing factors. The consumption of fish and possibly wild game may have been important in determining the highest whole body concentrations among individuals, especially several years after the Chernobyl accident.

Galeriu/LINDOZ was the only participant to produce confidence intervals that encompassed all observed mean whole body concentrations for men, women, and children (Figs 21-23). The estimates made by Peterson/CHERPAC, Suolanen/DETRA, and Yu/RESRAD are also fairly accurate (within a factor of two of the observations), although the concentrations during the first half of 1986 were overestimated. Suolanen/DETRA incorporated published data on the retention of ^{137}Cs in adults and children of the Finnish population but still tended to overestimate the whole body concentrations for adult females and children. The large overestimates produced by Attwood/FARMLAND were due to compounded conservatism concerning the estimate of concentrations in the diet and the extrapolation from diet to whole body concentrations. This could be largely due to the errors made in the food concentrations and also to the use of FARMLAND default assumptions.

Most participants calculated whole body concentrations from their estimates of daily intake (see Section 3.5). In several cases, results obtained for the whole body concentrations are probably due to compensatory effects – overestimates of daily intake and underestimates of food concentrations (e.g. milk and beef). This is especially likely considering that modellers produced estimates for averages of whole populations, while STUK provided measurements of actual individuals who might have altered their diets in response to disclosure of their measured concentrations; in other words, the measured whole body concentrations might be biased low.

3.7. VARIABILITY OF ^{137}Cs CONCENTRATIONS AMONG INDIVIDUALS

Distributions of measured whole body concentrations for men, women, and children for 1987 and 1990 are shown in Fig. 24. For adult males, the observed distribution of individual whole body concentrations at the end of 1987 was approximated by a log-normal distribution with a geometric mean (GM) of 37 Bq kg^{-1} and a geometric standard deviation (GSD) of 1.6. By the end of 1990, the concentrations in most males in the region had decreased (GM = 14 Bq kg^{-1}), but variability had increased (GSD = 1.9). The whole body concentrations for males in the top 2.5% of the distribution at the end of 1990 departed substantially from the idealized log-normal distribution and were nearly identical to the top 2.5% of the males observed at the end of 1987. The appearance of this special population subgroup among the distribution of individual whole body concentrations may be due to consumption by these individuals of large quantities of fish, wild game, and forest mushrooms.

The geometric mean for children decreased considerably between 1987 and 1990 (from 25 to 7 Bq kg^{-1}), but the variability increased (from GSD = 1.6 to GSD = 2.1), with the highest individual in 1990 actually exceeding the highest individuals in 1987. For women the change in variability was not so pronounced (GSD = 1.8 in 1987 to 1.9 in 1990), while the geometric mean decreased from 26 to 9 Bq kg^{-1}.

The distinction between variability and uncertainty is currently the state of the art for assessment modelling. To encourage participants to produce predictions for a stochastic variable, they were requested to reproduce the variability of individual whole body concentrations of ^{137}Cs for males at the end of 1987 and 1990 and to provide a statement of uncertainty about this estimate. Variability in individual whole body concentrations should take into account variability in both diet and individual metabolism.

Four participants submitted results for this assessment endpoint; of these, three gave confidence bounds about their predictions (Figs 25-26). The only participant to successfully produce confidence bounds that encompassed most of the observed values was Peterson/CHERPAC. Yu/RESRAD produced relatively accurate mean estimates of the whole body concentration, but variability among individuals was underestimated for both time periods. The results of both Peterson/CHERPAC and Yu/RESRAD were partially influenced by compensatory effects. Misprediction of ^{137}Cs in the diet resulted in significant underestimation by Kanyar/TERNIRBU for both 1987 and 1990. Suolanen/DETRA, using data specific for Finland, overestimated individual variability for 1987. In 1990, variability in the low end of the distribution was overestimated, but the high end was underestimated.

3.8. ESTIMATES OF INTERNAL AND EXTERNAL EFFECTIVE DOSE AND TOTAL DOSE

The final goal of the scenario was to predict mean values of the total effective doses to adults (20 years old in 1986) via several pathways of exposure. This portion of the scenario is an intercomparison among model predictions and the independent estimates of dose prepared by investigators at STUK. The 50-year dose estimates are projections. Dose calculations were received from nine of the eleven participants. Dose estimates were requested for the following pathways:

(1) inhalation of ^{137}Cs in the initial cloud,
(2) inhalation of ^{137}Cs resuspended from surface deposits,
(3) external exposure from ^{137}Cs in the passing plume,
(4) external exposure from ^{137}Cs deposited on ground and other surfaces, and
(5) exposure from ingestion of ^{137}Cs in foods.

Estimates for the inhalation dose from resuspension, the external dose for ground exposure, and the ingestion dose, as well as the total dose from all pathways, were requested for the periods 27 April 1986 - 30 April 1987, 27 April 1986 - 31 December 1990, and 27 April 1986 - 27 April 2036. For internal doses (inhalation and ingestion), the committed effective dose equivalent over a 50-year period was requested; for external exposure, the requested dose estimates were for effective dose equivalents for the given periods. Participants were also asked to list the three greatest contributors to the ingestion dose and total dose, respectively.

Due to some confusion concerning the definition of the ingestion dose, an opportunity was provided for recalculation to ensure that all estimates submitted were for the committed effective dose equivalent. Revised estimates of the ingestion dose were received from Galeriu/LINDOZ, Krajewski/CLRP, Sazykina/ECOMOD, and Yu/RESRAD, together with corresponding revised estimates for total dose. The figures in this section include these revised dose estimates. Other revised dose estimates submitted by participants are also included in the figures; explanations of these revisions are discussed in the appropriate contexts.

3.8.1. The effective dose from inhalation of and external exposure to the initial plume

The STUK estimate of the effective dose from inhalation of ^{137}Cs during the initial passing of the plume from Chernobyl was about 200 nSv, with an uncertainty of about a factor of five on either side of this estimate. Five participants produced relatively accurate predictions while four produced overestimates (Fig. 27, top). Zeevaert/DOSDIM and Attwood/FARMLAND overestimated the inhalation dose because they simulated the concentrations in air from the reported ground deposition and ignored the reported air concentrations for the scenario. Attwood/FARMLAND had assumed that the observed air concentrations were not representative of the whole region. The revised estimate shown for Attwood/FARMLAND was based on measured ^{137}Cs concentrations in air. The differences among model predictions are due to differences in the estimate of the time-integrated air concentration and the estimated filtering of air by buildings. The estimate shown for Suolanen/DETRA includes a revision to decrease the size of the uncertainty estimate; the estimate shown for Zeevaert/DOSDIM is a revision following correction of an error in the code.

The STUK estimate of the effective dose to people outdoors from external exposure to the cloud was about 5 nSv, with an uncertainty of a factor of five. The initial predictions of all but one participant fell within the uncertainty limits of the STUK estimated dose (Fig. 27, bottom). This overestimate (Horyna/SCHRAADLO) is partially due to overestimation of the amount of ^{137}Cs in air as well as to underestimation of the filtering of air by buildings. The initial estimate of Suolanen/DETRA fell within the uncertainty limits, but the revised value, while having a smaller uncertainty estimate, shows an underestimate of the dose. The estimate shown for Attwood/FARMLAND was revised to account for shielding by buildings.

3.8.2. The effective dose from inhalation of resuspended ^{137}Cs

The effective dose during 1 year from the inhalation of ^{137}Cs from resuspension of surface deposits was estimated by STUK to be about 50 nSv, or about 25% of the dose from the initial inhalation of the cloud. By December 1990 the effective dose had risen to about 60 nSv, and it is projected that the total inhalation dose from resuspension of ^{137}Cs will have increased only to about 65 nSv by the year 2036. This slow increase in the inhalation dose over time reflects the fact that the effectiveness of wind in resuspending surficial deposits is assumed to decrease exponentially with the age of the deposit. The uncertainties on these estimates are about a factor of five on either side of the best estimate.

Seven participants submitted results for the resuspension pathway (Fig. 28). Of these, Horyna/SCHRAADLO, Kanyar/TERNIRBU, and Suolanen/DETRA produced underestimates. The figures show revised results for both Suolanen/DETRA and Yu/RESRAD; initial predictions from both modellers used incorrect values for the mass loading factor.

3.8.3. The effective dose from external exposure to ground deposition

The effective dose estimated by STUK for external exposure to ^{137}Cs deposited on the ground surface increased with time from 0.06 mSv in April of 1987 to 0.19 mSv by December 1990 to 0.7 mSv by 2036 (Fig. 29). The uncertainties on these estimates are less than a factor of two. Doses calculated by STUK with the UNSCEAR-1988 model are also shown in the figure.

The 1987 STUK dose estimates were predicted by nearly all participants (Fig. 29). The underestimate by Kanyar/TERNIRBU for this time period was due to the assumption of rapid downward migration of ^{137}Cs enhanced by agricultural ploughing. For 1990, Yu/RESRAD produced an overestimate by assuming that ^{137}Cs is continuing to remain near the soil surface. The underestimates for the lifetime dose produced by Krajewski/CLRP and Peterson/CHERPAC reflect a more rapid downward migration of ^{137}Cs in soil than assumed by STUK. Revised predictions are shown for Yu/RESRAD and Suolanen/DETRA and Attwood/FARMLAND; those for Suolanen/DETRA and Attwood/FARMLAND reflect the lower dose estimates obtained when shielding was considered.

3.8.4. The effective dose from ingestion

The ingestion doses (committed effective dose equivalents from ingestion) estimated by STUK increased from 0.10 mSv in April of 1987 to 0.31 mSv by December 1990 to a projected dose over 50 years of about 0.70 mSv (Fig. 30). The 1987 and 1990 dose estimates were based on measurements of whole body concentrations. An initial projection of the dose over 50 years was based on dietary intake using a reference diet from the late 1980s and consumption of domestic foodstuffs. The revised projection shown in Fig. 30 is based on a radiocaesium ingestion level lower than that initially assumed. This lower projected dose takes into account reduced consumption of some of the wild food products.

Primary contributors to the ingestion dose are shown in Fig. 31 as percentages of the predicted or estimated ingestion dose. The estimated percentage contributions of various foodstuffs to the ingestion doses are based on information on the diet of the late 1980s, without any corrections for assumed ingestion level of radiocaesium. For 1987 and 1990, the estimated ingestion doses were dominated by the consumption of milk, beef, and freshwater fish; for the lifetime dose projection, mushrooms replace beef as a major contributor to dose.

The 1-year dose was overpredicted by all modellers, although the confidence bounds of several overlapped the STUK estimate. Predictions were much closer for the 4.5-year estimate and the 50-year projection. Most participants listed milk, beef, and freshwater fish as the major contributors to dose at all time points. The exceptions were Peterson/CHERPAC, who listed fruit rather than beef at all time points and Galeriu/LINDOZ, who listed mushrooms rather than beef for 1990. Most predictions corresponded to the STUK estimates in listing milk as the most important contributor to ingestion dose in 1987, with milk decreasing in importance and fish increasing in importance toward the later time points.

Predicted ingestion doses shown for Galeriu/LINDOZ, Krajewski/CLRP, Sazykina/ECOMOD, Yu/RESRAD, and Zeevaert/DOSDIM include revised values. The revised values for Yu/RESRAD reflect downward revisions in the predicted contribution of beef to the total ingestion dose. The percentage contributions shown for Galeriu/LINDOZ are based on his initial predictions for ingestion dose. Zeevaert/DOSDIM listed rye rather than fish as a primary contributor to ingestion dose in his initial predictions for 1987.

3.8.5. The total effective dose from all pathways of exposure

The total dose estimated by STUK from all pathways of exposure increased from 0.16 mSv in 1987 to 0.50 mSv by December 1990 to 1.4 mSv for the 50-year projection (Fig. 32). Contributions of the external and ingestion doses are shown in Fig. 33 as percentages of the total dose. (Inhalation doses were not included in the figure as in most cases these were negligible in comparison to the other two.) The STUK estimates show ingestion dose as contributing about two-thirds of the total dose at 1 year and 4.5 years, but slightly more than half of the total dose over 50 years.

Most participants produced overestimates of the total dose. Attwood/FARMLAND produced consistent overestimates for all time periods due to overestimation of both external and ingestion doses. Lower estimates of the lifetime dose were produced by some modellers due to assumption of either a more rapid rate of ^{137}Cs fixation or a more rapid downward migration of ^{137}Cs, as well as to lower estimates of the long-term contribution of grains to the diet of livestock and the neglect of food sources from the natural ecosystem. All participants predicted a greater contribution from ingestion dose than external dose for 1987, but several of them predicted external dose to be as important as or more important than ingestion dose for 4.5 and 50 years.

Revised predictions for total dose are shown for Galeriu/LINDOZ, Krajewski/CLRP, Sazykina/ECOMOD, Suolanen/DETRA, Yu/RESRAD, and Zeevaert/DOSDIM. Initial predictions of total dose from Peterson/CHERPAC were not consistent with the pathway-specific predictions; corrected values for total dose are shown here. Although values for total dose were not submitted by Galeriu/LINDOZ or by Suolanen/DETRA for 1987 and 1990, the sums of the external and ingestion doses that were submitted by these participants are shown here for the sake of completeness. In cases where the sum of the predicted ingestion and external doses exceeded the value of the predicted total dose, or where no value for the total dose was given by the participant, the percentage contributions were calculated with respect to the sum of the external and ingestion doses.

4. MAJOR EXPLANATIONS OF MISPREDICTIONS

The major reasons for model misprediction fall into six general categories: (1) formulation of the conceptual model, (2) selection of values for transfer coefficients and other model parameters, (3) compensatory effects, (4) errors in the computer code, (5) differences in the use and interpretation of the information given in the scenario, and (6) common mistakes such as use of the wrong unit-conversion factors (for a general discussion of the evaluation of model reliability, see Ref. [10]). Specific types of errors or problems are described below, followed by a brief description of some of the revised predictions produced by modellers after they had an opportunity to determine the reasons for their misprediction. Individual evaluations of model performance have been prepared by the participants and are included in Appendix II. The evaluations include the participants' explanations for their own mispredictions, together with descriptions of any improvements made to the models and the resulting revisions in the model predictions.

4.1. FORMULATION OF THE CONCEPTUAL MODEL

Problems of this type include the use of an equilibrium model to describe a dynamic situation, the aggregation of discrete processes into a single model parameter, and failure to include an important process or pathway. Use of a quasi-equilibrium model rather than a dynamic model affected model predictions primarily in the first year in this test exercise. The prediction by quasi-equilibrium models of annual averages for later years gave acceptable results for many endpoints.

For Scenario S, a particularly important finding was the change in the relative importance of the dominant pathways contributing to the whole body burdens of ^{137}Cs from the first year after contamination to later time periods. For the first year, factors of particular importance included the composition of livestock diets (in particular, the use of stored vs. fresh feed) and the planting and harvesting dates. Because the release occurred in the spring, major differences in model predictions occurred with small changes in planting dates. The stage of growth of the vegetation at the time of the initial release was a critical factor. The initial interception and retention of contamination on vegetation and the surface weathering of vegetation were not a factor for crops or pasture vegetation (and hence the milk pathway) because these plants were not yet growing, but these factors were potentially important for such things as trees, berry plants, and greenhouse crops grown in peat. For later years, important processes identified were the fixation and migration of ^{137}Cs in soil, the bioaccumulation of ^{137}Cs in fish, decontamination of soil and water, and the amounts of semi-natural food products (particularly mushrooms, wild game, and fish) in the human diet.

Omission of pathways from the conceptual model is another potential source of error. For southern Finland, omission of fish or mushrooms from the assumed diet could lead to underpredictions of human intake and whole body concentrations several years after the initial release, due both to the importance of these items in the diets and to the persistent high levels of contamination in these items.

4.2. SELECTION OF PARAMETER VALUES

The choice of values for transfer coefficients and other parameters is a common source of differences in model predictions; this is especially the case when modellers are dealing with sites or situations different from those for which the model was developed or with which the modeller is familiar. Accurate predictions to within a factor of two of observed values were consistently produced by those who selected parameter values derived from literature data on the behavior of ^{137}Cs in subarctic regions or in specific soil types.

4.3. COMPENSATORY EFFECTS

Model testing for midpoints (e.g. animal feeds and various foodstuffs for human consumption) as well as endpoints permits the detection of compensatory effects in a model. Compensatory effects occur when an overprediction in one compartment is offset by an underprediction in the flow to another compartment, or vice versa, so that the apparent accuracy of the endpoint is greater than that of either individual model component.

4.4. ERRORS IN THE COMPUTER CODE

This category includes such things as errors in coding the equations and typographical errors in the code. The perennial occurrence of such errors highlights the importance both of intercomparison of results between independent modellers and of graphical representation of model predictions. Many errors of this type are readily detected when the predictions are graphed, particularly when discrepancies between independent modellers are examined.

4.5. USE AND INTERPRETATION OF THE SCENARIO INFORMATION

Variation in user interpretation (or misinterpretation) of the site-specific information in the scenario description led to some differences or errors in model predictions. Examples of misinterpretation of the scenario include modelling of mixed rather than separate cereals, use of dry vs. wet weight for pasture vegetation, and use of the end of the calendar quarter vs. the average for the quarter. Differences also occurred from use of actual vs. average information for such things as weather information, planting and harvesting dates, feeding regimes, and dates of changes between pasture and stable. Additionally, there were questions concerning the actual diets of people and livestock, as well as the question of whether the pasture samples used as test data were representative of the areas where the cattle actually grazed (see Section 3.2.1). A major conclusion, of course, is that site-specific information for a test scenario should be as accurate, complete, and representative as possible, in order to minimize the potential for differences in user interpretation. Nevertheless, under actual assessment conditions, completely relevant site-specific data are seldom if ever available. Therefore, the test conditions presented by Scenario S approximate those of a real assessment situation that requires interpretation of imperfect data sets by the assessor.

4.6. EXAMPLES OF REVISED PREDICTIONS

The test scenario requested that, upon receipt of the test data, modellers submit as applicable a summary of reasons for mispredictions, a description of necessary changes in the models, and a demonstration of improvements in the model predictions. Specific discussions of improvements made are found in Appendix II, together with detailed documentation by the individual participants. A few selected examples are shown here for situations where model predictions were substantially improved due to changes in assumptions or parameter values. In addition, revised dose predictions are given in Section 3.8.

Comparisons of initial and revised predictions for milk and beef are shown for selected modellers in Figs 34-37. Kanyar/TERNIRBU, in revising predictions for milk, adjusted for less rapid diffusion of ^{137}Cs into deeper soils and therefore a higher concentration available for uptake into plants and eventually into milk (Fig. 34, top). Yu/RESRAD adjusted predictions in beef both by correcting for an initial underprediction of ^{137}Cs in feed and by adjusting the transfer factor for beef (Fig. 34, bottom). Peterson/CHERPAC adjusted the concentration ratio from soil to pasture vegetation upwards by a factor of 7.8 to revise predictions for both milk and beef (Fig. 35, top and center). Corrected predictions for mushrooms are also shown for Peterson/CHERPAC (Fig. 35, bottom).

Attwood/FARMLAND corrected a parameter value and made adjustments for the modelling of winter feeding of both dairy and beef cattle (Fig. 36, top and center). The remaining mispredictions are attributed to assumptions made about diet and the modelling of the harvesting of silage and hay during 1986. Also shown are revised predictions for pork (Fig. 36, bottom), following correction of an error in the calculations and adjustment of assumptions made concerning agricultural practices.

Galeriu/LINDOZ adjusted soil-to-plant transfer for animal feed to account for different soil types and also adjusted the fixation rate of ^{137}Cs in soil; revised predictions for milk, beef, and pork are shown in Fig. 37. Whole body concentrations for men and women based on the revised values for these foodstuffs are shown in Fig. 38, and dose predictions based on the revisions are given in Section 3.8.

Zeevaert/DOSDIM had a calculational error in the code which affected most of his initial predictions. Revised predictions are shown in Figs 39 and 40 for several endpoints following correction of the error; revised dose predictions are given in Section 3.8. No other adjustments were made in these revised predictions. The most significant improvements were for wheat and fish (Fig. 39, top and center).

Additional examples of revised predictions are given in Appendix II by many of the modellers. For instance, Sazykina/ECOMOD, for milk and beef, used a smaller annual decrease in soil and grass contamination (20% instead of 50%) and for milk, also changed the value of the milk transfer coefficient (from 0.8% d L^{-1} to 1.5% d L^{-1}).

5. COMPARISON OF TEST DATA FOR SCENARIOS CB AND S

The availability of two independent data sets for model testing, Central Bohemia (CB) and southern Finland (S), provided an opportunity to compare the behaviour of the contaminant concentrations in two very different locations over a period of several years. The test data used for the CB exercise initially covered a three-year period (through April 1989), while the test data for Scenario S extend through the end of 1990. However, I. Malátová and her colleagues at the National Institute of Public Health, Czech Republic provided supplemental data for Central Bohemia for two additional years so that comparisons for both locations over a five-year period could be made.

Obviously, one major source of difference between concentrations observed in CB and S is the difference in total deposition: 19 900 Bq m^{-2} (95% confidence interval, 13 900 to 25 900 Bq m^{-2}) for southern Finland as compared to 5570 Bq m^{-2} (95% confidence interval, 4050 to 7660 Bq m^{-2}) for Central Bohemia. For that reason, observed and time-integrated ^{137}Cs concentrations in milk, beef, pork, and humans were normalized to the total deposition (Table II, Figs 41-44). The uncertainties in Figs 41-44 include both the uncertainty in the observations and the uncertainty in the total deposition for the respective locations.

TABLE II. NORMALIZED VALUES FOR TIME-INTEGRATED CONCENTRATIONS OF ^{137}Cs FIVE YEARS POST-DEPOSITION FOR SCENARIOS CB AND S [a].

	Scenario CB	Scenario S
	Time-Integrated Conc./ Total Deposition (Bq d kg^{-1} per Bq m^2)	Time-Integrated Conc./ Total Deposition (Bq d kg^{-1} per Bq m^2)
Milk [b]	0.609	1.06
Beef	2.41	4.58
Pork	1.71	0.655
Human whole body	1.72	2.07

[a] Values represent concentrations at the beginning of 1991.
[b] For milk, the units are Bq d L^{-1} per Bq m^2.

The differences in the normalized observations for the early measurements (approximately the first year) demonstrate the dependence of the observations on the characteristics of the initial deposition. For instance, ^{137}Cs was deposited in CB by both wet and dry processes, while for S, deposition occurred mainly during periods of rain. The distance from Chernobyl may have also affected the characteristics of the initial deposition at each location. For the later years, concentrations in foodstuffs were influenced greatly by the soil properties, and the concentrations in humans were influenced by the food types consumed. Cesium-137 has remained bioavailable longer in the soil of southern Finland than in that of Central Bohemia, resulting in persistently higher concentrations in milk, beef, and pork for S than CB during the years after 1987 (Figs 41-43). For pork, the differences are due to the diets of pigs in the two regions. In Central Bohemia, pigs are fed primarily on milk products such as whey, and the concentrations of ^{137}Cs in pork in CB follow the same trends as for milk. In Finland, however, the pigs eat mostly grains; the pork concentrations do not appear to decline with time because the concentrations in feed grains have not declined.

The normalized average whole body concentrations of ^{137}Cs in humans (adult males and females) are not greatly different for the two locations in the earlier years (Fig. 44). However, after five years the concentrations are almost three times higher for southern Finland than for Central Bohemia. The major difference is probably due to differences in the human diet between the two regions, with people in Finland obtaining a much higher proportion of their diet from semi-natural food sources (e.g. fish, wild game, and mushrooms), which contained persistently high levels of ^{137}Cs. When average whole body concentrations are compared, it should be recognized that the observations for Central Bohemia are not necessarily representative of the entire population of the region (measurements were made primarily for people connected with the institute carrying out the measurements), while the Finnish data represent a more systematic, though not entirely random, sampling approach. As discussed in Section 3.7, the Finnish data also suggest the presence of a subgroup of the population with different dietary habits leading to very high whole body concentrations; this in turn will affect the average concentration for the population.

The distributions of individual whole body concentrations for adults for Central Bohemia and southern Finland were compared for 1987 and 1990 (Figs 45 and 46). When these data were normalized for total deposition, essentially no difference was seen between CB and S for 1987 (Fig. 45). For 1990, however, there was no overlap at all, with the Finnish data showing both higher normalized concentrations and greater variability among concentrations (Fig. 46). Again, this difference is the result of the different soil properties, the types of food consumed, and the portion of the population consuming large quantities of food from natural and semi-natural systems.

6. DISCUSSION OF UNCERTAINTY ANALYSES

In this test exercise, estimates of uncertainty were required for both the test data and the model predictions; these estimates provide a statement of confidence about the model predictions. Different statements of uncertainty are required for a true but unknown mean value vs. a true but unknown distribution of values. Most of the test exercise dealt with uncertainty on the estimates of the mean values. For one test endpoint, however, the objective was to simulate the variability among individuals of ^{137}Cs in the whole body. In this case, it was necessary to produce estimates of uncertainty about the true but unknown distribution of whole body concentrations.

Ten of the eleven participants included estimates of uncertainty on their model predictions, while the other gave a semi-qualitative estimate of about 1 order of magnitude about the predicted values. Four modellers attempted to reproduce the distribution on whole body concentrations, and three of these included estimates of uncertainty for the distribution. This is the first time that an international model validation study has attempted to distinguish between the issues of inter-individual variability (Type A uncertainty) and uncertainty due to lack of knowledge about fixed but unknown quantities (Type B uncertainty). (For more in-depth discussion on the need to distinguish between variability and uncertainty in radiological assessments, see Refs [10,11].)

Uncertainty estimates differed among investigators, illustrating the judgmental nature of uncertainty analysis; this in part reflects the judgmental nature of modelling in general. Participants differed in their methods of estimating uncertainty, with some making a subjective judgment at the end of the exercise and others doing a formal propagation of uncertainty throughout the exercise (see Table I in Section 2). At least as important were differences in subjective judgment about various pathways or parameters and differences in the level of familiarity with the site and with available data.

The ranges of uncertainty over all of the test endpoints varied from less than a factor of two to more than a factor of ten about the best estimate, reflecting different philosophies about uncertainty. Some differences are due to judgment, either about the uncertainty in the model results or about the uncertainty in the model input data. Other differences are due to interpretation of Monte Carlo results. The lowest estimates of uncertainty given for model predictions are in fact statements of overconfidence, because predicted confidence intervals fail to overlap that of the observed data at several time periods.

Bergström/ECOPATH, whose predictions generally had narrow ranges of uncertainty, assumed that the Monte Carlo results produced by ECOPATH represented inter-individual variability. She decreased the results to reflect the fact that the uncertainty in the mean should be smaller than that for individual observations. Other modellers viewed their Monte Carlo results as alternative realizations of a true but unknown mean from which confidence bounds for the mean were obtained directly. The large uncertainty in Zeevaert/DOSDIM reflects high uncertainty in the estimate of the transfer of cesium from soil to plant.

Rather than using a formal method of uncertainty estimation, Attwood/FARMLAND gave a semi-qualitative estimate of about one order of magnitude about the predicted values. The calculations were made within the context of a generic assessment using a minimum of site-specific information without any model adjustments to account for the specific situation in southern Finland.

For model testing of regional average concentrations in Southern Finland of ^{137}Cs in nontraditional pathways such as wild game, fish, and mushrooms, the uncertainties were small. This unexpected result was due to the availability for these pathways of site-specific data on bulk transfer coefficients.

A variety of items were identified as being dominant sources of uncertainty in the final results. These included (1) the composition of animal and human diets, especially the proportion of natural and semi-natural food products in the diets and the variability of diet among individuals; (2) the transfer coefficients for milk, beef, and pork; (3) distribution of feeds and food types among geographical subregions of the test area; and (4) the rate of ^{137}Cs fixation in surface soil for both undisturbed pasture and ploughed agricultural land.

Uncertainty estimates should be an expression of the modeller's confidence in the model predictions when the test data are not known. Once the test data are revealed, the uncertainty estimates should be revised. It has been found, in evaluation of model predictions vs. observations (test data), that inclusion of estimates of uncertainty is absolutely essential for a sound interpretation of the results. It has also been found that this evaluation is most effectively done when the results (test data and predictions) are presented graphically.

7. CONCLUDING REMARKS

7.1. CONCLUSIONS FROM THE SCENARIO S TEST EXERCISE

The objectives of the Multiple Pathways Assessment Working Group have been to test the predictive capabilities of exposure models, to identify the most important reasons for model misprediction, and to demonstrate the effects of model improvement. A specific goal of the Scenario S exercise was the prediction of doses to average members of a designated population from external and internal exposure to ^{137}Cs from the Chernobyl accident.

Predictive capabilities of the various models were demonstrated in Section 3 for a large number of endpoints, including estimates of internal and external doses. Model performance in many cases was excellent, with predictions within a factor of two of the observations; discrepancies between the estimates of annual average concentrations produced by most participants and the test data seldom exceeded a factor of ten. In most cases, these discrepancies were biased high (overestimation of observed values). Of particular importance in achieving accurate model predictions were the experience of the user, the flexibility of the model, and the availability of abundant site-specific data. The least accurate model predictions tended to occur as a result of mistakes (e.g. coding errors or errors in hand calculations or unit conversions), the inexperience of the user, or use of default rather than site-specific parameter values. In many ways, an exercise that was begun for the testing of models ended by being a test of modellers and assessors.

A number of examples of model improvement are described in Section 4.6, and others are included in participants' individual evaluations (Appendix II); revisions to predicted doses are described in Section 3.8. Detailed descriptions of how each modeller or modelling group benefited from the exercise are also in Appendix II. A number of the modellers made improvements to their models at the start of this test exercise, either to take advantage of lessons learned in the CB exercise or other previous work, or to expand the capabilities of their models to include new endpoints (e.g. fish or mushrooms).

When considering either performance of or improvements to models, the purpose of the model and the goals of the model user must be considered. If the modeller chose not to include endpoints such as fish or mushrooms, then the predictions for daily intake, whole body concentration, and ingestion dose will reflect the absence of pathways which were important for this location; for other locations or populations, absence of these pathways might have no effect on predictions of ingestion dose or whole body concentrations. Similarly, deliberate use of default rather than site-specific parameter values may produce results of low accuracy which are nevertheless acceptable for the model user's own purposes. Uncertainty estimates should also reflect the model's expected or intended performance. Again, the individual descriptions and evaluations given by the participants (Appendix II) are essential reading.

In this context, it is also important to distinguish between predictions made in real emergency assessment situations, in which the modeller would have had access to any available information (e.g. milk concentrations) for calibration purposes, and predictions made for a validation exercise such as Scenario S, in which some information was withheld. On the other hand, in other types of real assessment situations, such as projections of the future impact of a nuclear facility, types of information that were supplied to modellers in the Scenario S exercise (e.g. actual meteorological data) would not be available at all.

Scenario S has been the most comprehensive test of multiple pathways exposure assessment models conducted to date. This scenario has been the first of its kind to include portions of the human diet originating from the natural and semi-natural ecosystem. It is also the first to test for the importance of the consumption of freshwater fish in the determination of human whole body concentrations of ^{137}Cs initially deposited from the atmosphere. The data collected for this exercise have confirmed the importance of the contribution of natural and semi-natural ecosystems to ingestion doses to critical groups, as well as to the entire population, for several years post-deposition.

The test data for this exercise illustrate the differences that occur in the dietary uptake and whole body concentrations of ^{137}Cs for individuals due to differences in sex and age. The test data also demonstrated that different pathways dominated the exposure of the residents of southern Finland at different times following the contaminant release. In the first year or two, milk was the major dietary contributor to exposure of the population, followed by meat (domestic beef) and fish; later on fish became much more important than beef. Over a human lifetime, the most significant dietary components for the average resident of southern Finland are expected to be fish, milk, and forest mushrooms, in that order.

Changes with time in the dominant pathways of human exposure were affected by soil composition and hence soil fixation of ^{137}Cs. Food products derived from the natural ecosystem were particularly important because the bioavailability of ^{137}Cs in the soils, especially the forest soils, did not decline much with time, and the soils therefore provided a continuing source of ^{137}Cs to the food chain. The ^{137}Cs concentrations in barley and oats, which were grown in soils of varying types, including coarse mineral soils and peat soils as well as clay soils, remained at relatively constant levels even after several years post-deposition; this trend was reflected in pork produced from these feeds.

In Scenario S, as opposed to Scenario CB, the modellers were told the name of the test area and were permitted to ask questions of the authors of the scenario description. The test was blind only in that the actual test data for the midpoints and endpoints of the scenario were not revealed until after predictions had been submitted. In addition, the participants were asked not to consult the published literature for the site.

Differences between the test data from Scenarios CB and S were reduced to within a factor of two to three once the data were time-integrated and normalized to the total amount of ^{137}Cs deposited within each region. The largest difference observed between these locations was that the time-integrated concentrations (normalized for total deposition) of ^{137}Cs did not level off as fast for S as for CB. Differences in soil types between the two regions and the contribution of food products from the natural ecosystem are thought to be the major explanations for this observation.

The process of testing independent model calculations against independent data sets also provided useful information to the originators of the test data. The discussions led to rethinking of interpretations of some measurements by the developers of the test scenario and to in-house revisions to some estimates of concentrations, dietary intakes, and doses.

7.2. ADDITIONAL CONCLUSIONS FROM THE VAMP MULTIPLE PATHWAYS ASSESSMENT WORKING GROUP

Two detailed, high-quality data sets designed for model-testing purposes and including estimates of uncertainty are now available both for additional modellers who wish to use some or all of the information to test their own models and for future modellers to use in the development or testing of new models. Inexperienced modellers can use these data sets to gain experience with their models or with the modelling process, with the important benefit of being able to test the accuracy of their answers.

The reports on the exercises include detailed documentation of each model (including model structure, equations, assumptions, and parameter values), graphical presentations of model results compared both with other model results and with the test data, and the modellers' own evaluations of their performance in the test exercise. Future modellers can examine other people's approaches to specific problems to see how well those approaches worked for those problems or to compare them with their own approaches.

Participants in these test exercises were provided an opportunity for: (1) correction of errors in their computer codes; (2) identification of compensatory effects in the model structures; (3) discussion of specific processes and the best ways to model them; (4) discussion of differences in scenario interpretation; (5) discussion of ways to improve model performance; (6) comparison of model structures, equations, and choice of parameter values; and (7) improvement of the interpretations of the test data, especially the conversion of whole body ^{137}Cs concentrations to committed effective doses.

The test exercises identified or reemphasized a number of important aspects of successful modelling:

- The experience of the modeller, especially with respect to understanding the processes being modelled, is perhaps the single most important factor in determining successful model performance.
- Computer codes should permit flexibility in model structure to allow adaptation for site-specific conditions.
- Compensatory effects in intermediate steps of an exposure pathway can give good results for the wrong reason.
- Inclusion of estimates of uncertainty for both the test data and the model predictions is absolutely essential for a sound interpretation of the results.
- Uncertainty estimates are highly dependent on judgment and thus differ among investigators.
- Uncertainty estimates produced by individual assessors frequently do not encompass the observed values; they are thus statements of overconfidence.
- As previously concluded by other model-testing exercises (e.g. Refs [12,13]) critical assessments should be performed by more than one assessor or modelling group. Multiple independent assessments are effective in disclosing discrepancies in user judgment and differences in interpretation of input data. In these cases, resources should be allocated to resolving these differences before drawing final conclusions.
- The evaluation of model complexity and model performance must be considered in light of the intended purpose and level of accuracy of the model in question. For this reason, participants were required to provide a detailed analysis of the performance of their own models or codes.

Quantitative measures of model performance were sought to facilitate objective comparisons of predictions and observations. In order to accommodate simultaneous comparison of several different aspects of model performance (e.g. peak values, the dynamic behavior of the entire time series, and overlapping uncertainty estimates), it was decided to use graphical comparisons. Comparisons across models were made by placing on the same page multiple graphs of similar scale and containing the same test data, with each individual graph containing the results from a single model. For endpoints which did not involve a time-series (e.g. deposition, dose estimates), the results for each endpoint, with uncertainties, were displayed on a single graph.

Explanation of the reasons for model misprediction often requires information from experimentalists who are concerned with describing process-level scientific phenomena. To some extent this information was acquired through the interaction of participants in the Multiple Pathways Assessment Working Group with scientists in the Urban, Terrestrial, and Aquatic Working Groups of VAMP. In addition, sufficient time must be available within the modelling exercise to resolve questions that arise. In the case of Scenario S, three separate meetings were necessary following the release of the test data.

These general conclusions are expected to hold for a variety of assessment situations. However, the task of model validation has only begun – it is not finished. Participants in the Multiple Pathways Assessment Working Group have identified a number of needs for the future:

- more testing at the process level,
- more testing for pathway midpoints,
- testing for endpoints of critical population groups (e.g. agricultural workers, dairy farmers, hunters, fishermen, and harvesters of forest mushrooms),
- testing at more sites,
- testing for a wide variety of radionuclides, and
- extending testing to include nonradioactive trace contaminants.

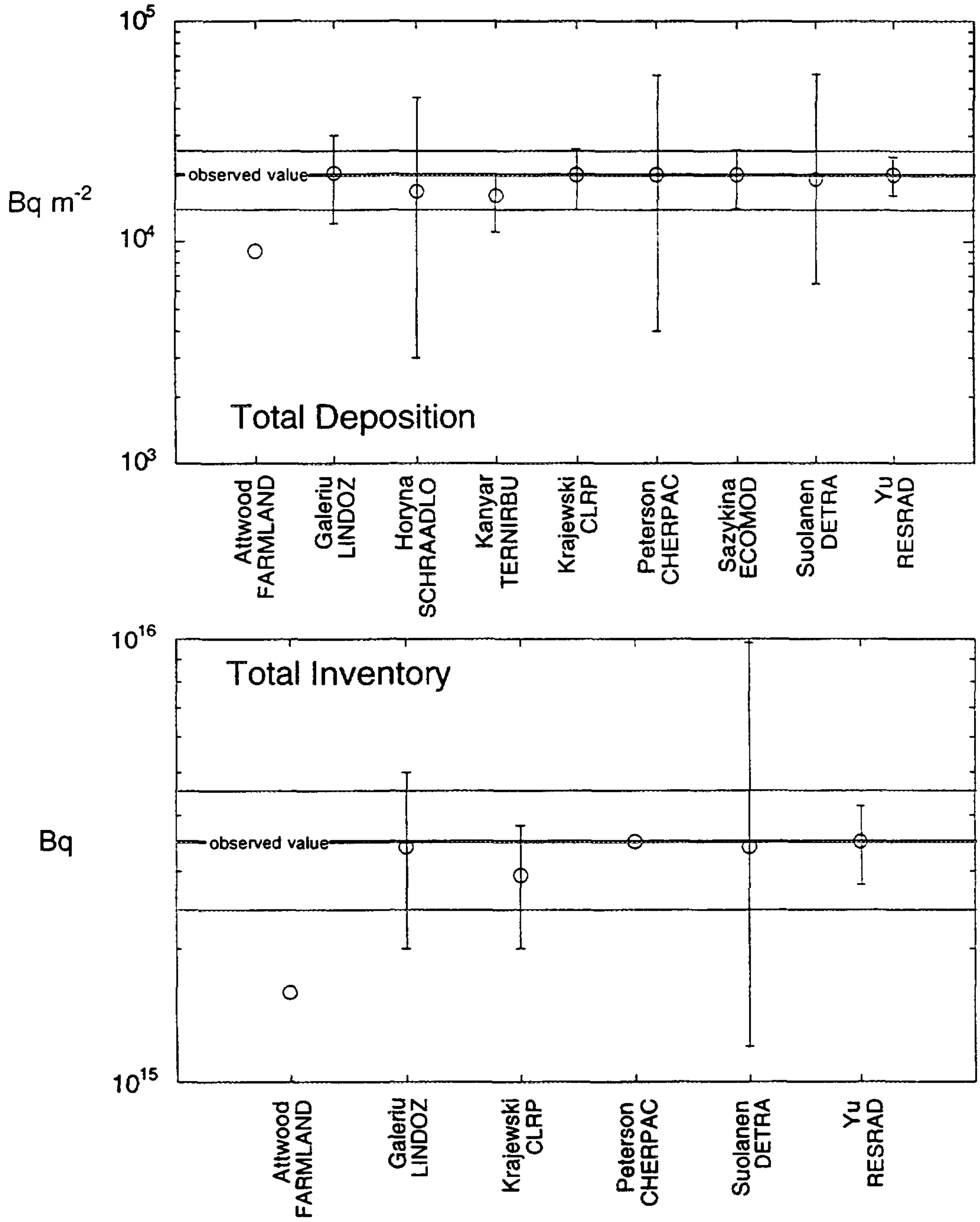


Fig. 2. A comparison of predictions to observations for the mean deposition density (top) and total deposition inventory (bottom) of ^{137}Cs in southern Finland. The mean values derived from observed data and their 95% confidence intervals are indicated by horizontal lines. The predicted means are open circles with vertical bars indicating the 95% subjective confidence intervals about the means. Results shown include corrections for Peterson/CHERPAC (total inventory) and Suolanen/DETRA (both).

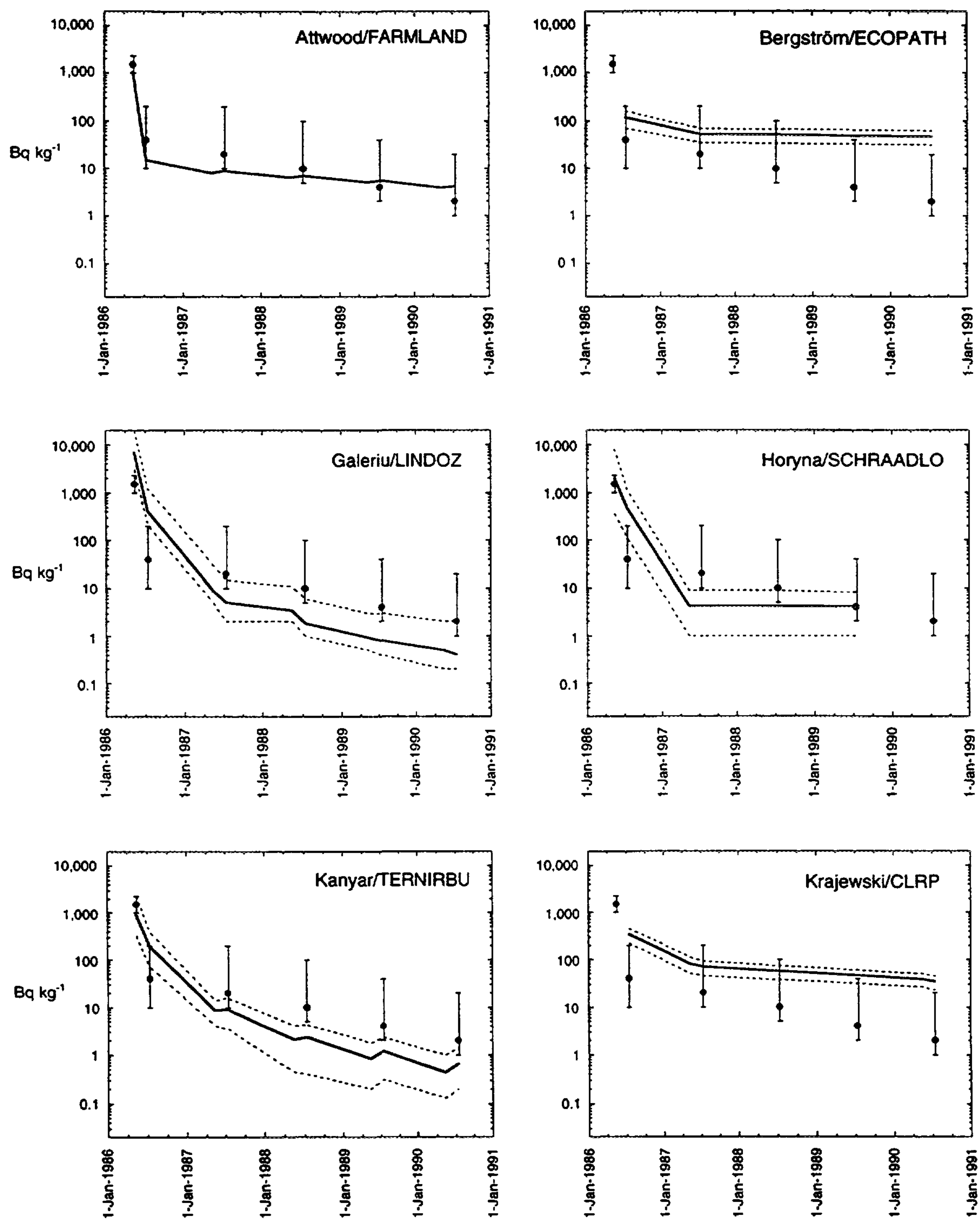


Fig. 3. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in pasture vegetation in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

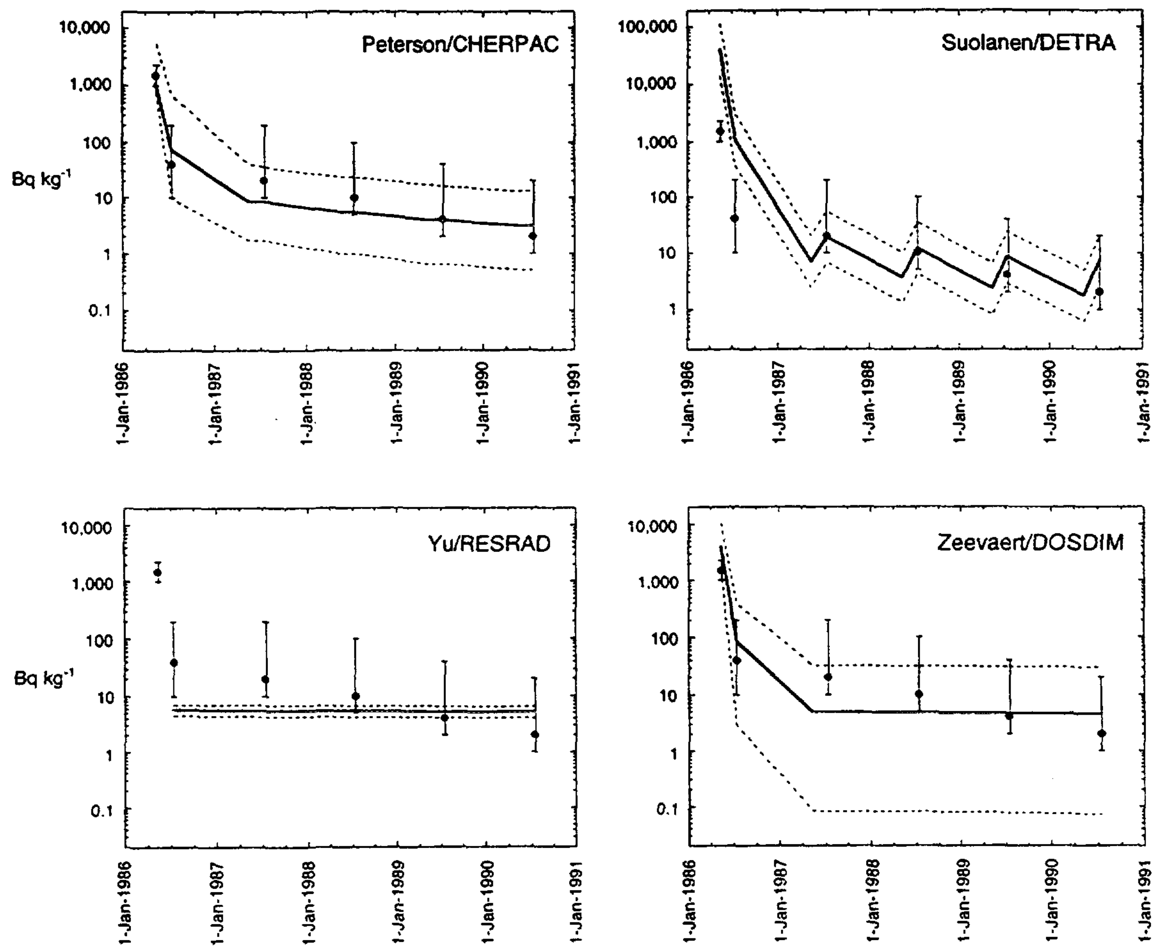


Fig. 3 (continued)

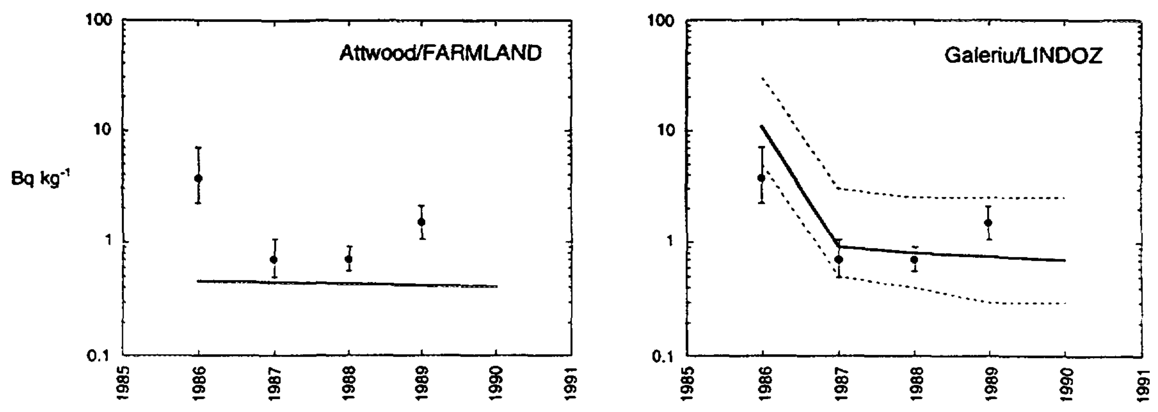


FIG. 4. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in barley in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

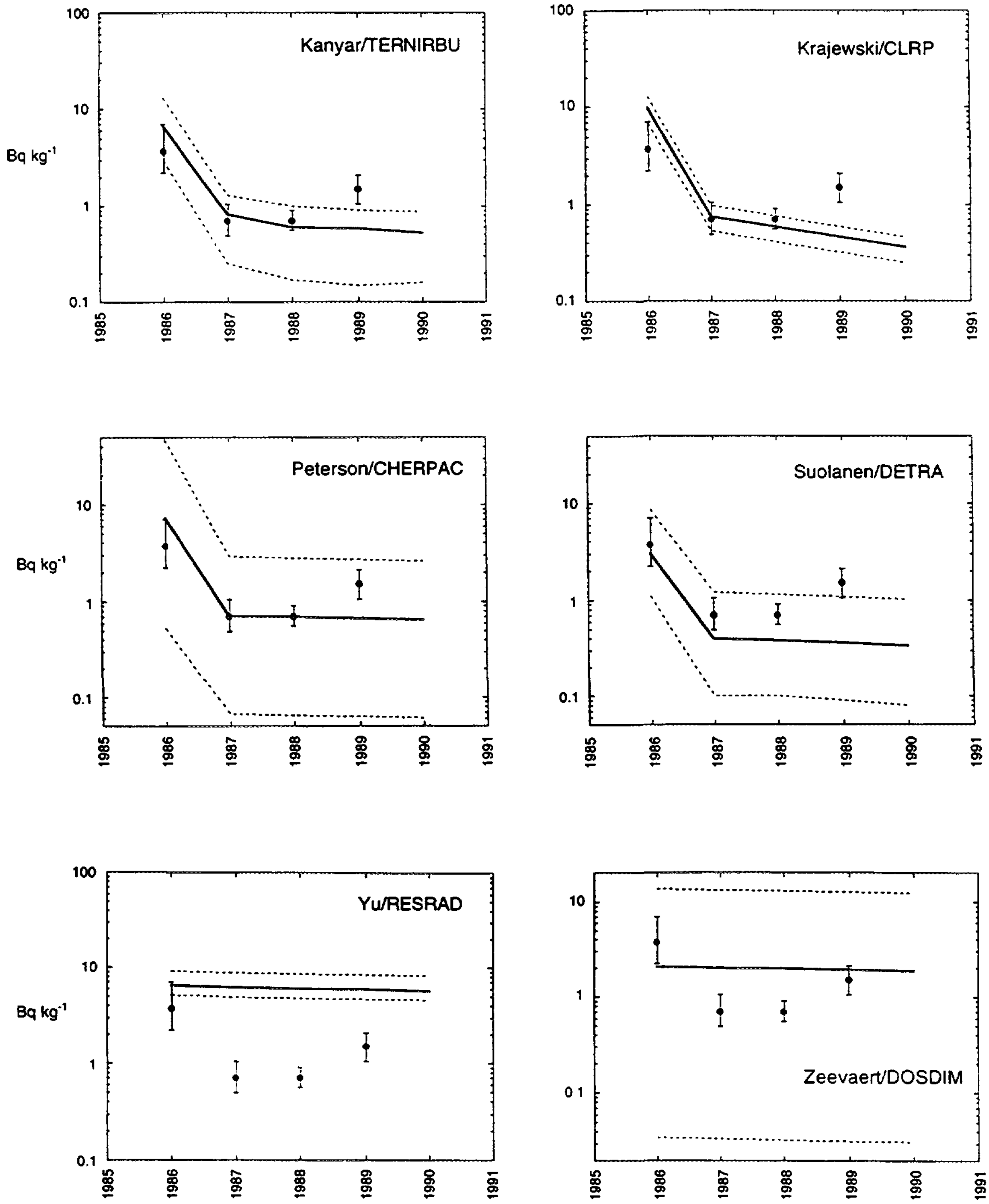


Fig. 4 (continued)

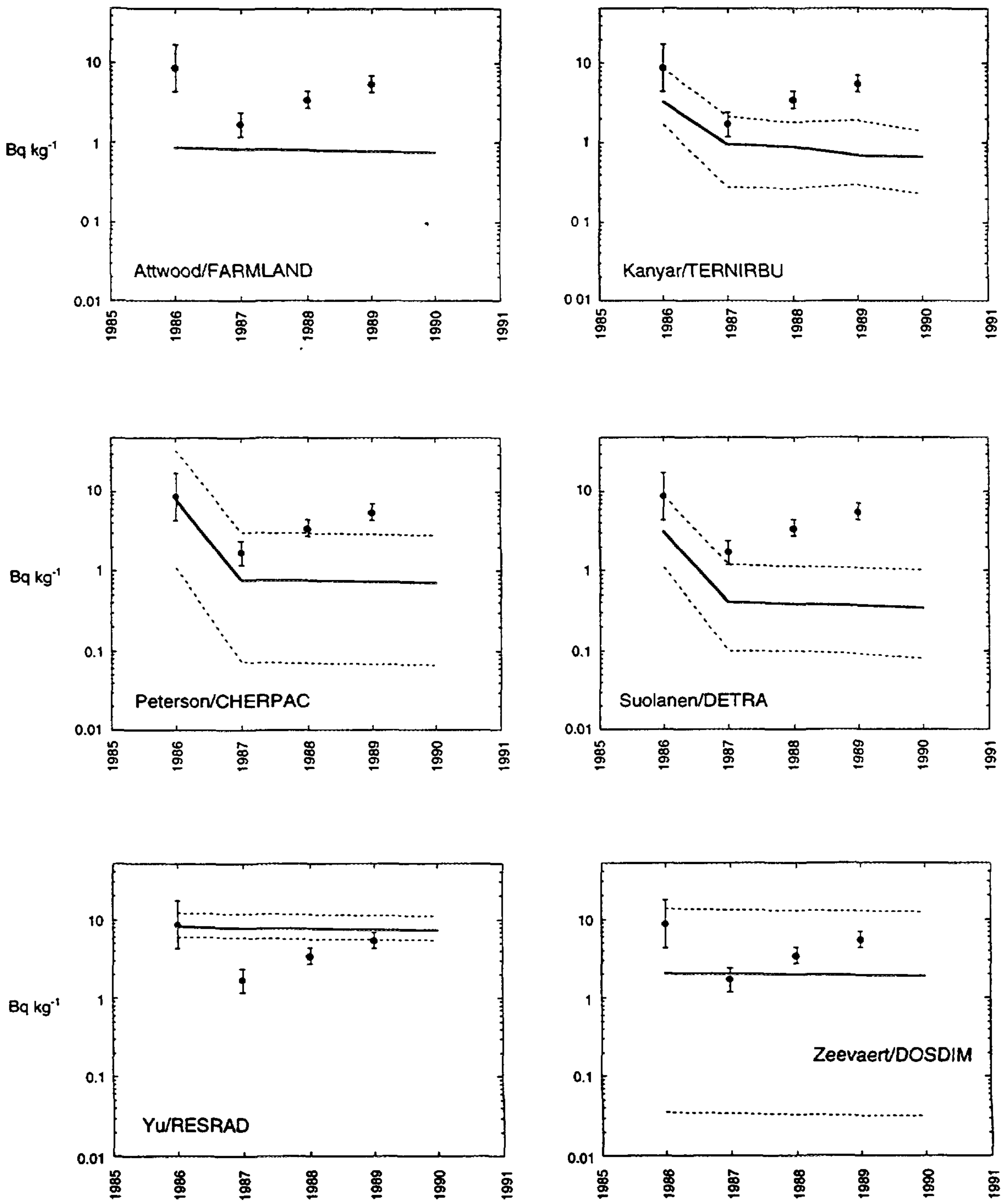


FIG. 5. A comparison of model predictions with observations for mean concentrations of ^{137}*Cs in oats in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).*

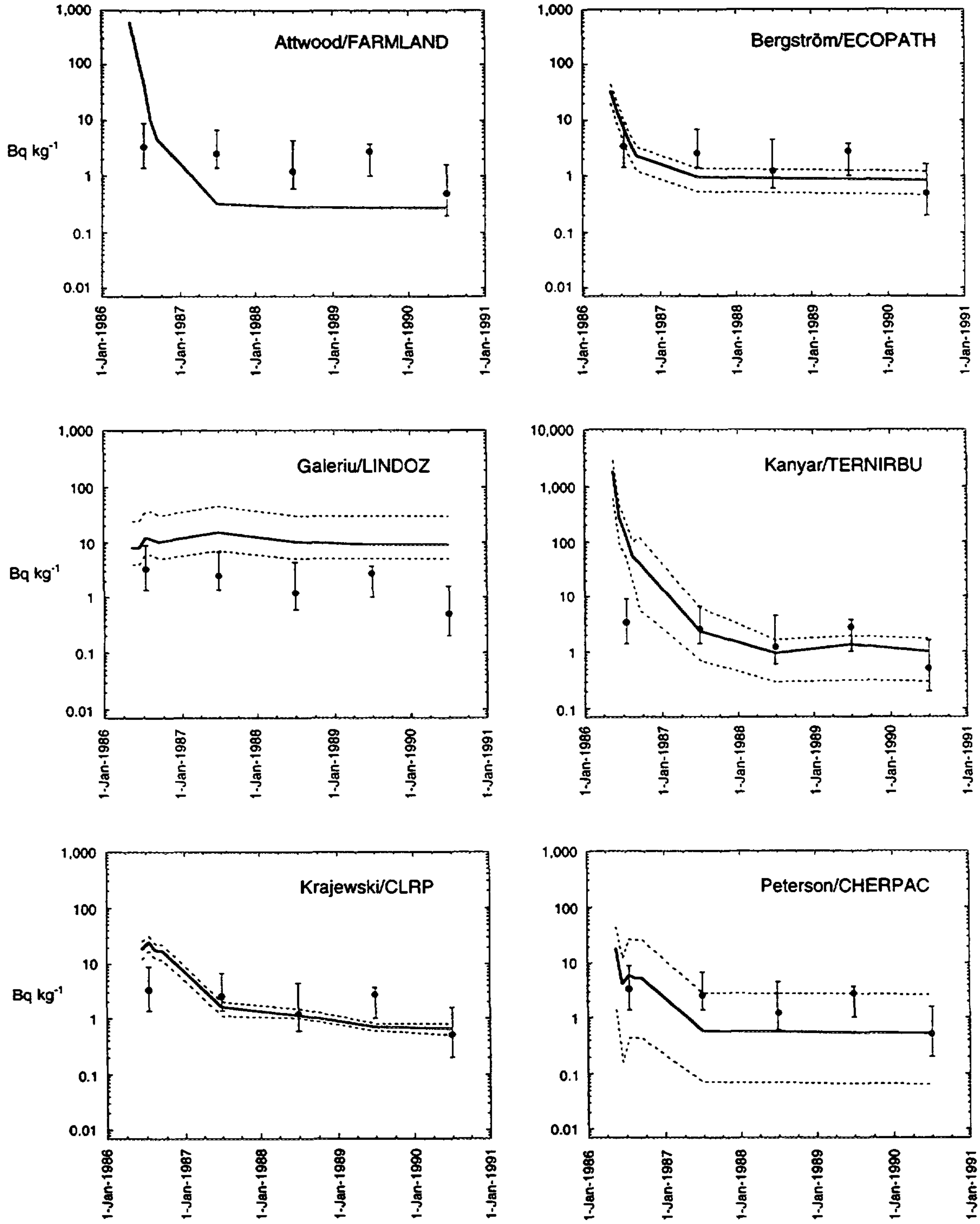
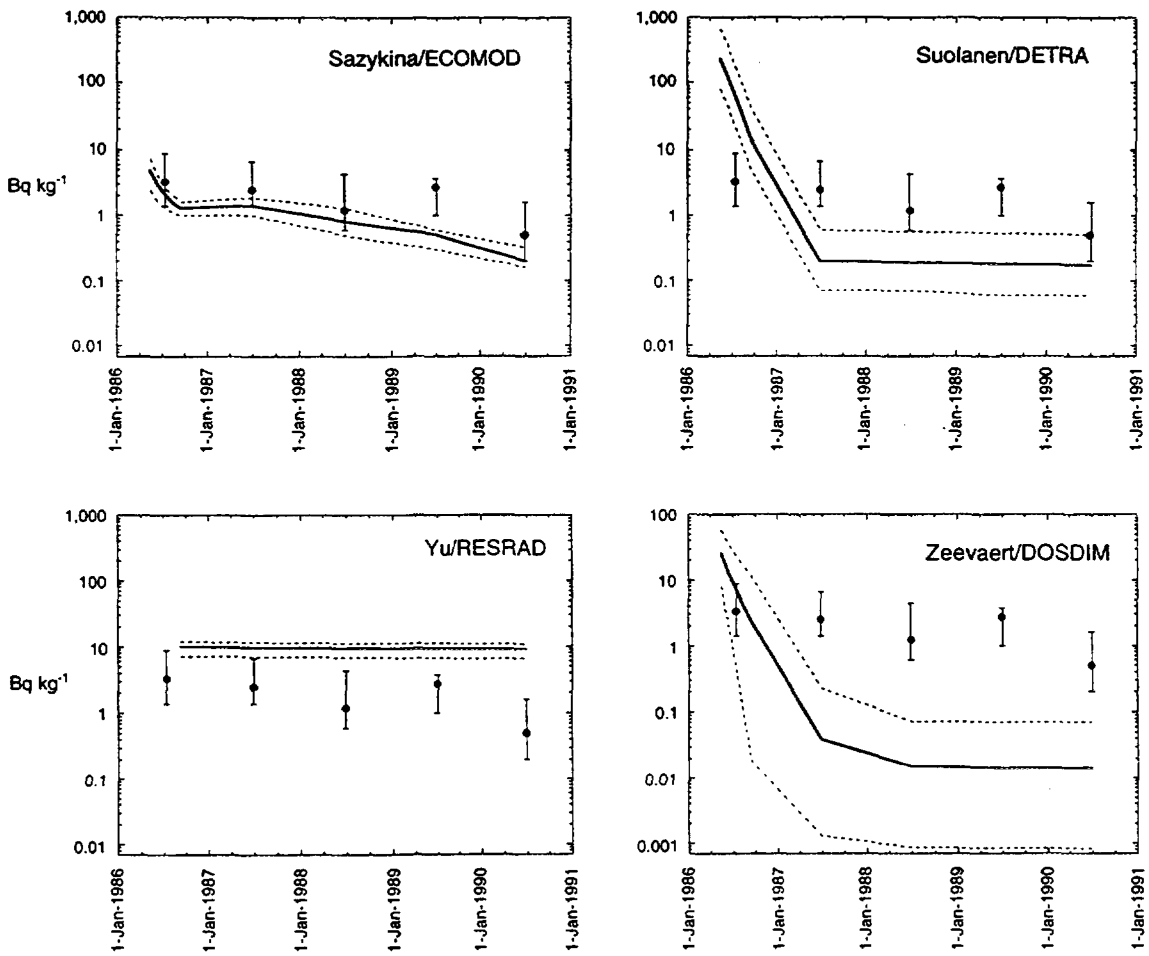


FIG. 6. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in leafy vegetables in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).



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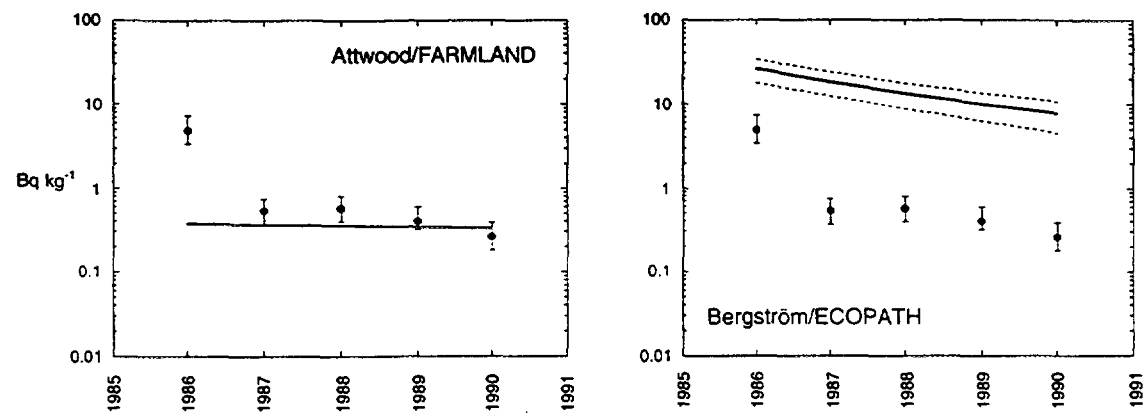
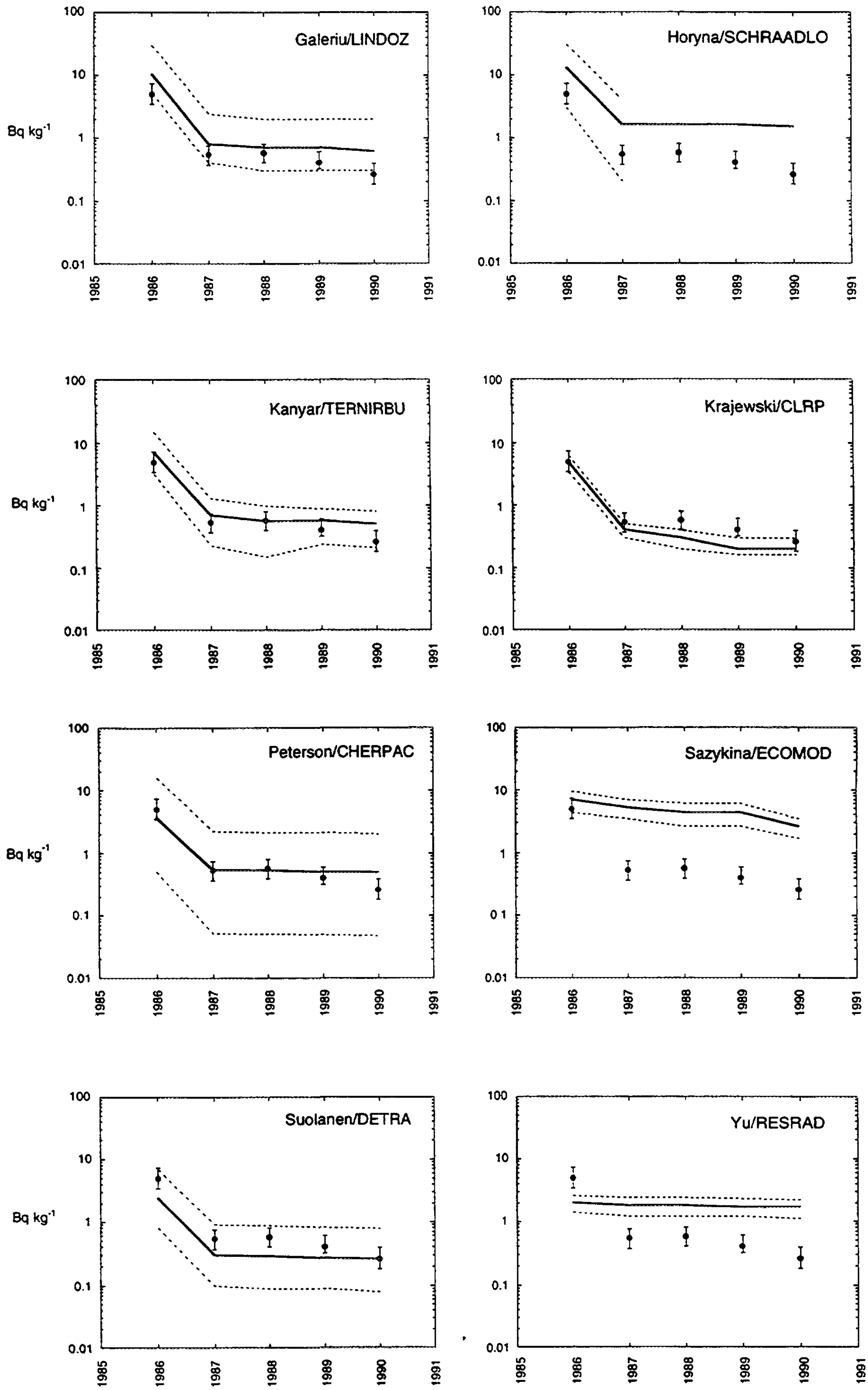


FIG. 7. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in wheat in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).



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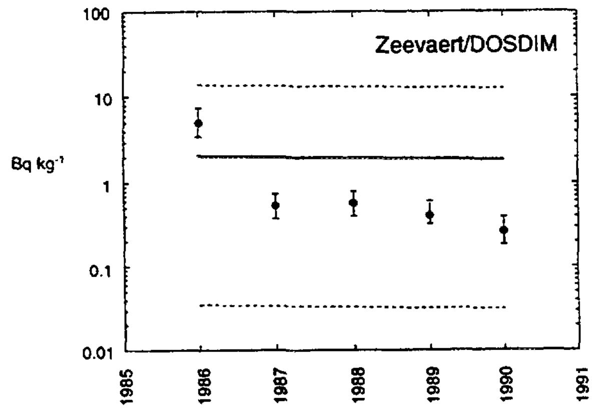

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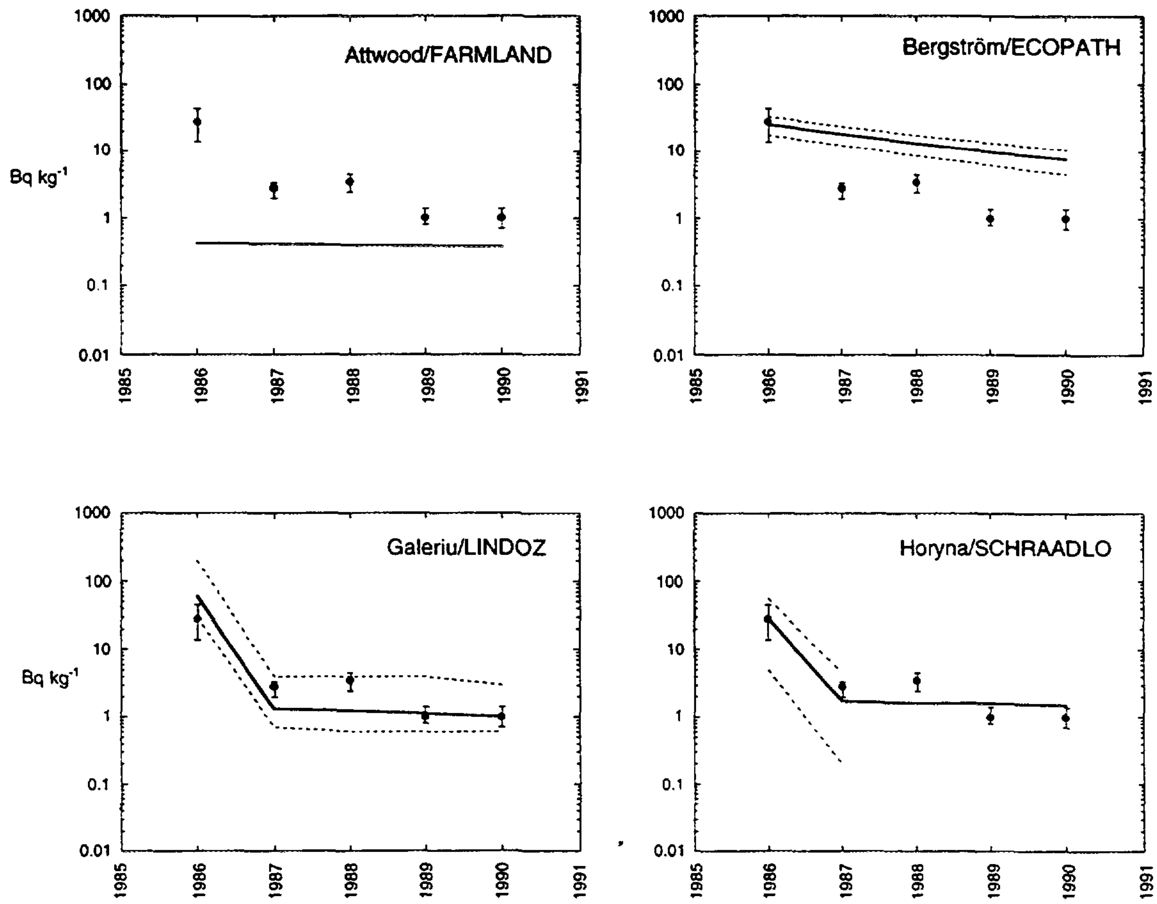
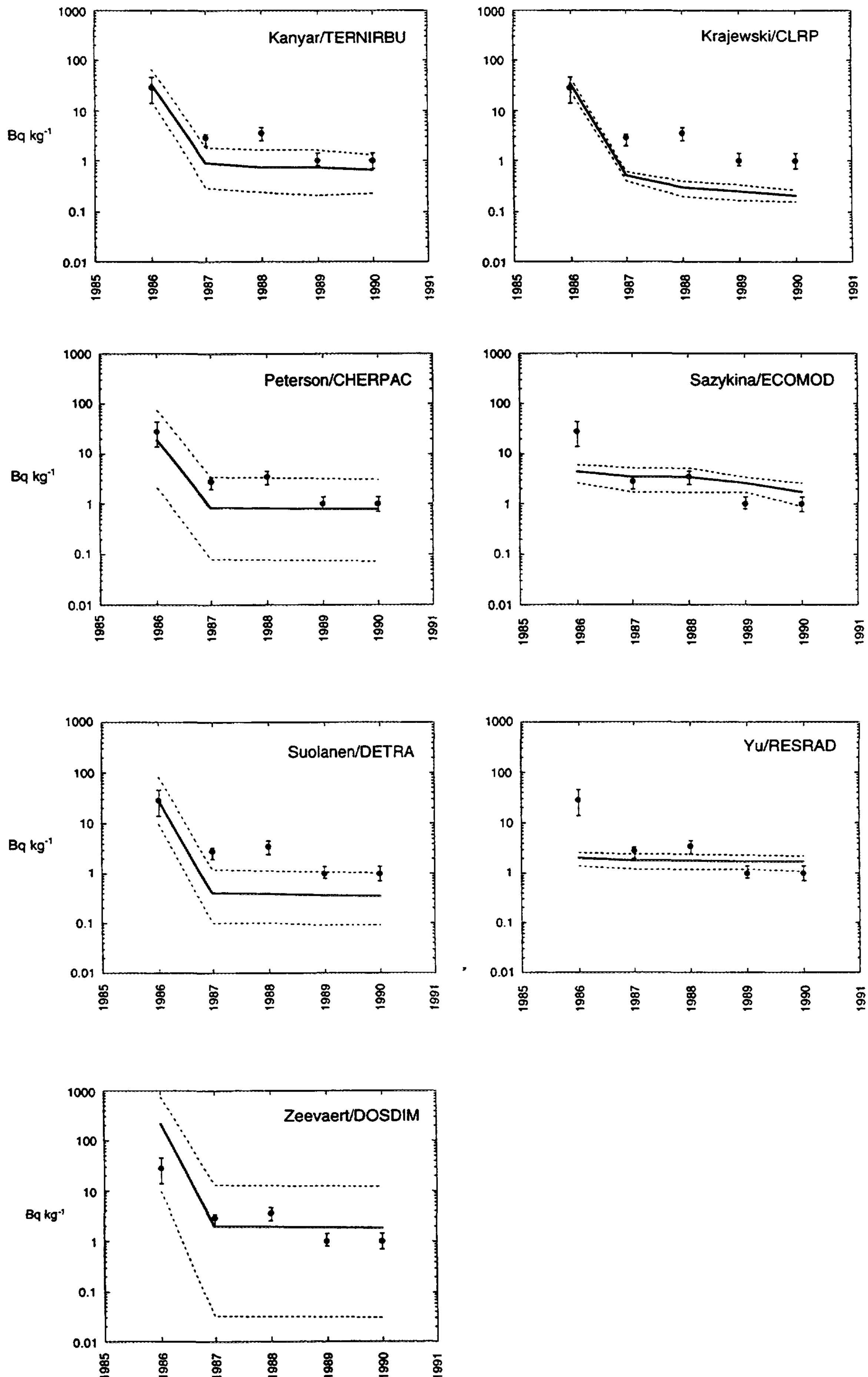


FIG. 8. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in rye in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).



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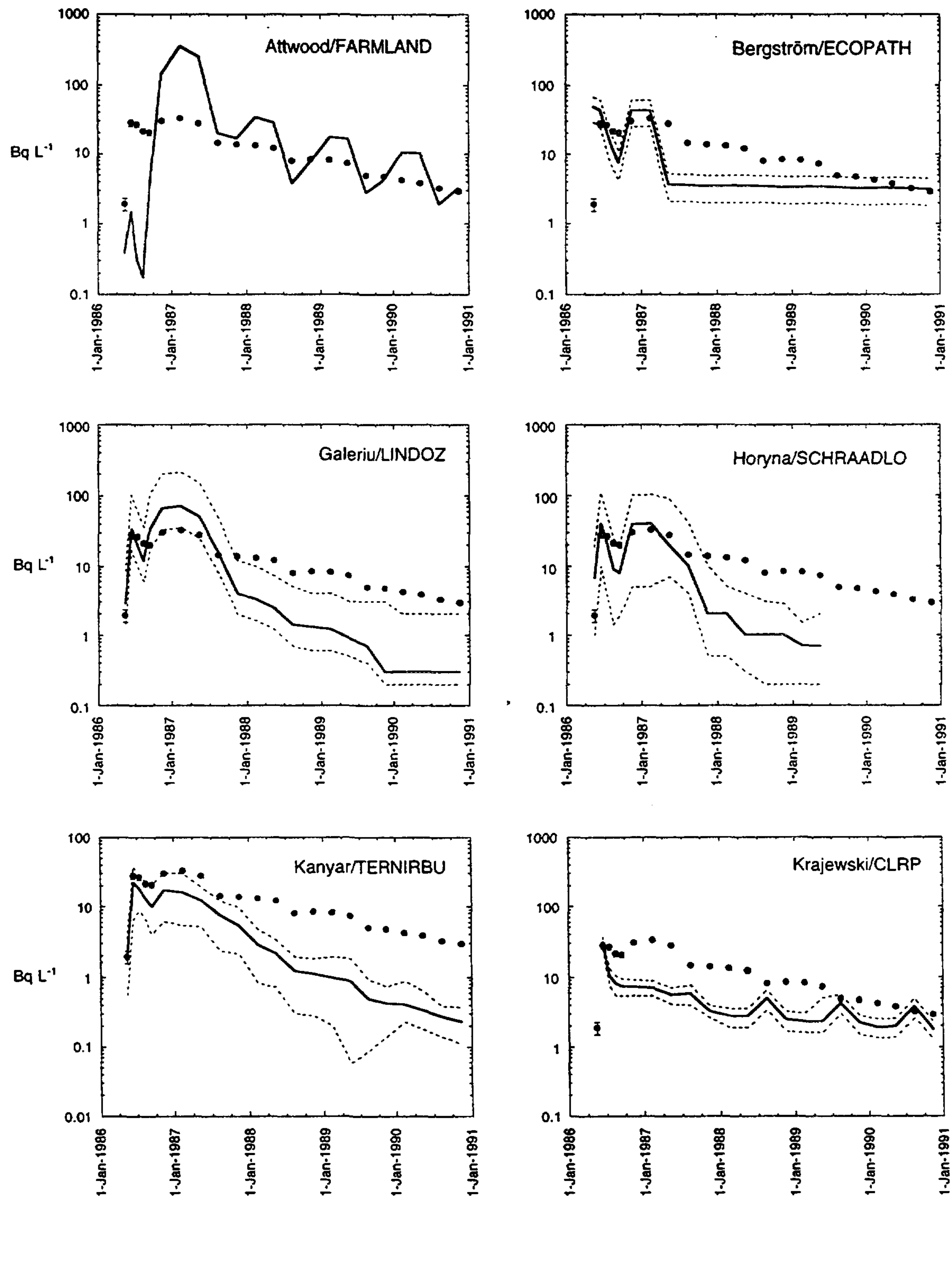
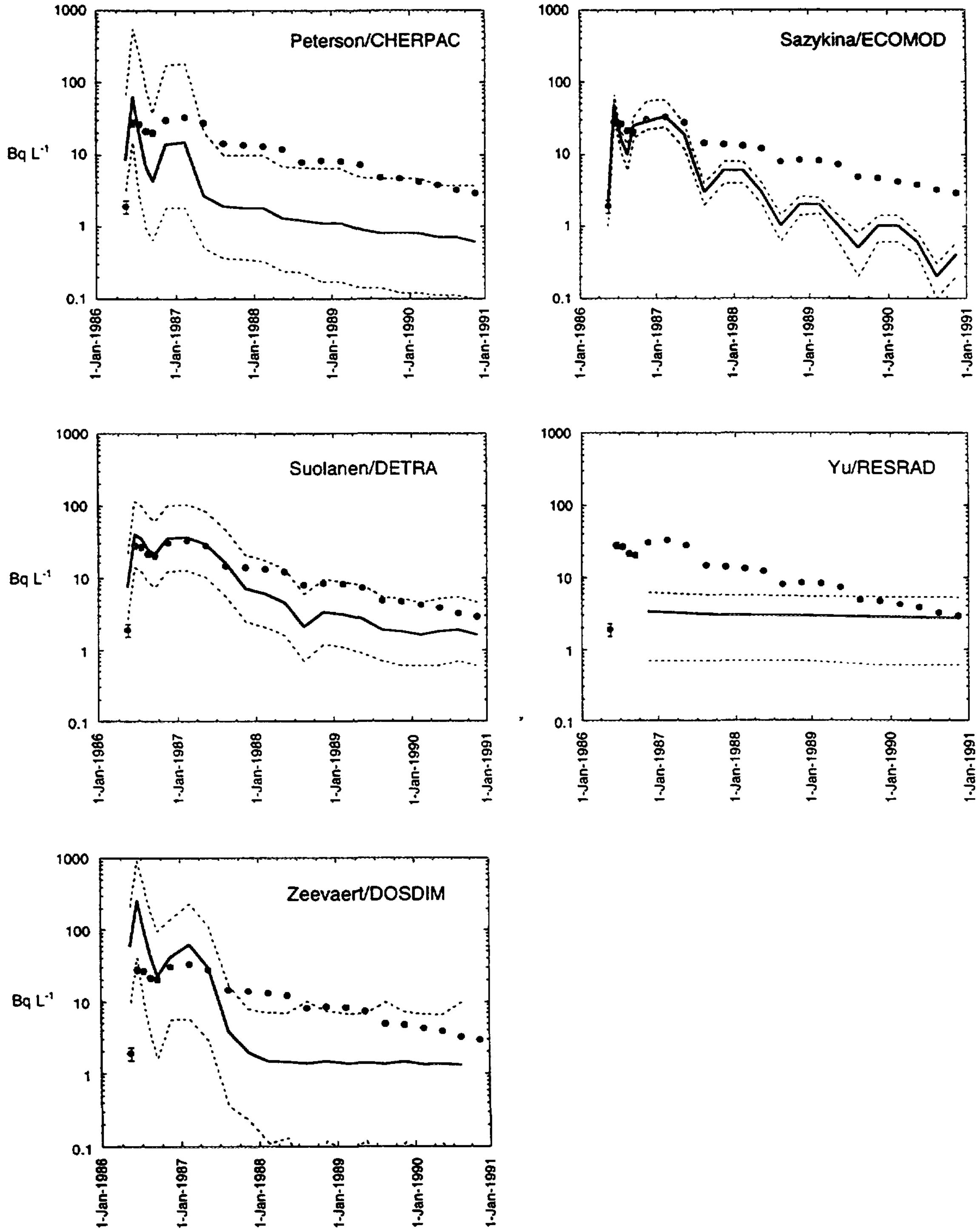


FIG. 9. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in milk in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).



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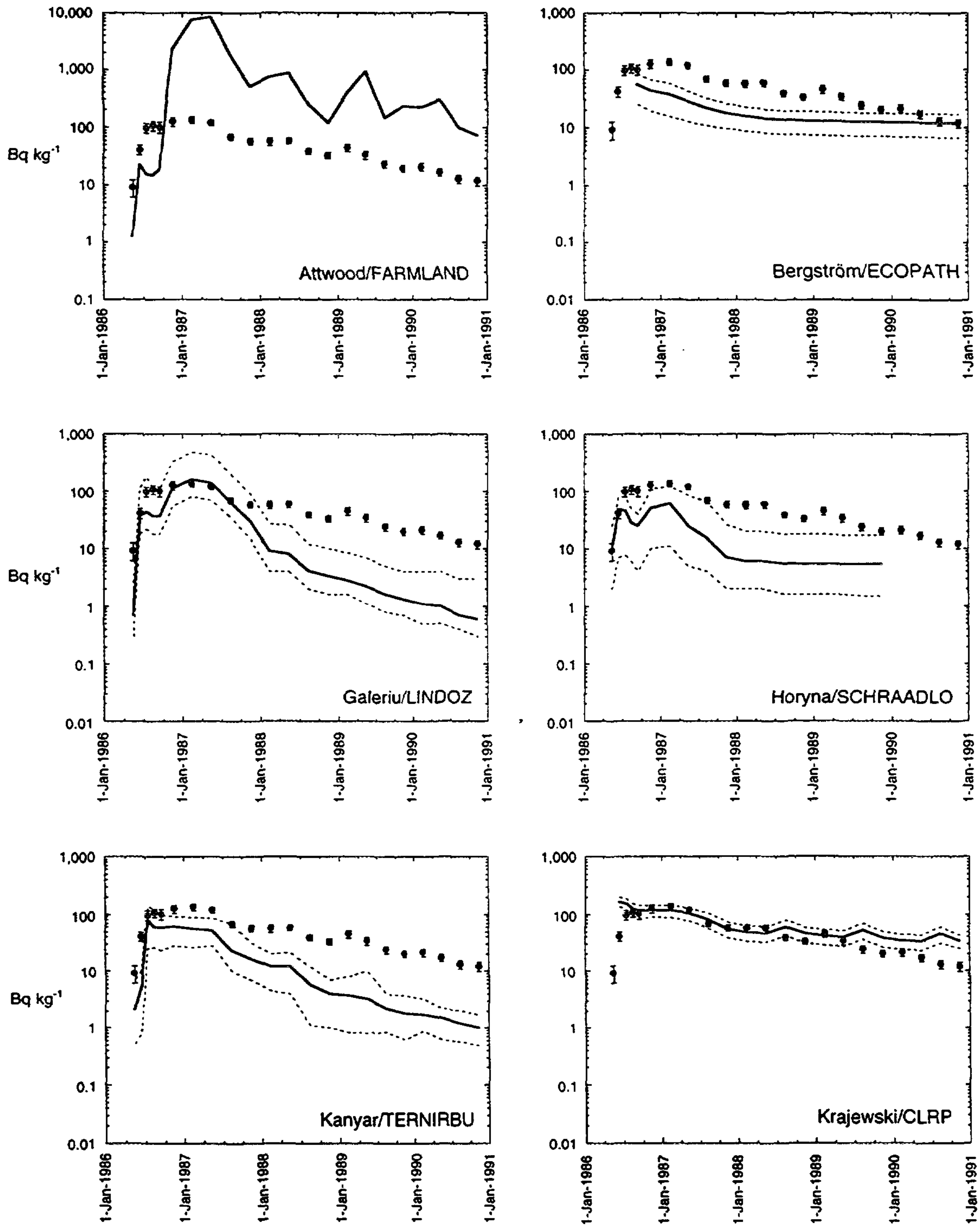
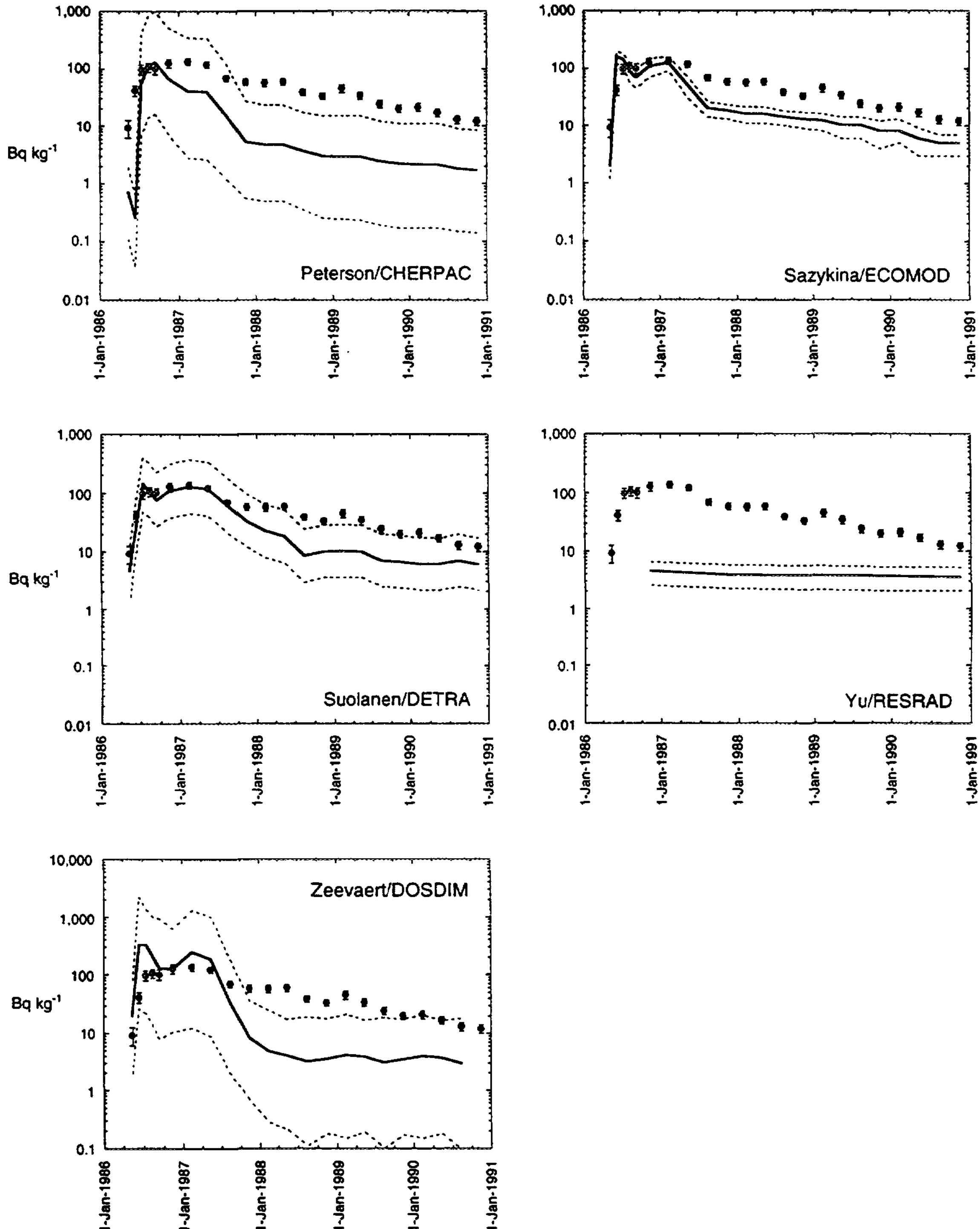


FIG. 10. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in beef in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).



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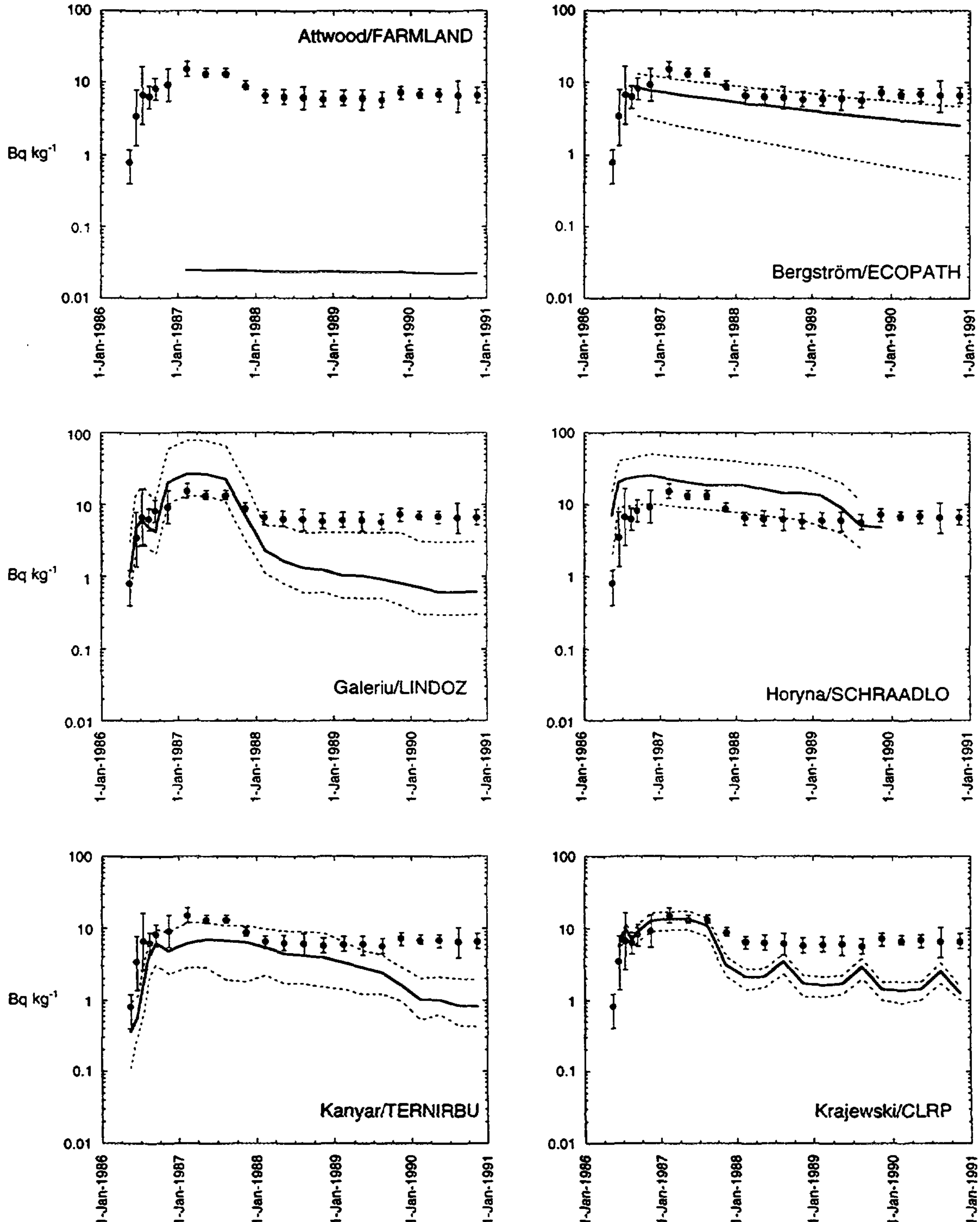
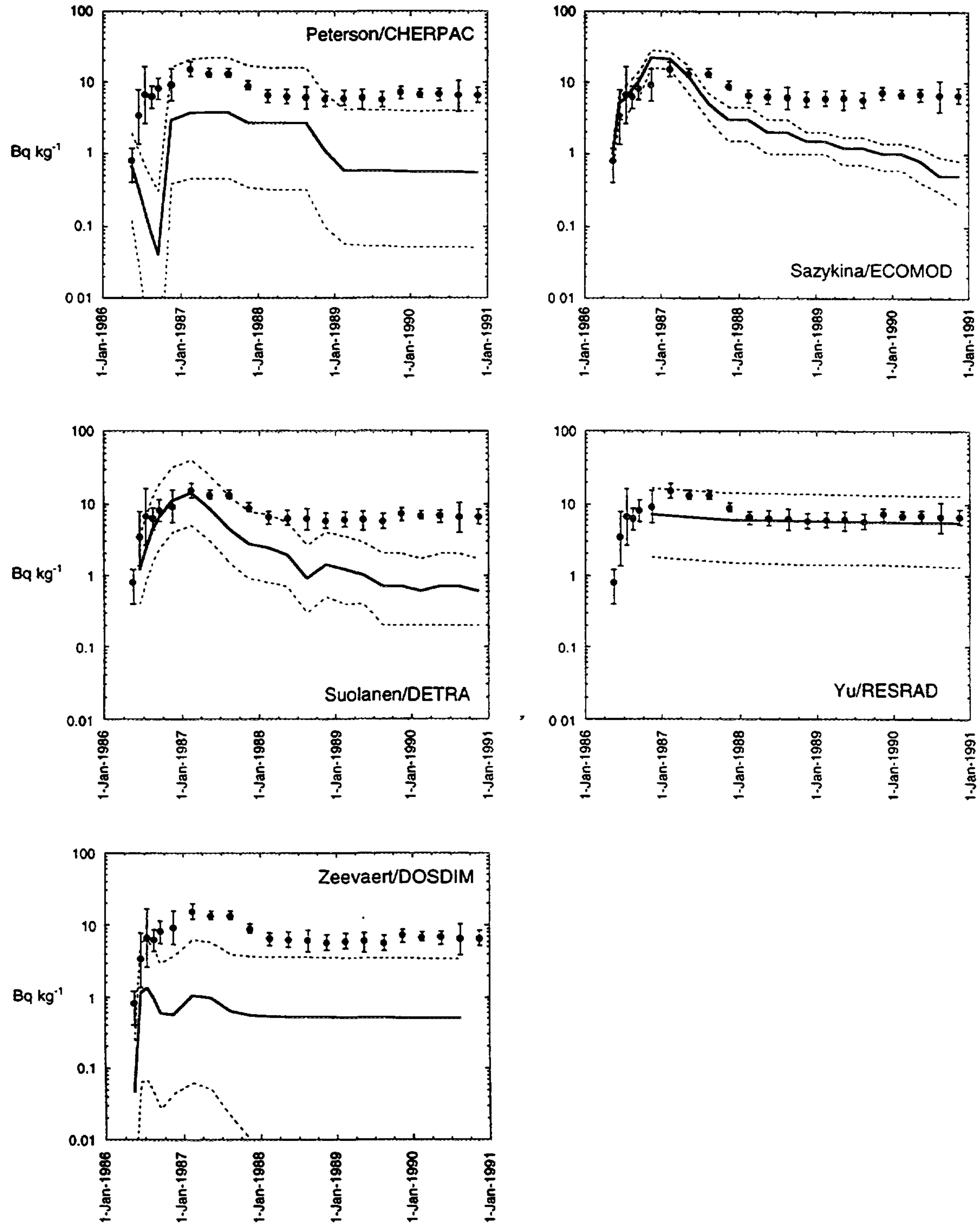


FIG. 11. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in pork in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).



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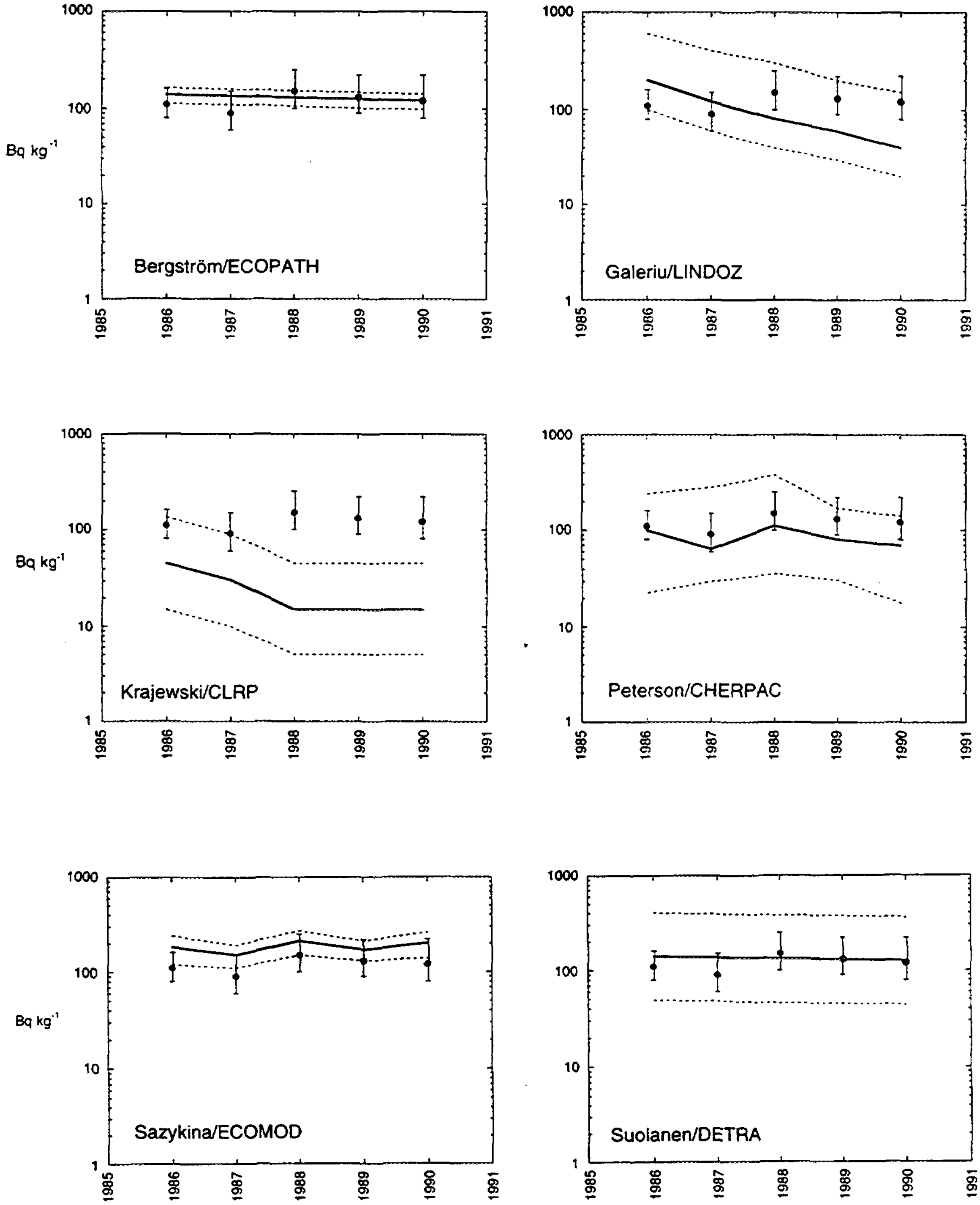

FIG. 12. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in berries in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

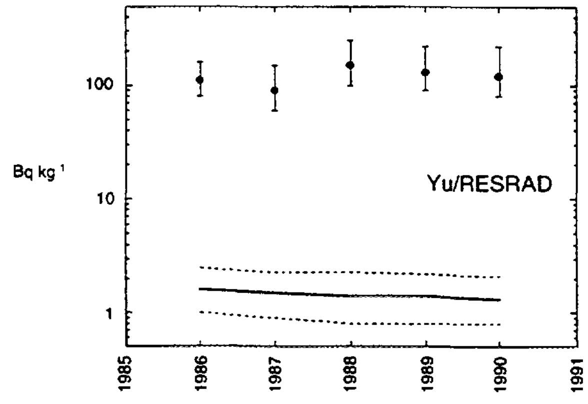

Fig. 12 (continued)

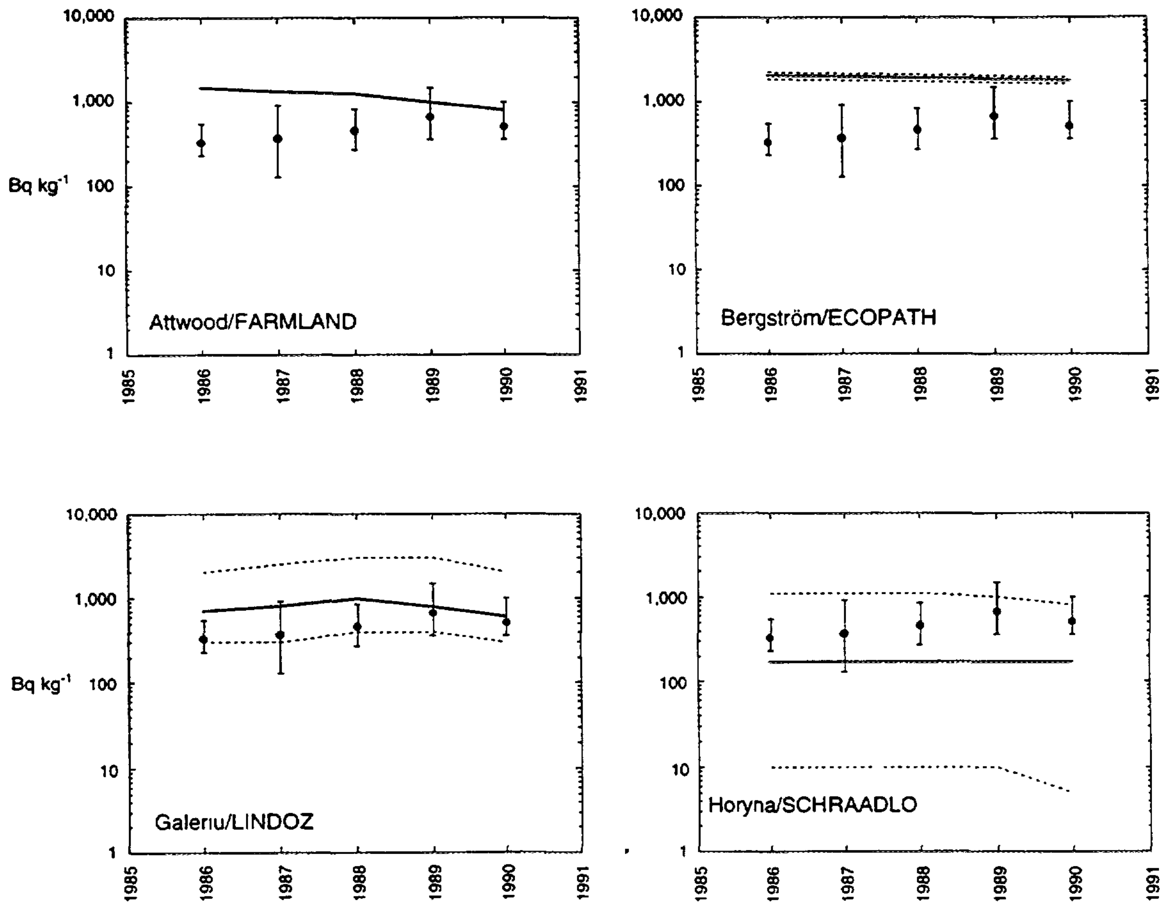

FIG. 13. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in mushrooms in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

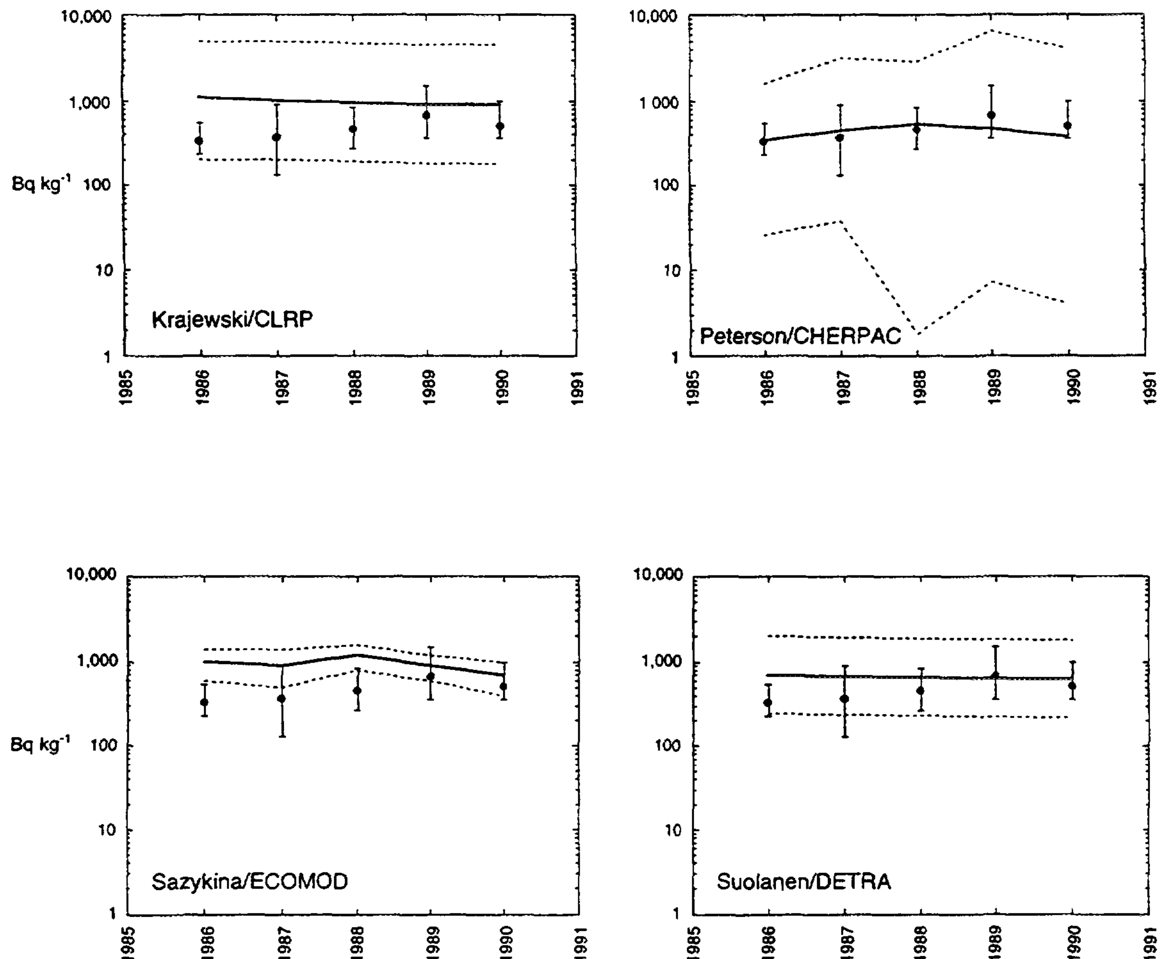

Fig. 13 (continued)

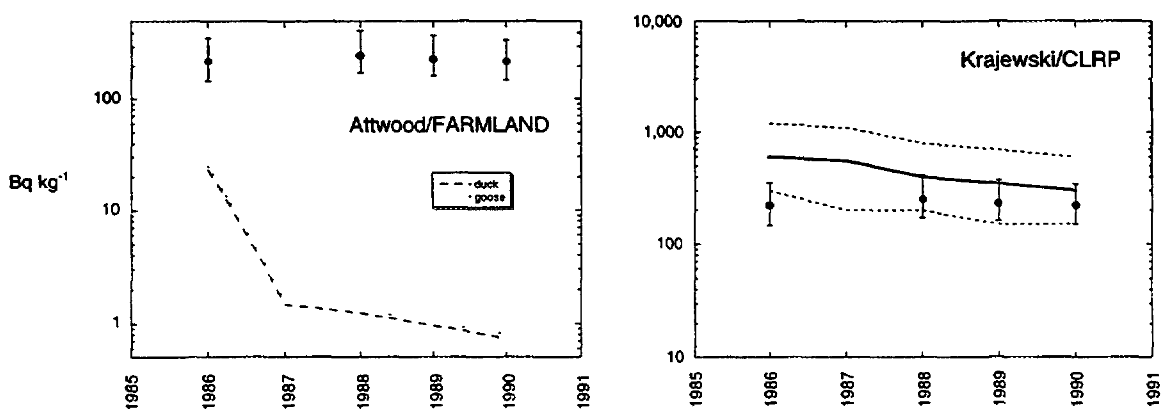

FIG. 14. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in small game in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

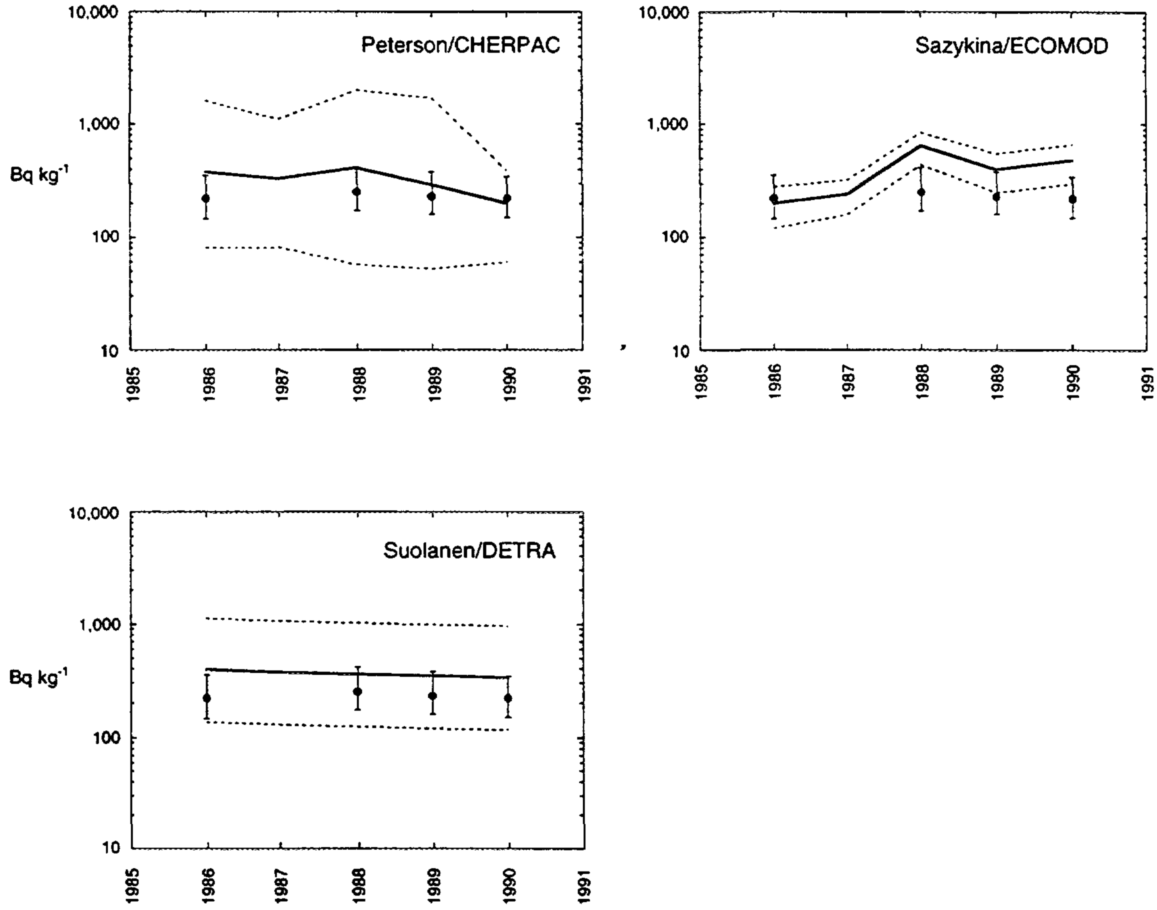

Fig. 14 (continued)

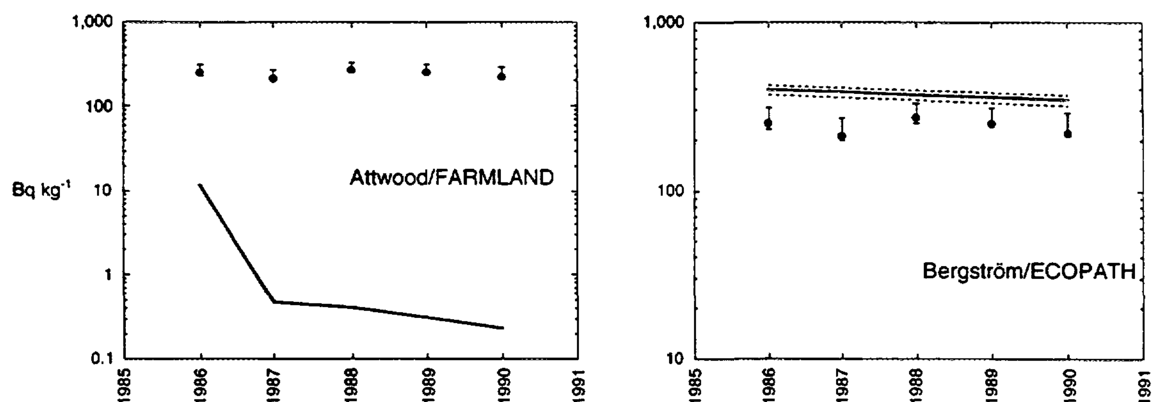

FIG. 15. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in big game in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

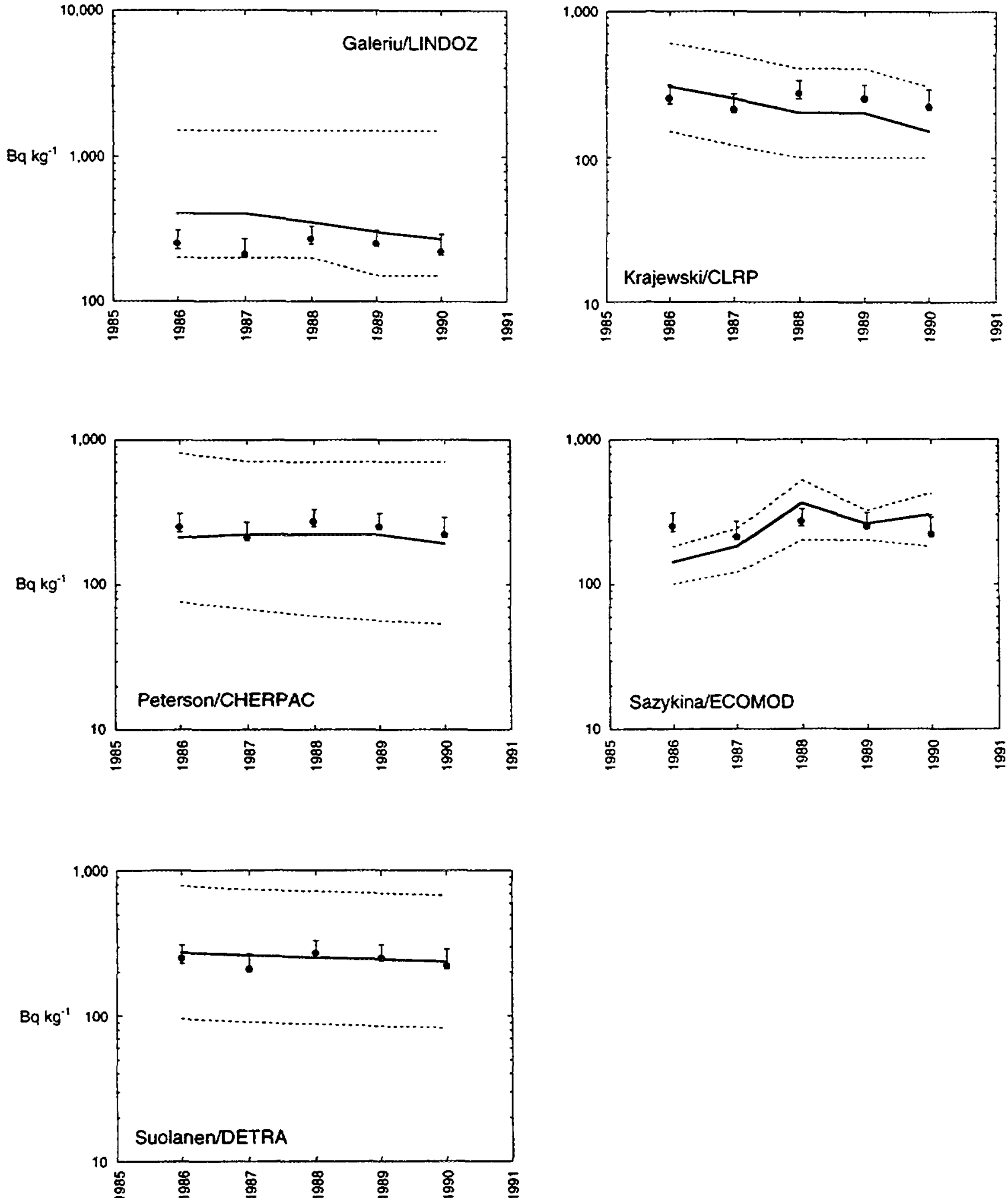

Fig. 15 (continued)

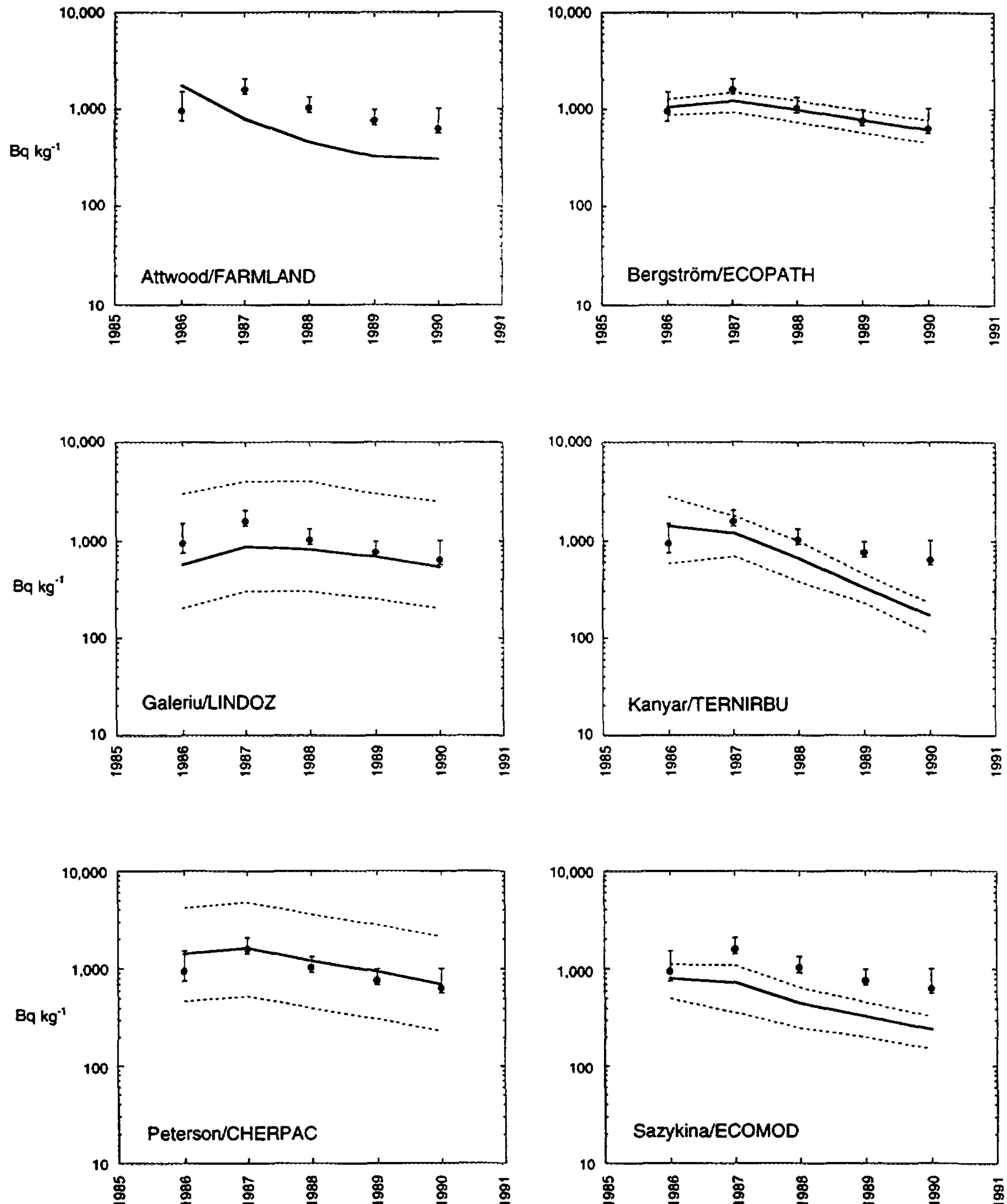

FIG. 16. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in freshwater fish in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

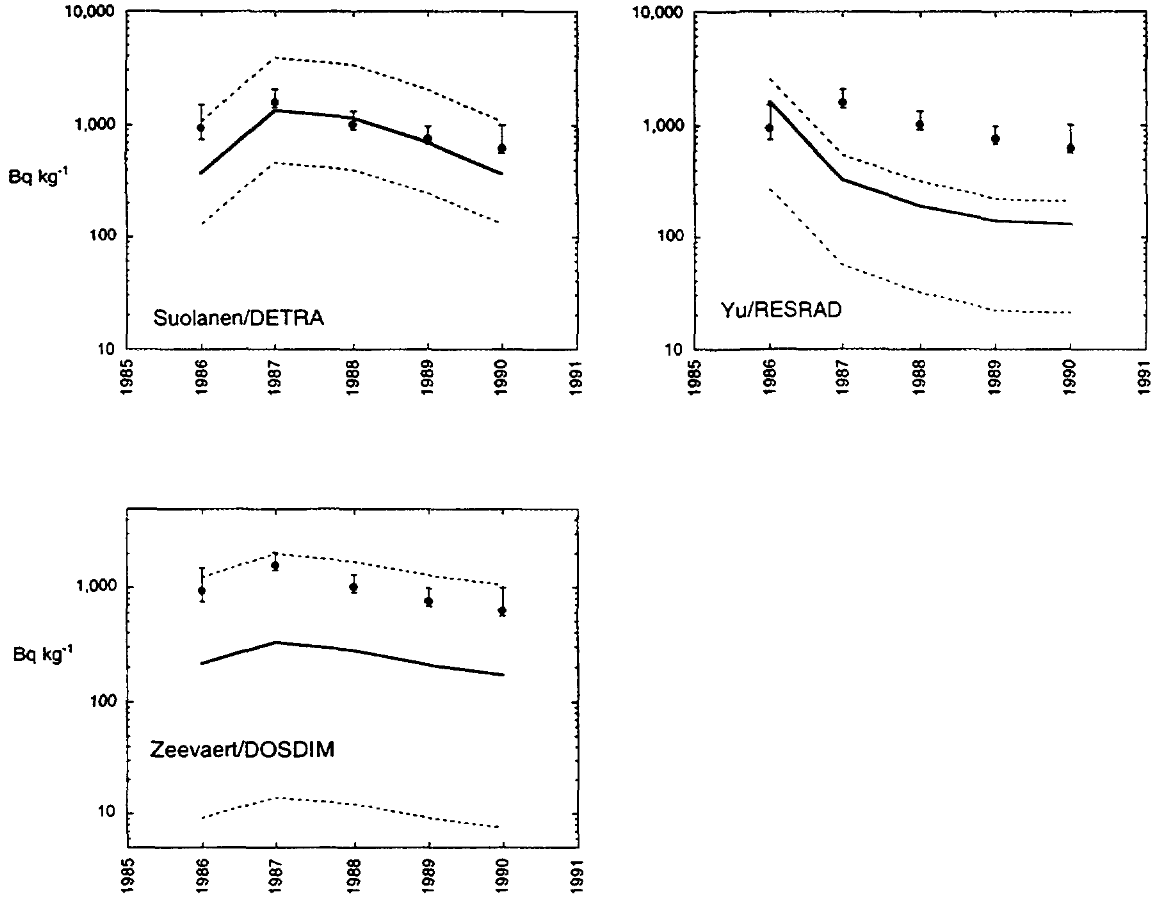

Fig. 16 (continued)

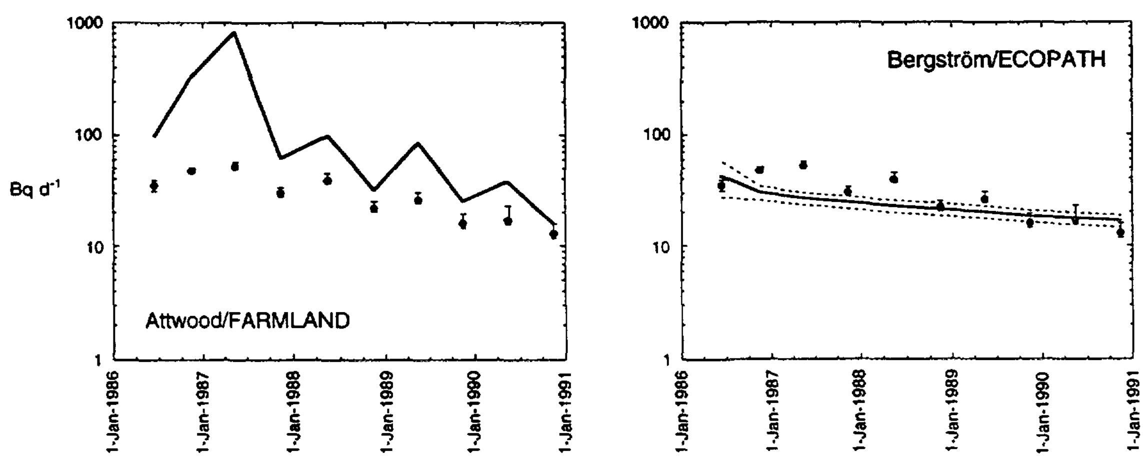

FIG. 17. A comparison of model predictions with STUK estimates for mean daily intake of ^{137}Cs by adult males in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

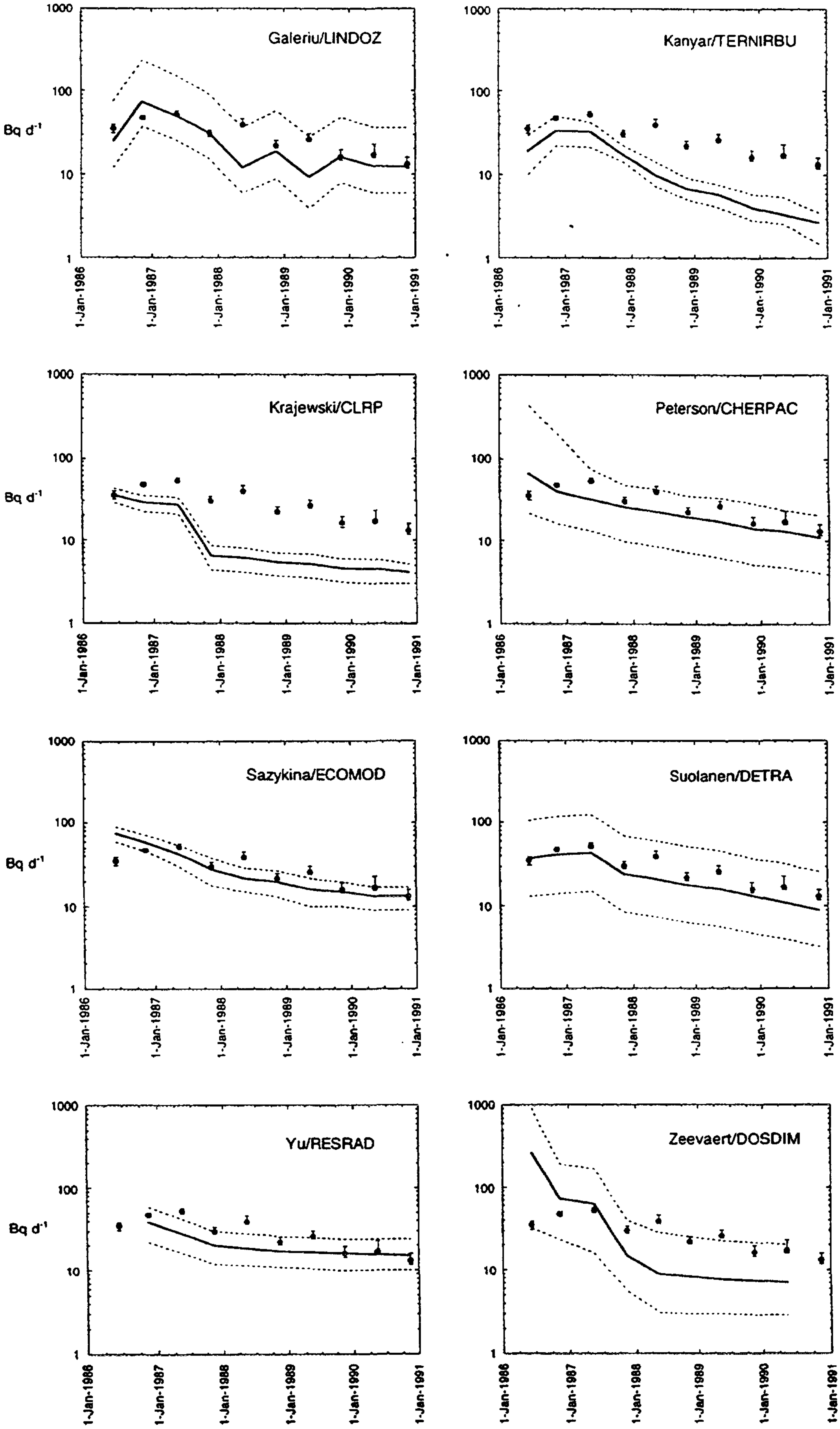

Fig. 17 (continued)

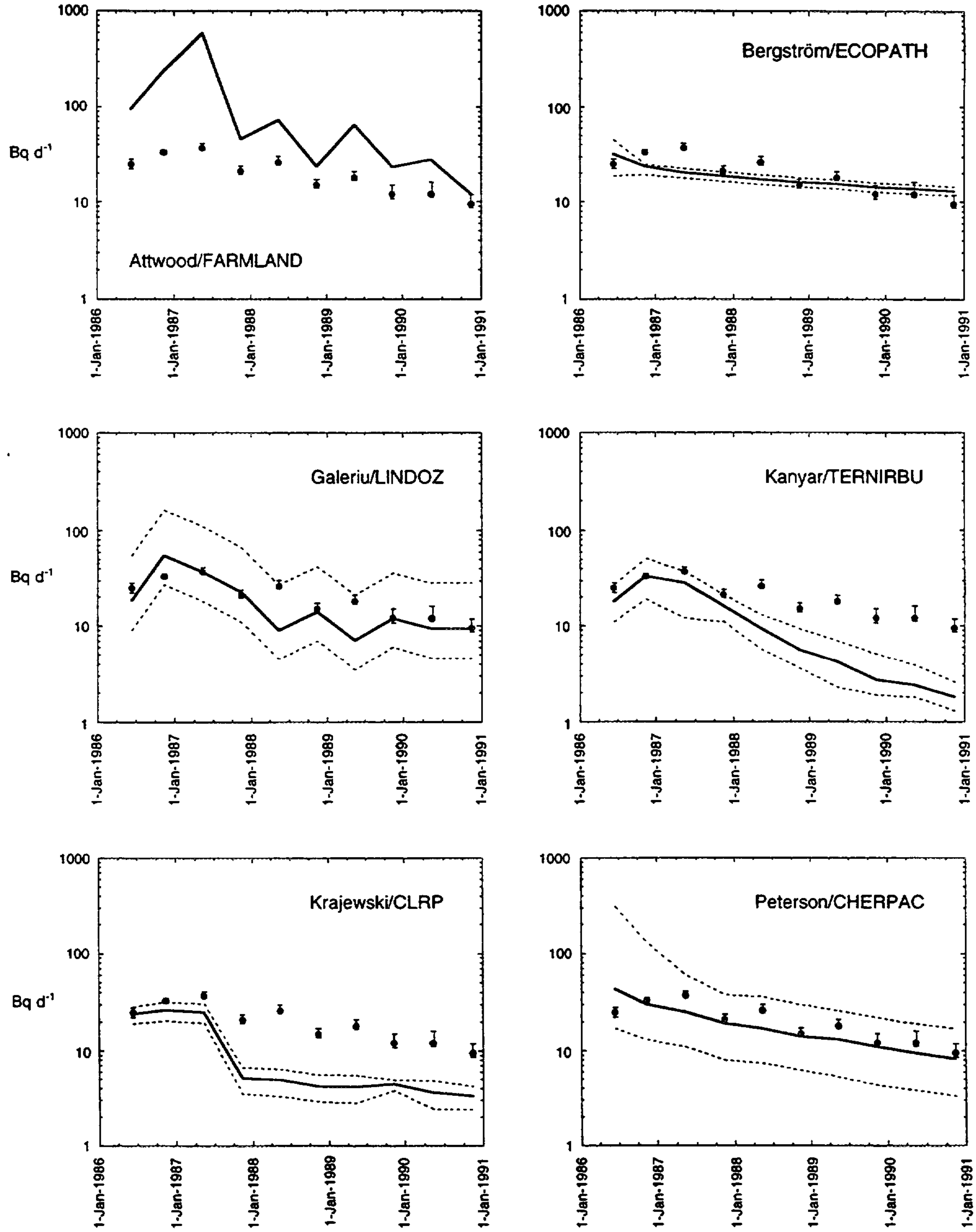

FIG. 18. A comparison of model predictions with STUK estimates for mean daily intake of ^{137}Cs by adult females in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

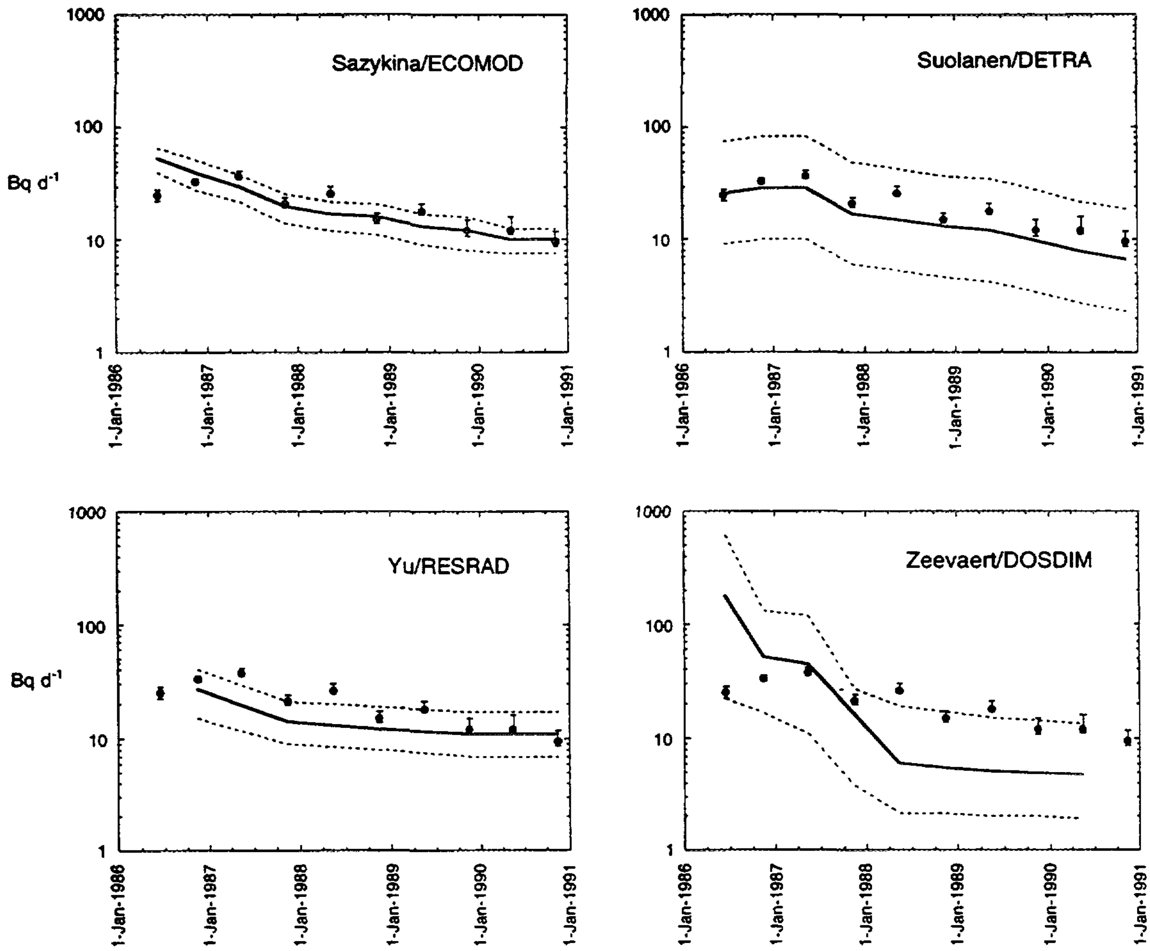

Fig. 18 (continued)

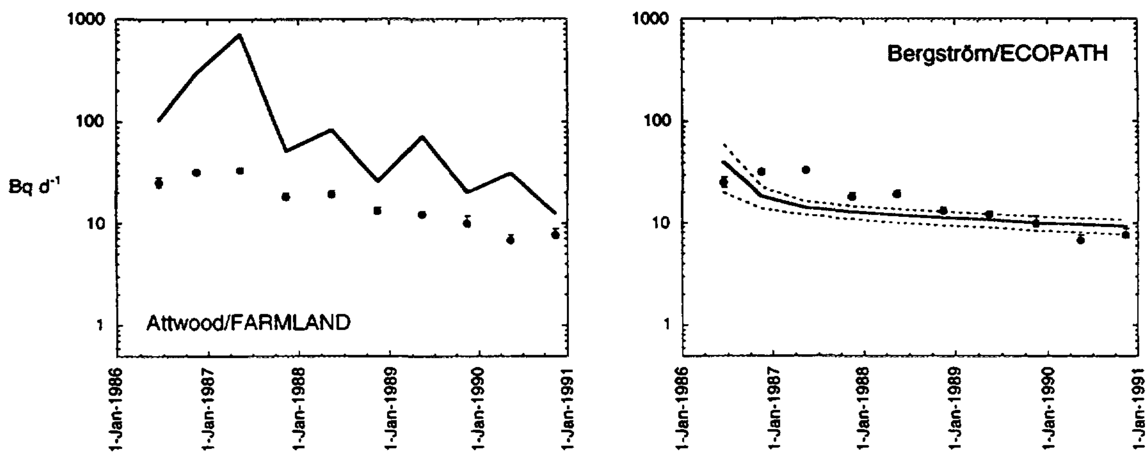

FIG. 19. A comparison of model predictions with STUK estimates for mean daily intake of ^{137}Cs by children in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

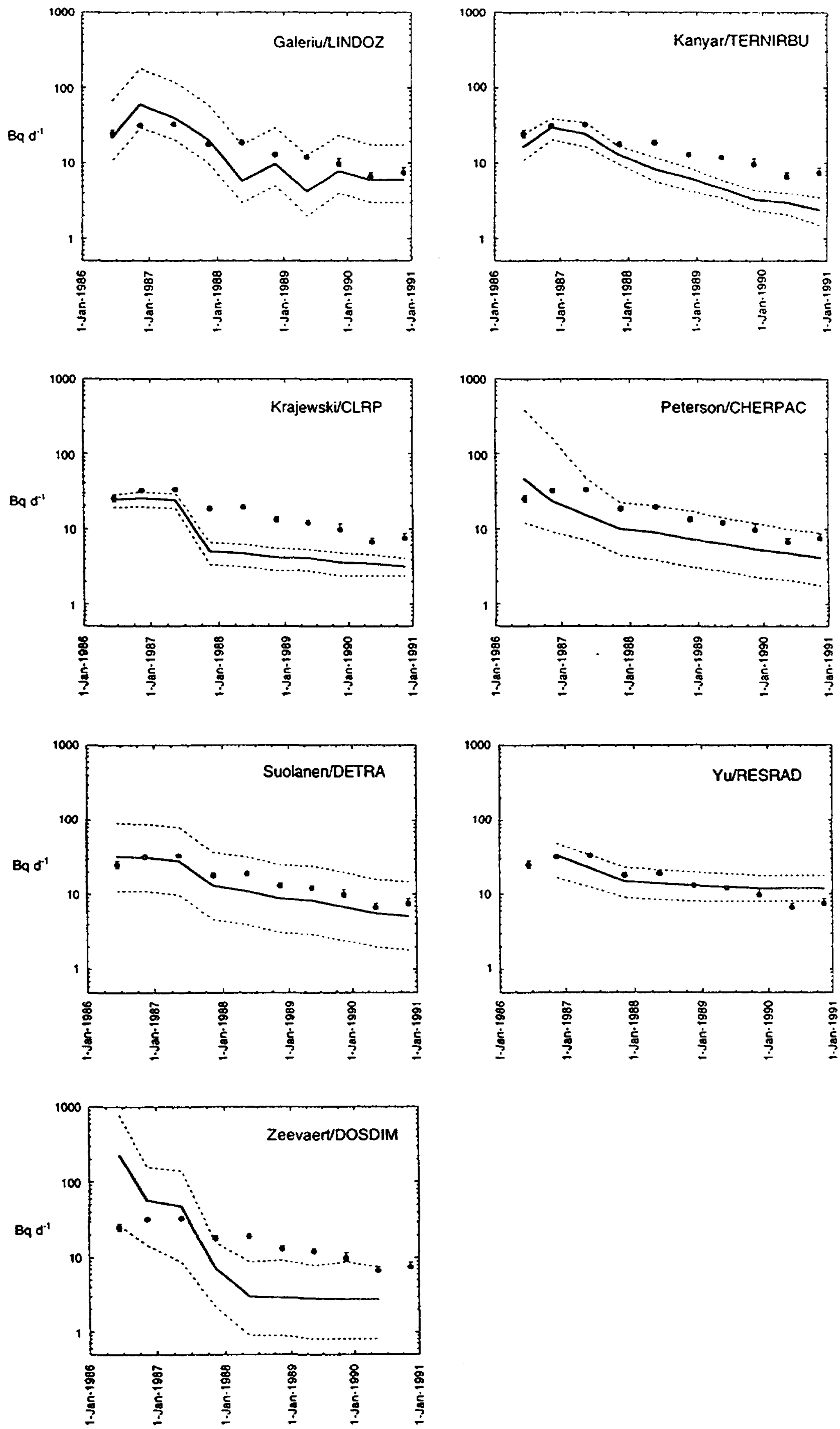

Fig. 19 (continued)

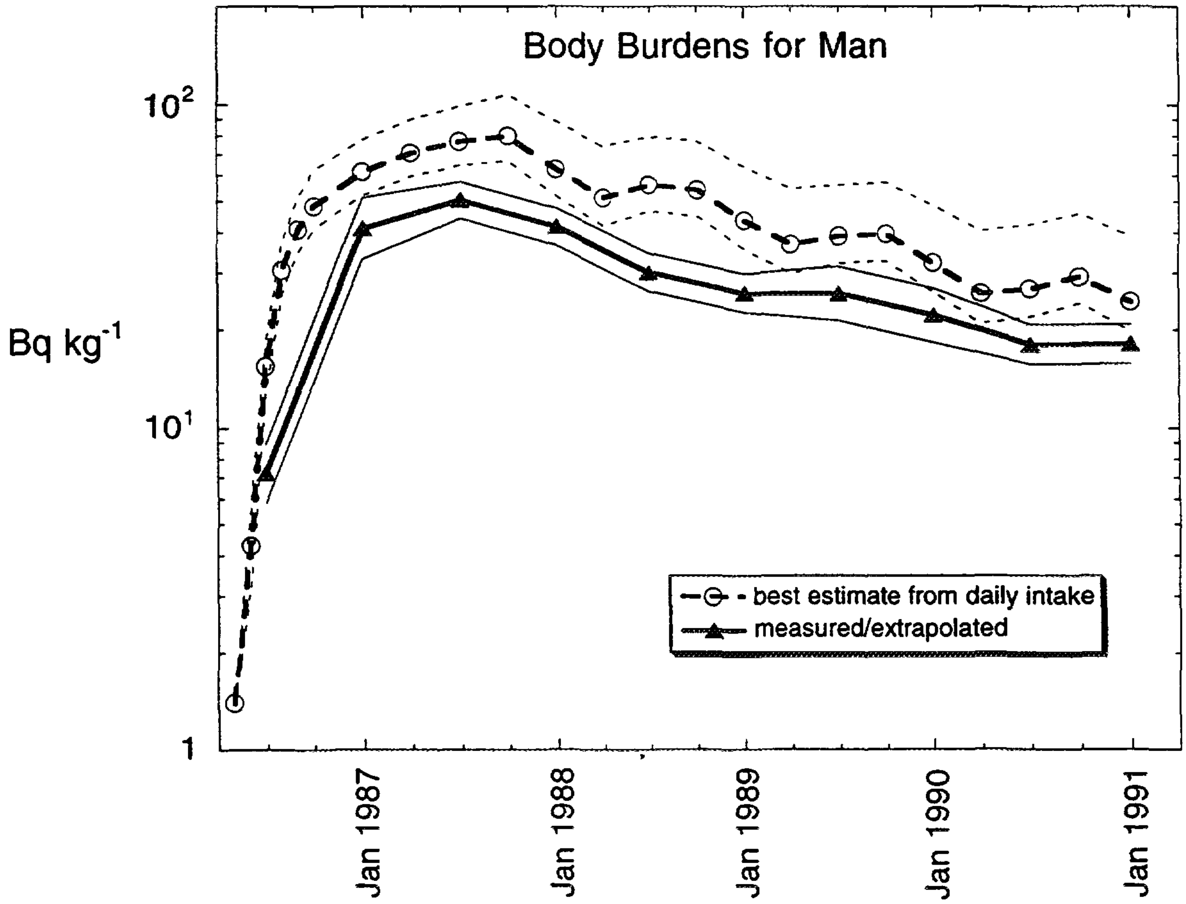

FIG. 20. Comparison of measured and extrapolated whole body concentrations of ^{137}Cs for adult males in southern Finland with concentrations estimated from daily intake rates. The 95% subjective confidence limits are indicated by dashed lines. Winter values for whole body concentrations were measured; the summer values were extrapolated from measured values. The best estimates were calculated using the ICRP double exponential function model and biological half-lives of 85 d (slow component, fraction of total = 0.9) and 2 d (fast component, fraction of total = 0.1). Confidence limits on the best estimates include both the uncertainty on intake and the confidence intervals of the metabolic parameters given above. The following 95% confidence limits were assumed: lower confidence limit, biological half-life = 80 d, slow component = 0.8; upper confidence limit, biological half-life = 110 d, slow component = 0.9.

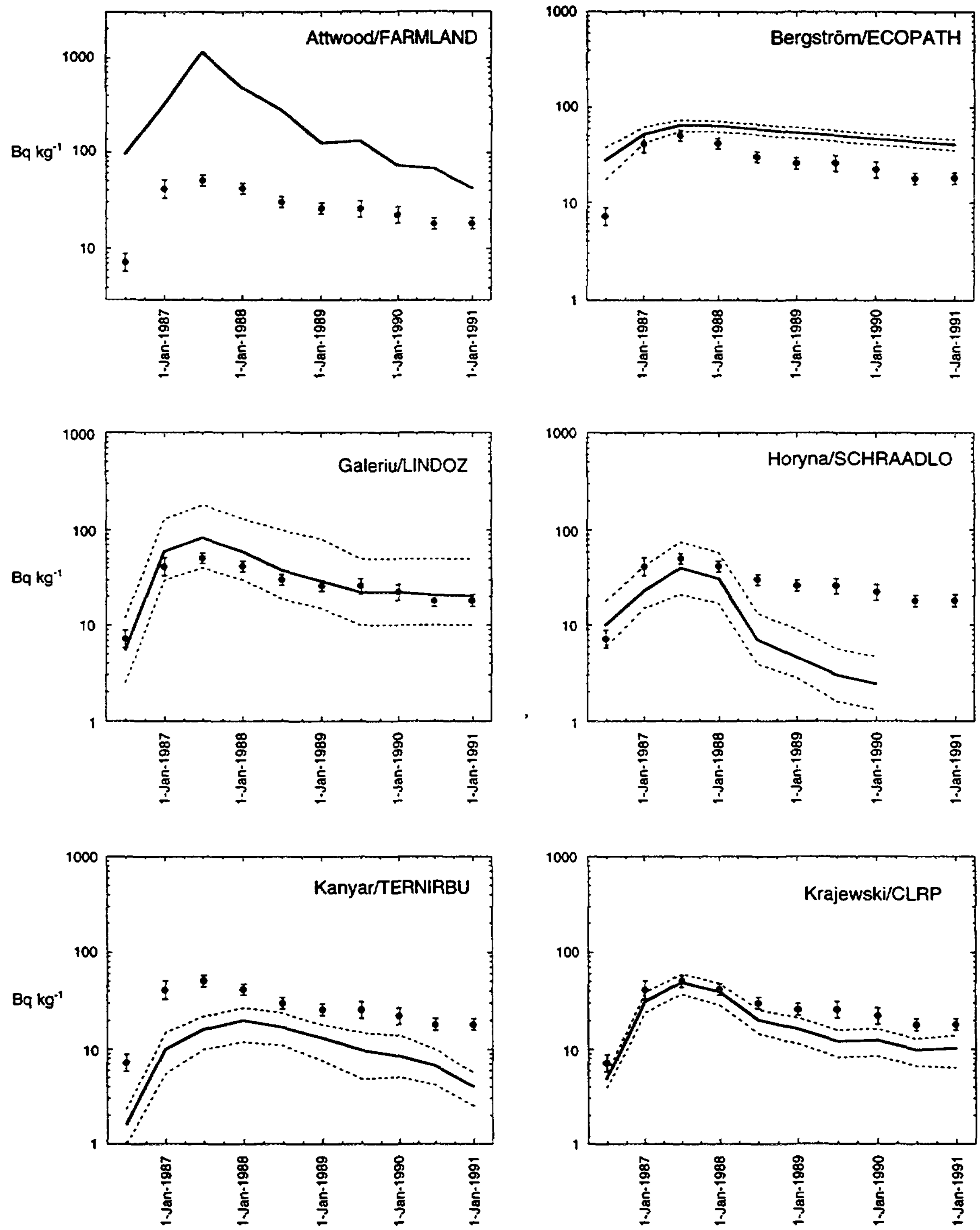

FIG. 21. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in adult males in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

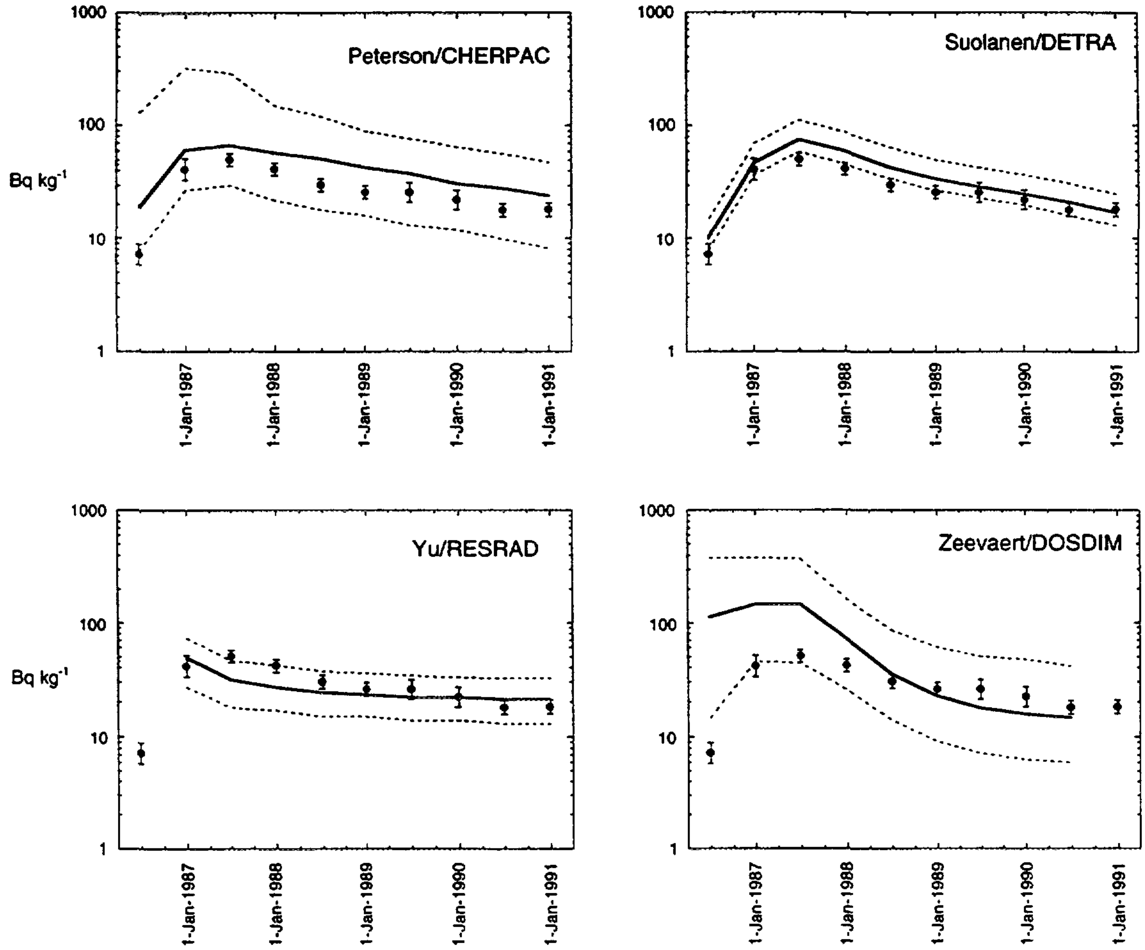

Fig. 21 (continued)

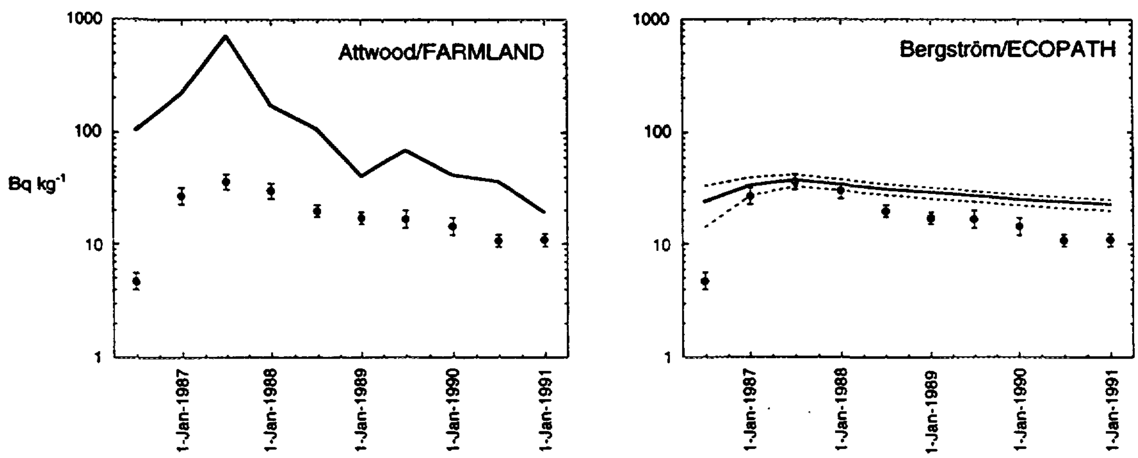

FIG. 22. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in adult females in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

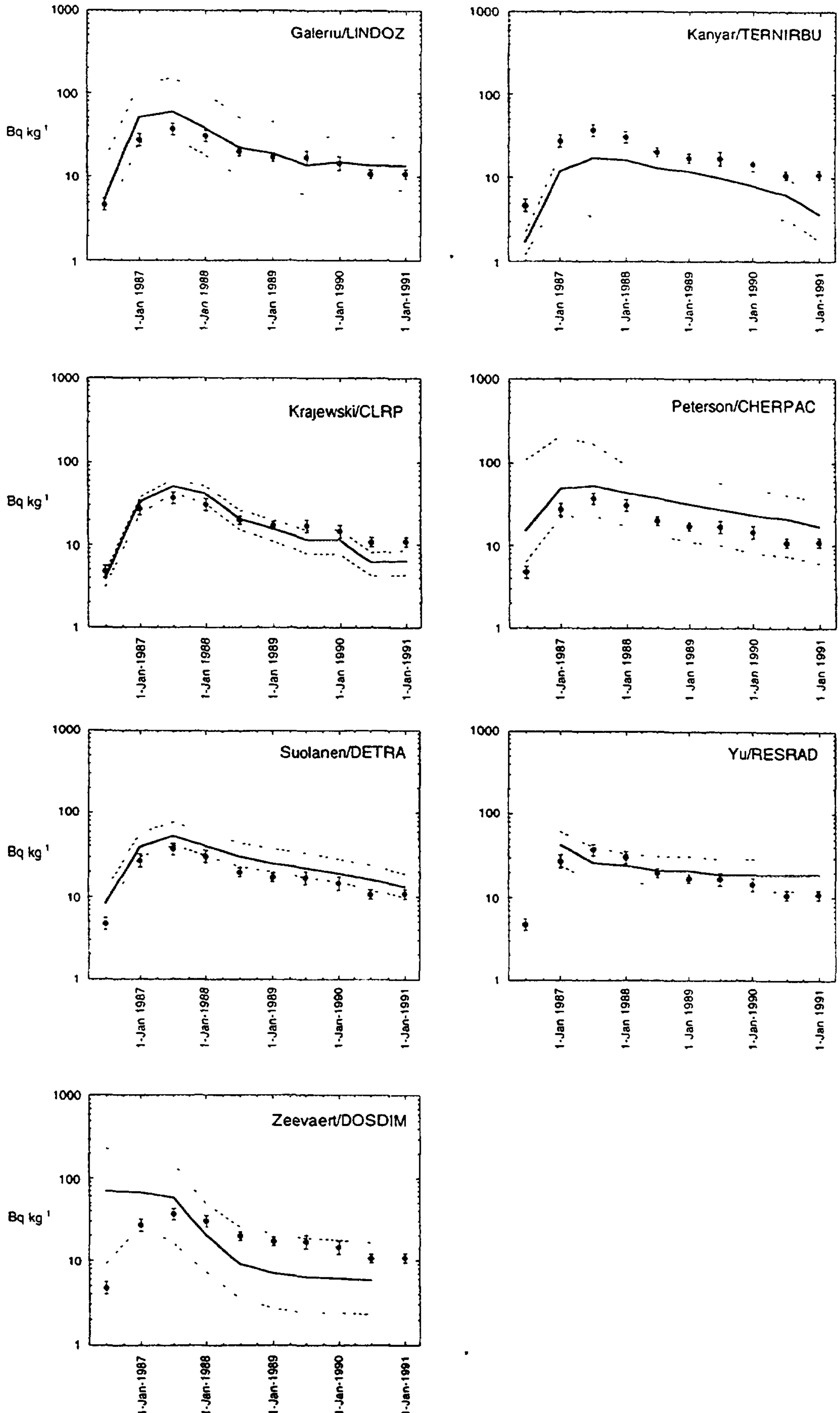

Fig. 22 (continued)

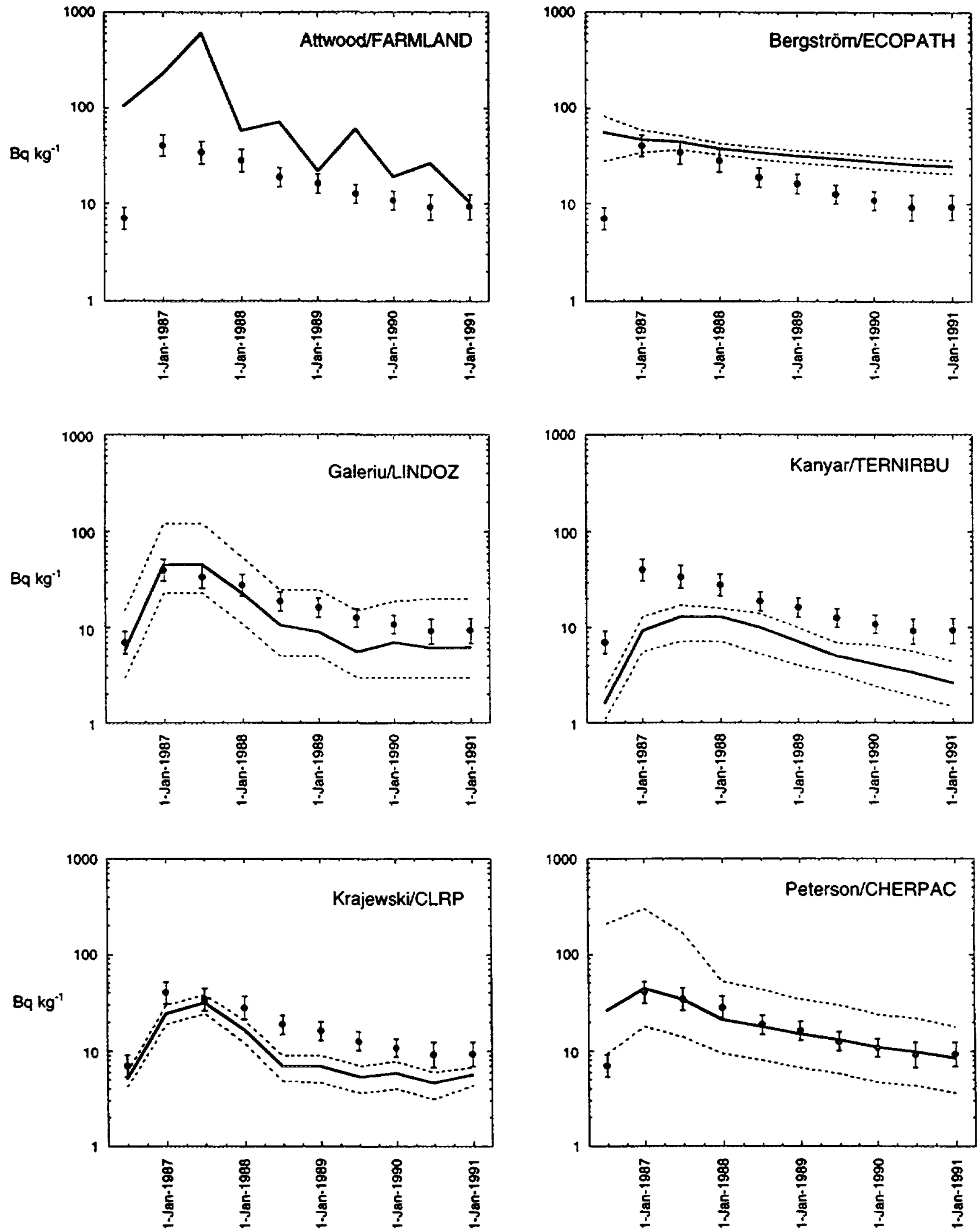

FIG. 23. A comparison of model predictions with observations for mean concentrations of ^{137}Cs in children in southern Finland. Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

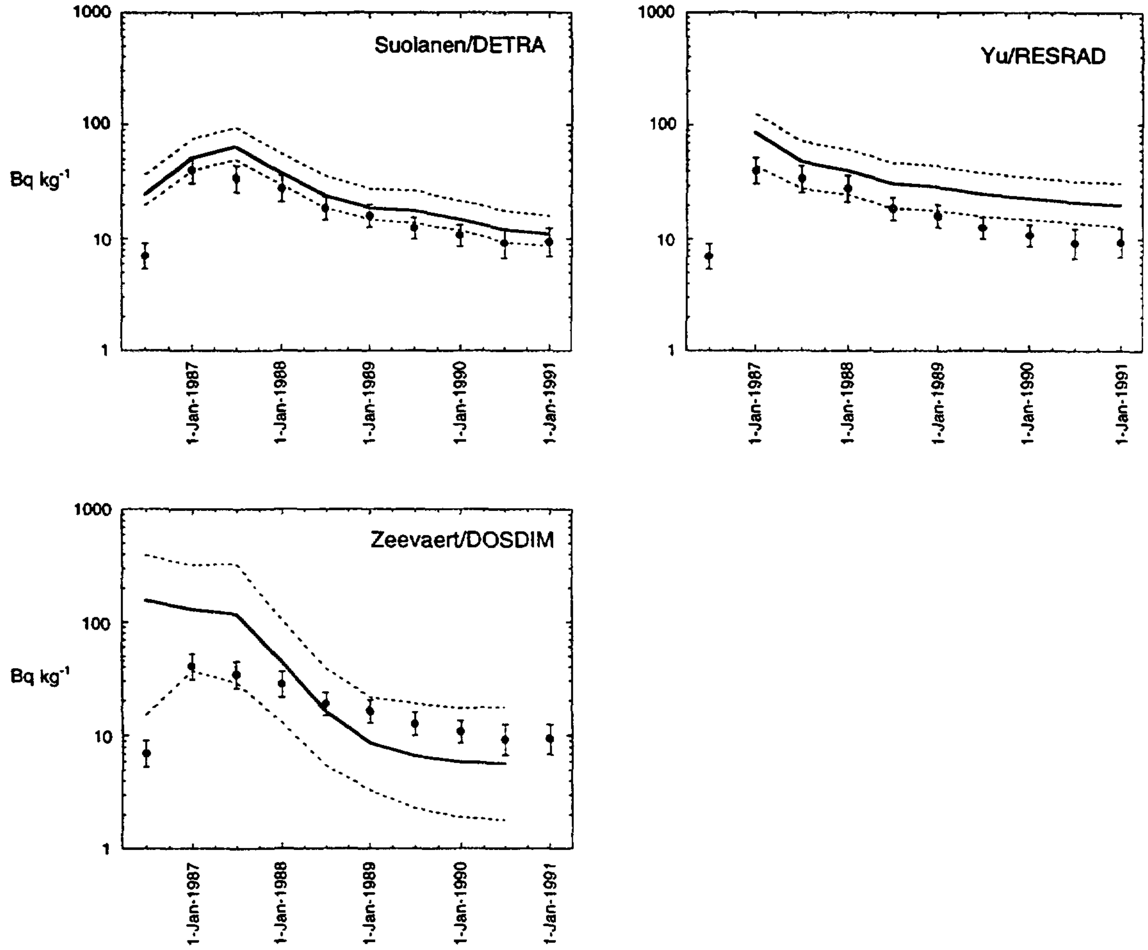

Fig. 23 (continued)

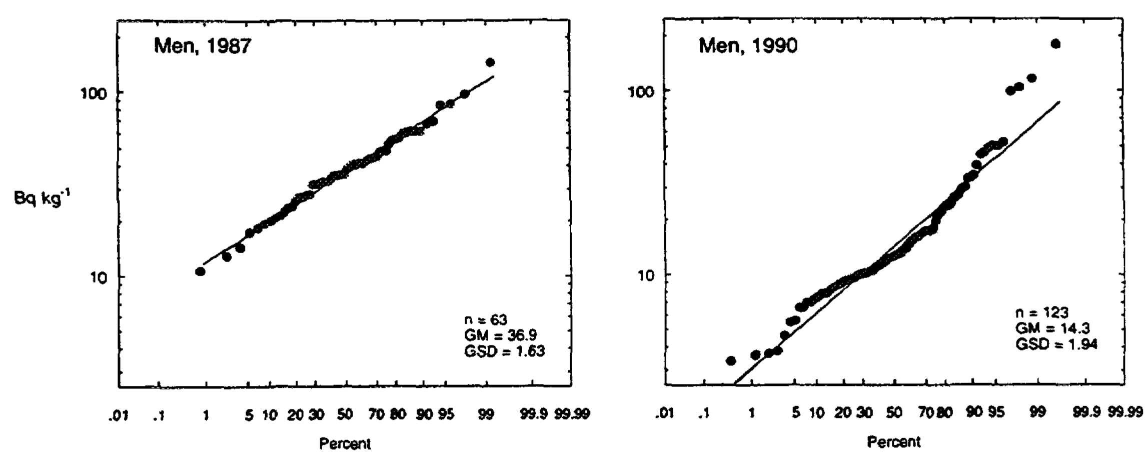

FIG. 24. Distributions of whole body concentrations of ^{137}Cs for men, women, and children for southern Finland in 1987 and 1990.
The geometric mean (GM) and geometric standard deviation (GSD) are given for each plot, together with the number of individuals measured (n).

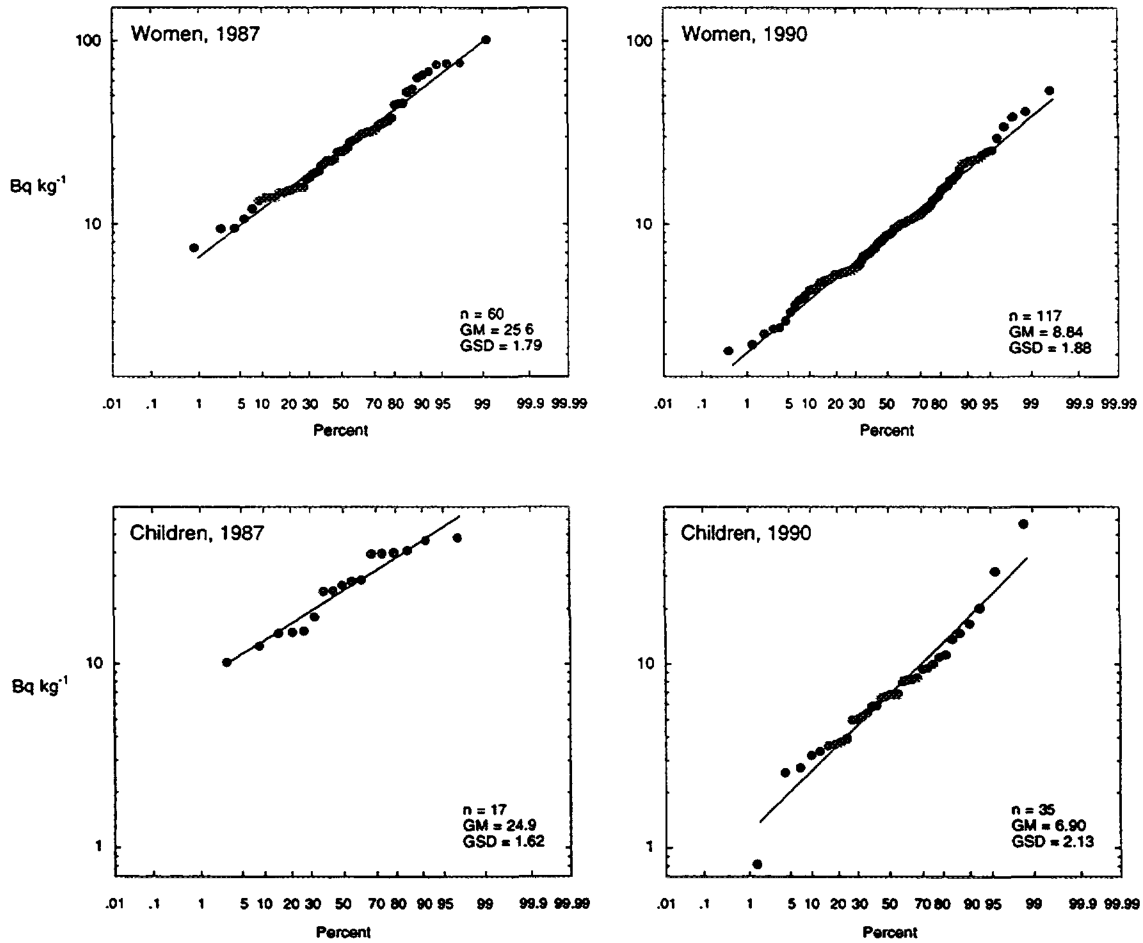

FIG. 24 (continued)

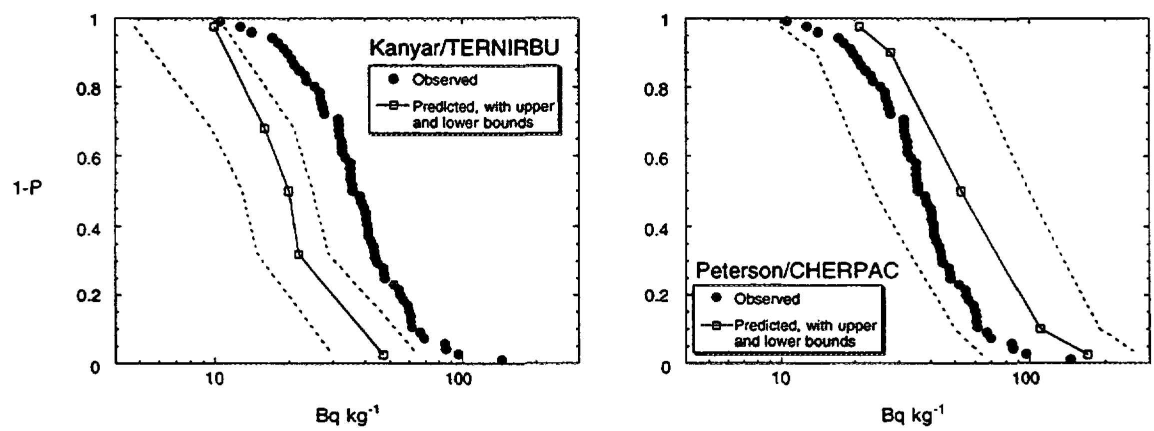

FIG. 25. A comparison of model predictions with observations for the distribution of concentrations of ^{137}Cs in individual adult males in southern Finland at the end of 1987.

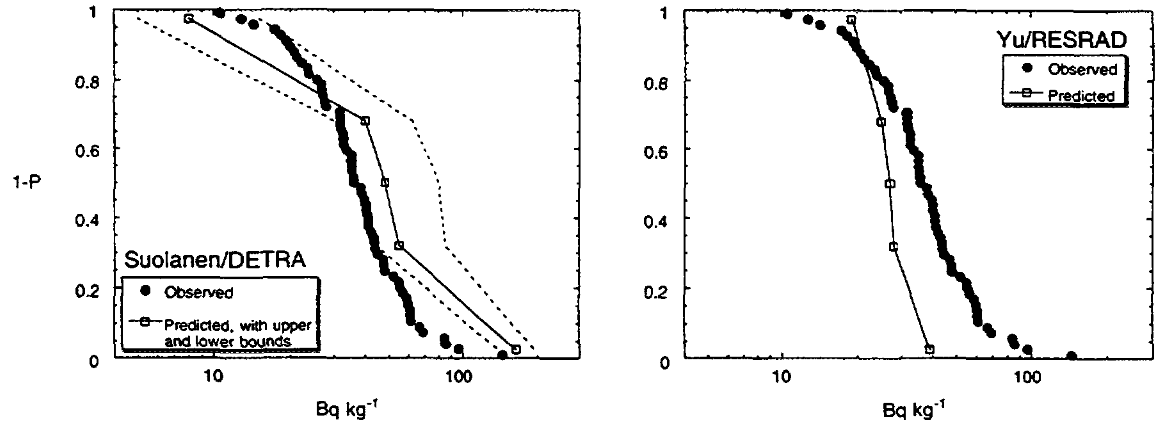

FIG. 25 (continued)

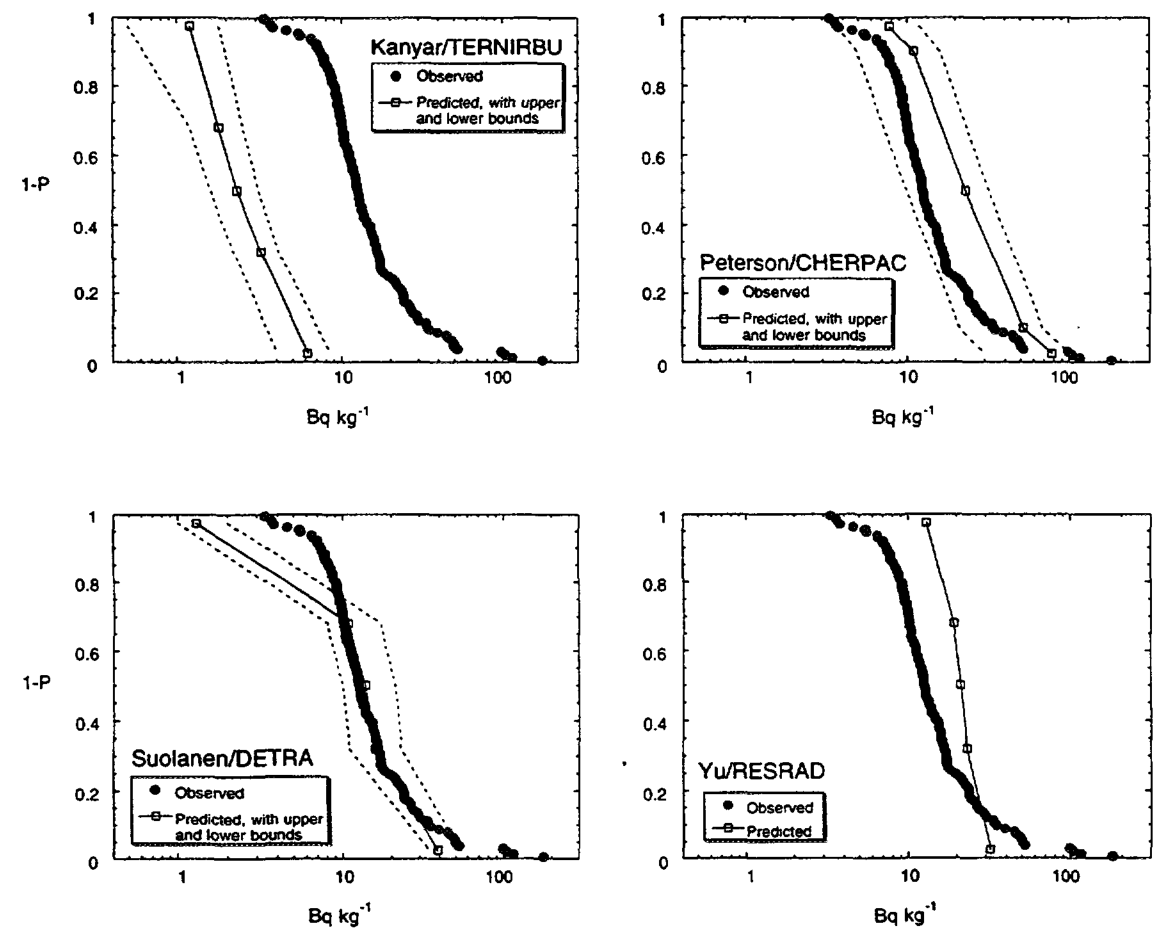

FIG. 26. A comparison of model predictions with observations for the distribution of concentrations of ^{137}Cs in individual adult males in southern Finland at the end of 1990.

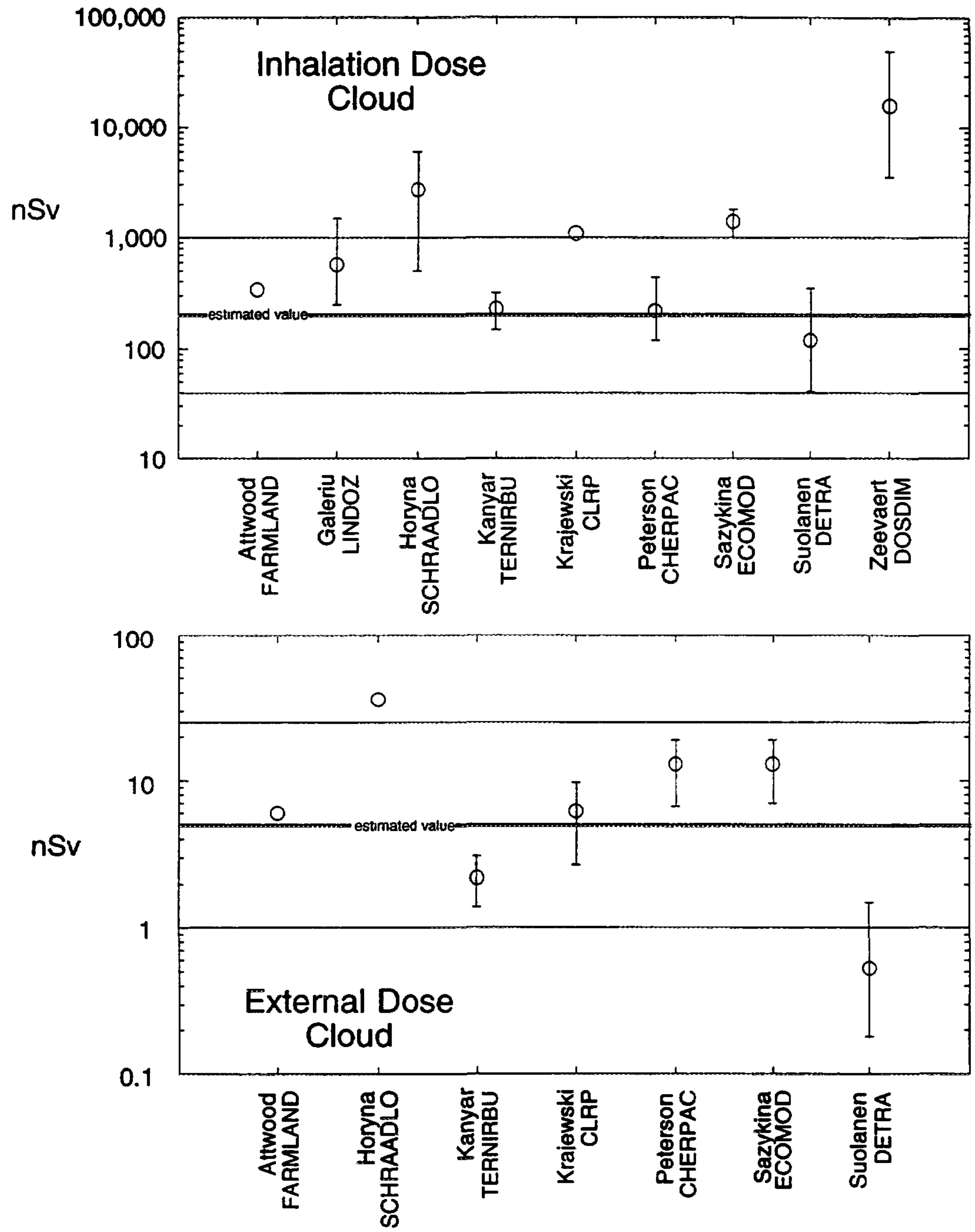

FIG. 27. A comparison of predictions to estimates for the effective doses of ^{137}Cs from inhalation of (top) and external exposure to (bottom) the initial plume from Chernobyl. The estimates derived from observed data and their 95% confidence intervals are indicated by horizontal lines. The predicted doses are open circles with vertical bars indicating the 95% subjective confidence intervals about the means.

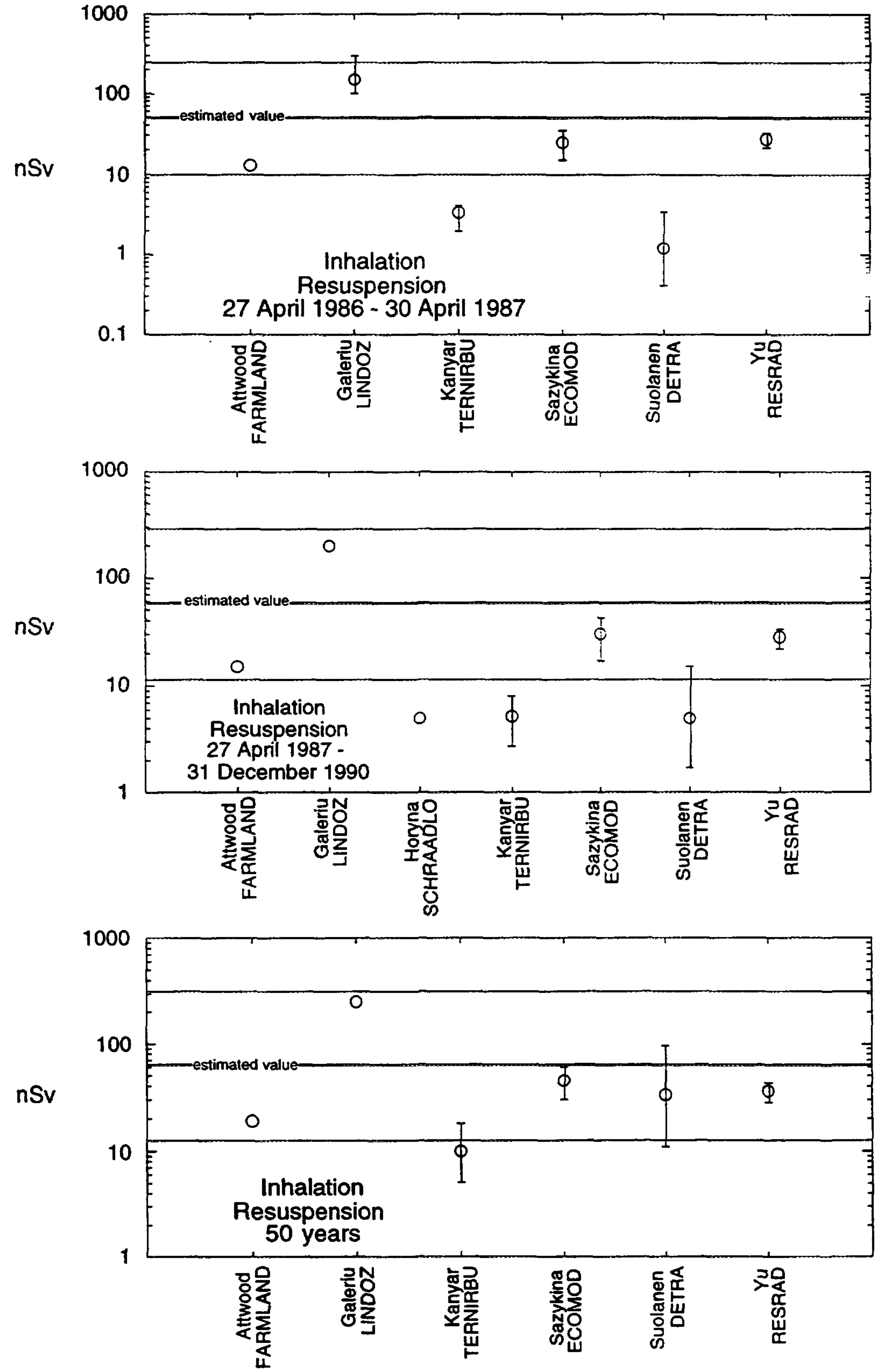

FIG. 28. A comparison of predictions to estimates for the effective doses of ^{137}Cs at different times from inhalation of resuspended material.

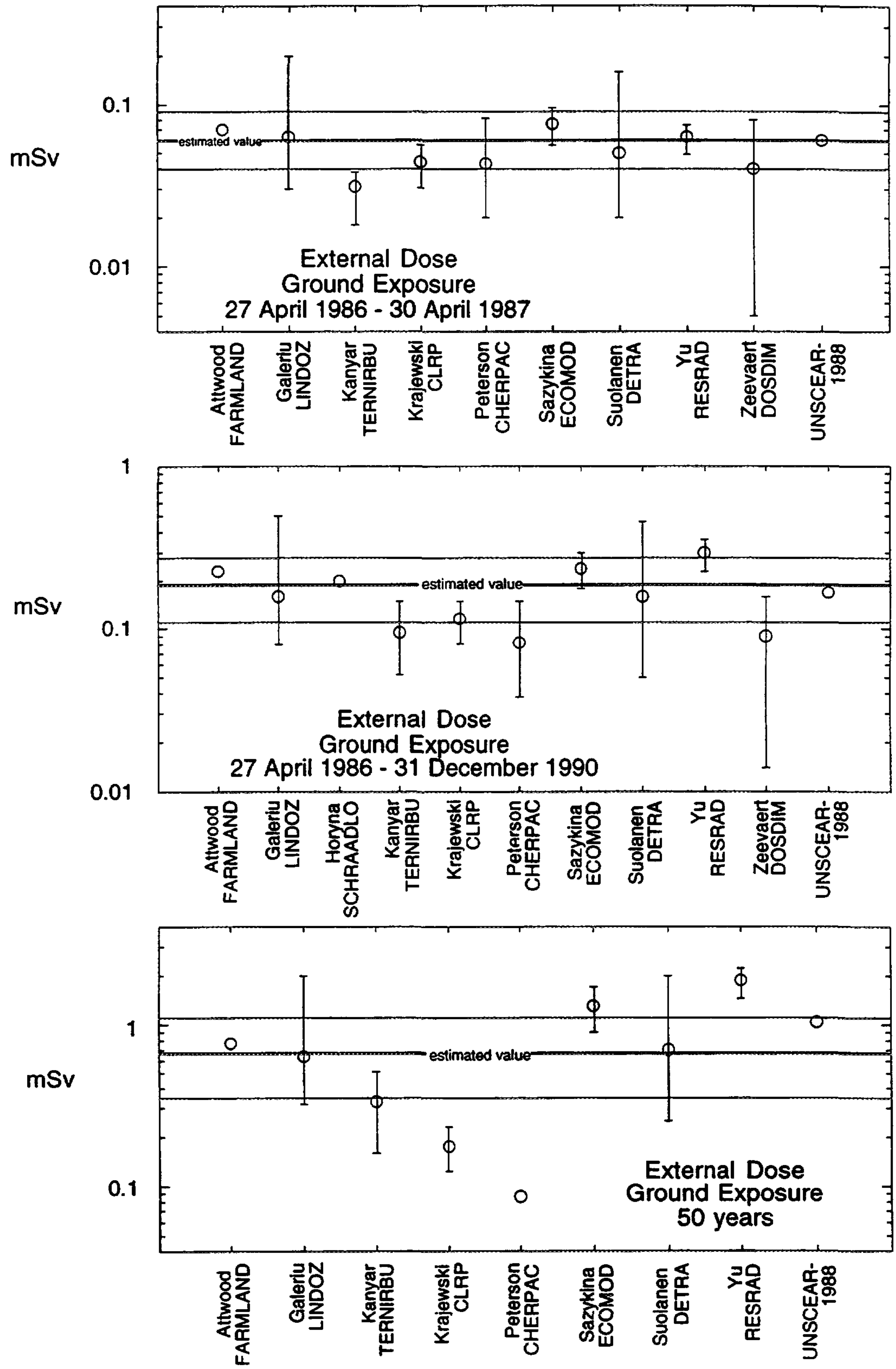

FIG. 29. A comparison of predictions to estimates for the effective doses at different times from external exposure to ^{137}Cs deposited on the ground surface.

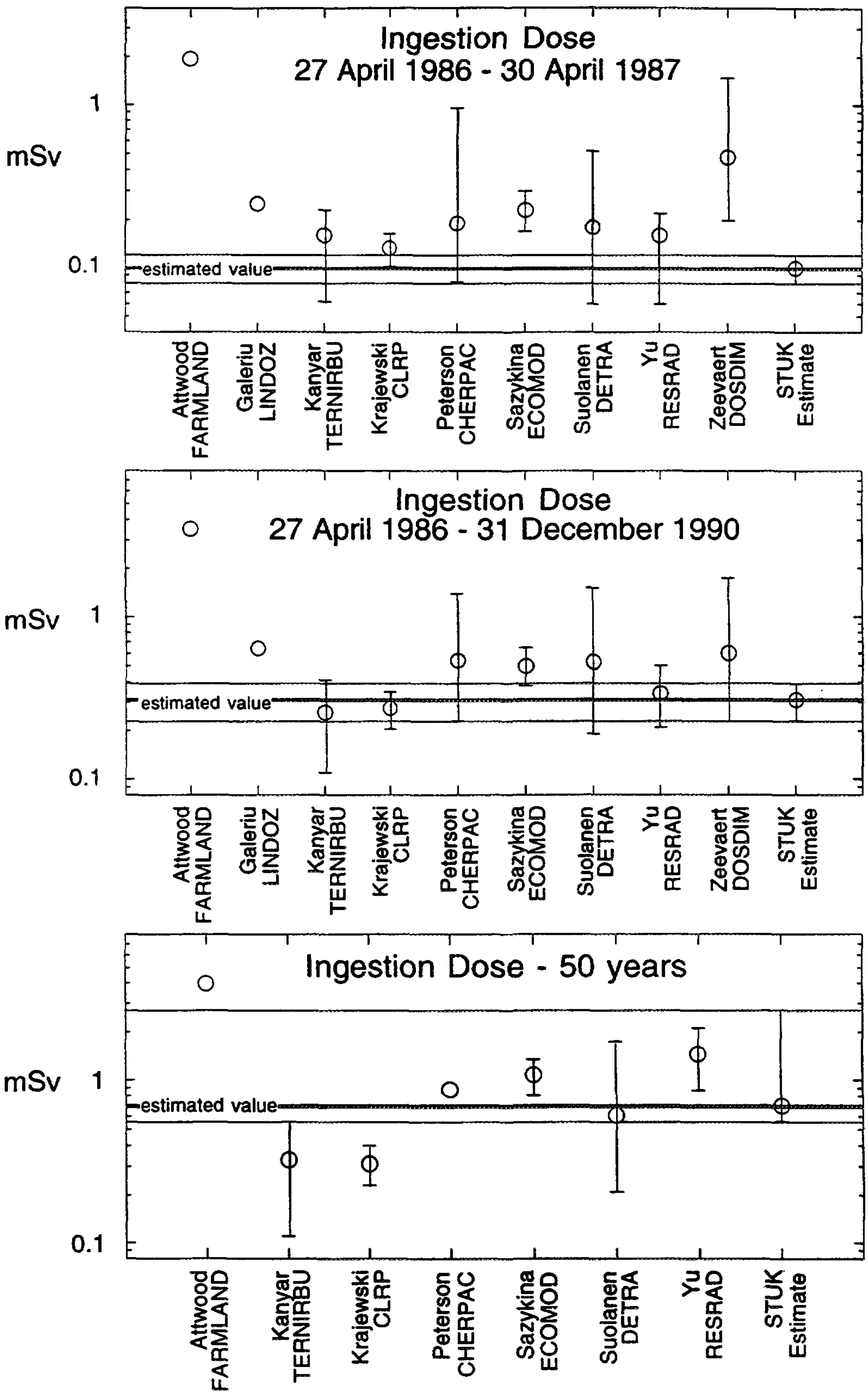

FIG. 30. A comparison of predictions to estimates for the committed effective doses at different times from ingestion of ^{137}Cs in food.

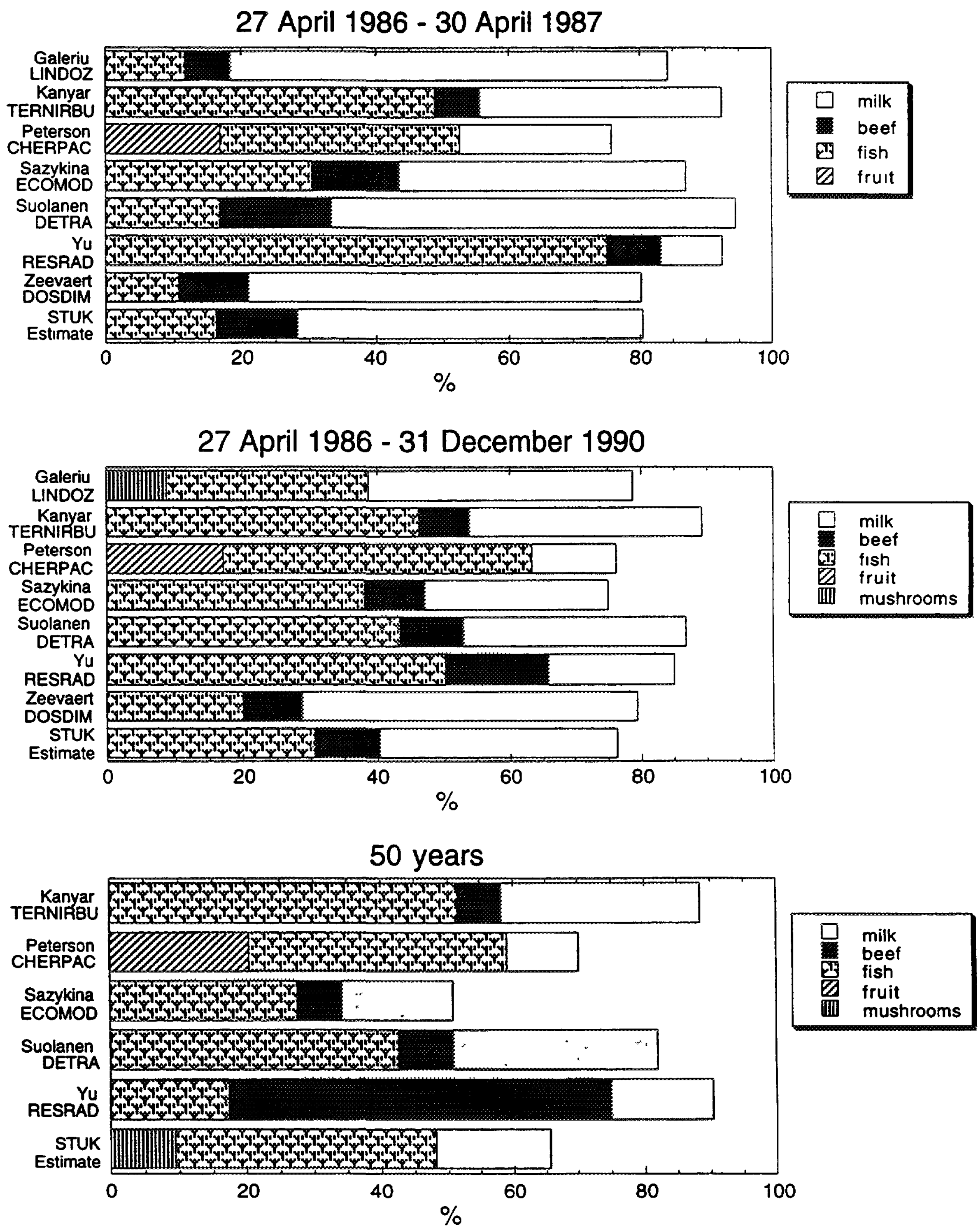

FIG. 31. A comparison of predictions to estimates for the three major contributors (in percentages) to the effective dose from ingestion of ^{137}Cs in food.

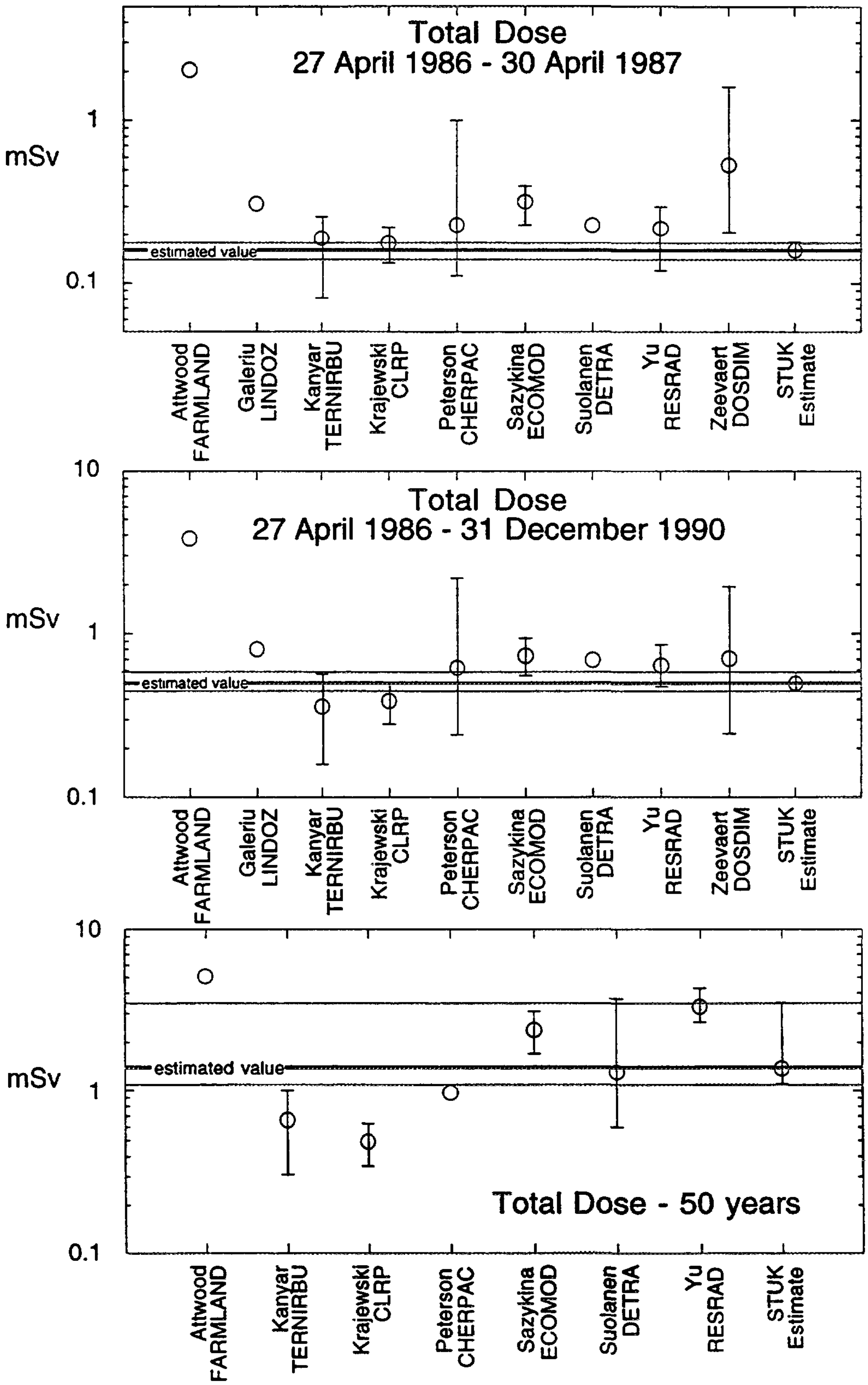

FIG. 32. A comparison of predictions to estimates for the effective total doses of ^{137}Cs at different times.

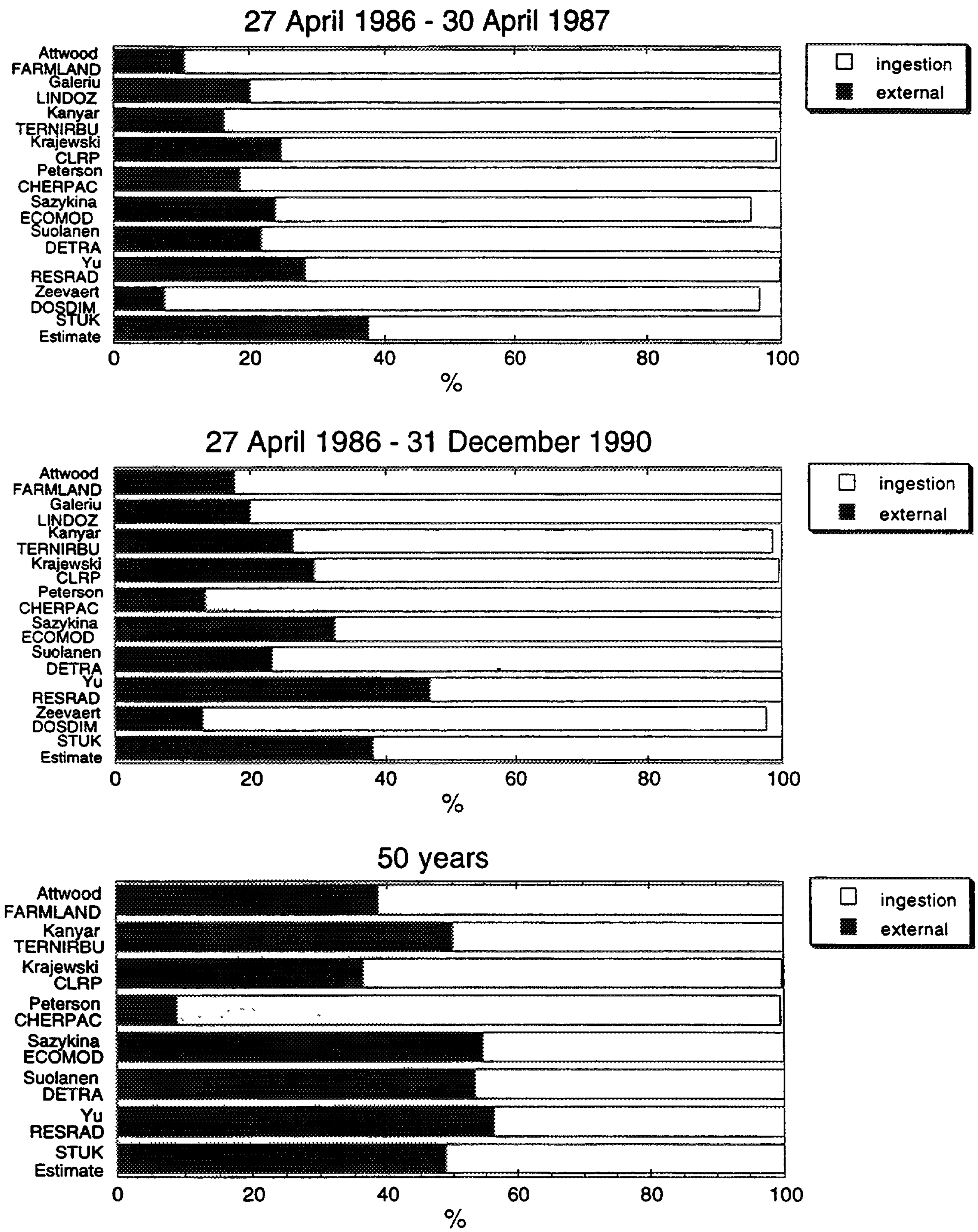

FIG. 33. A comparison of predictions to estimates for the two major contributors to the total effective dose of ^{137}Cs.

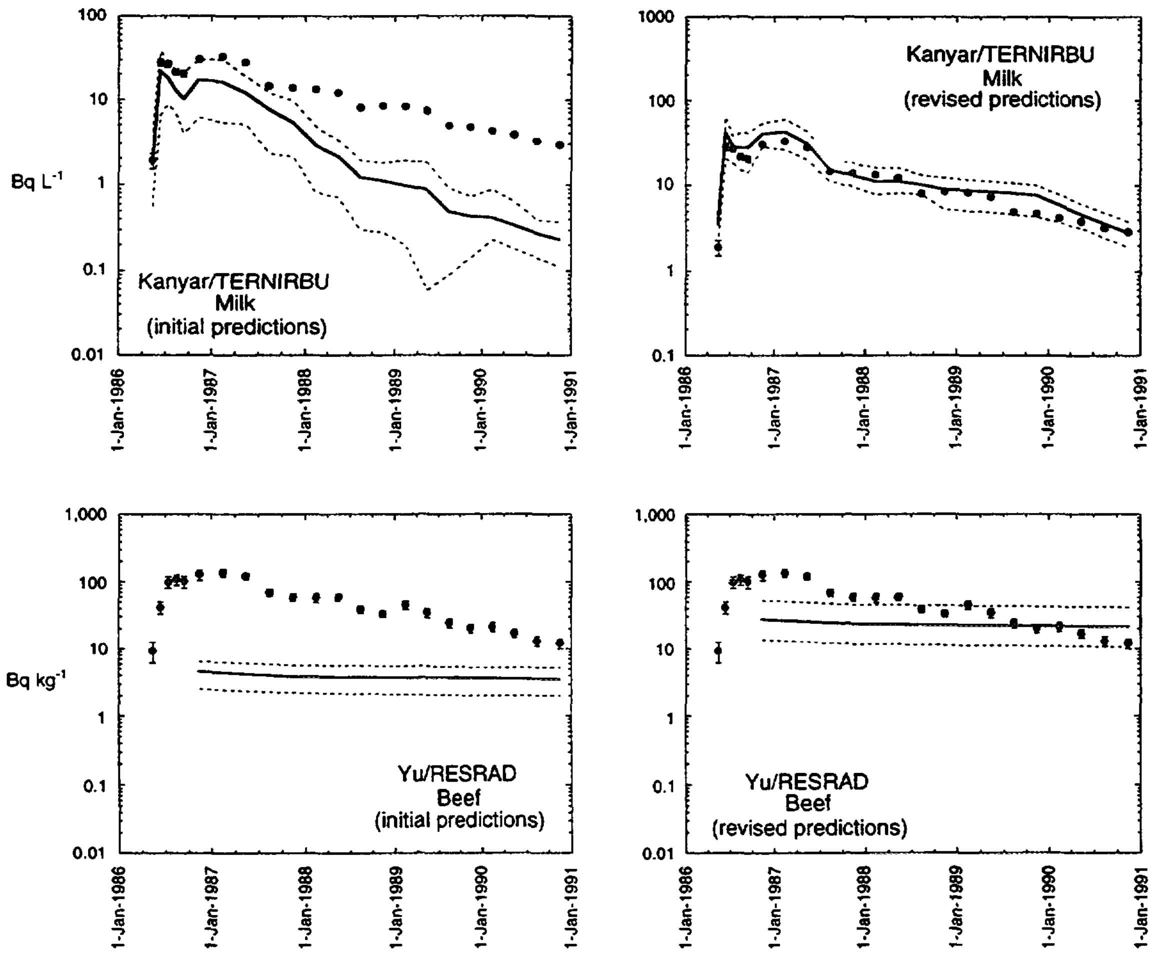

FIG. 34. Comparison of initial (left) and revised (right) predictions for milk for Kanyar/TERNIRBU (top) and for beef for Yu/RESRAD (bottom).

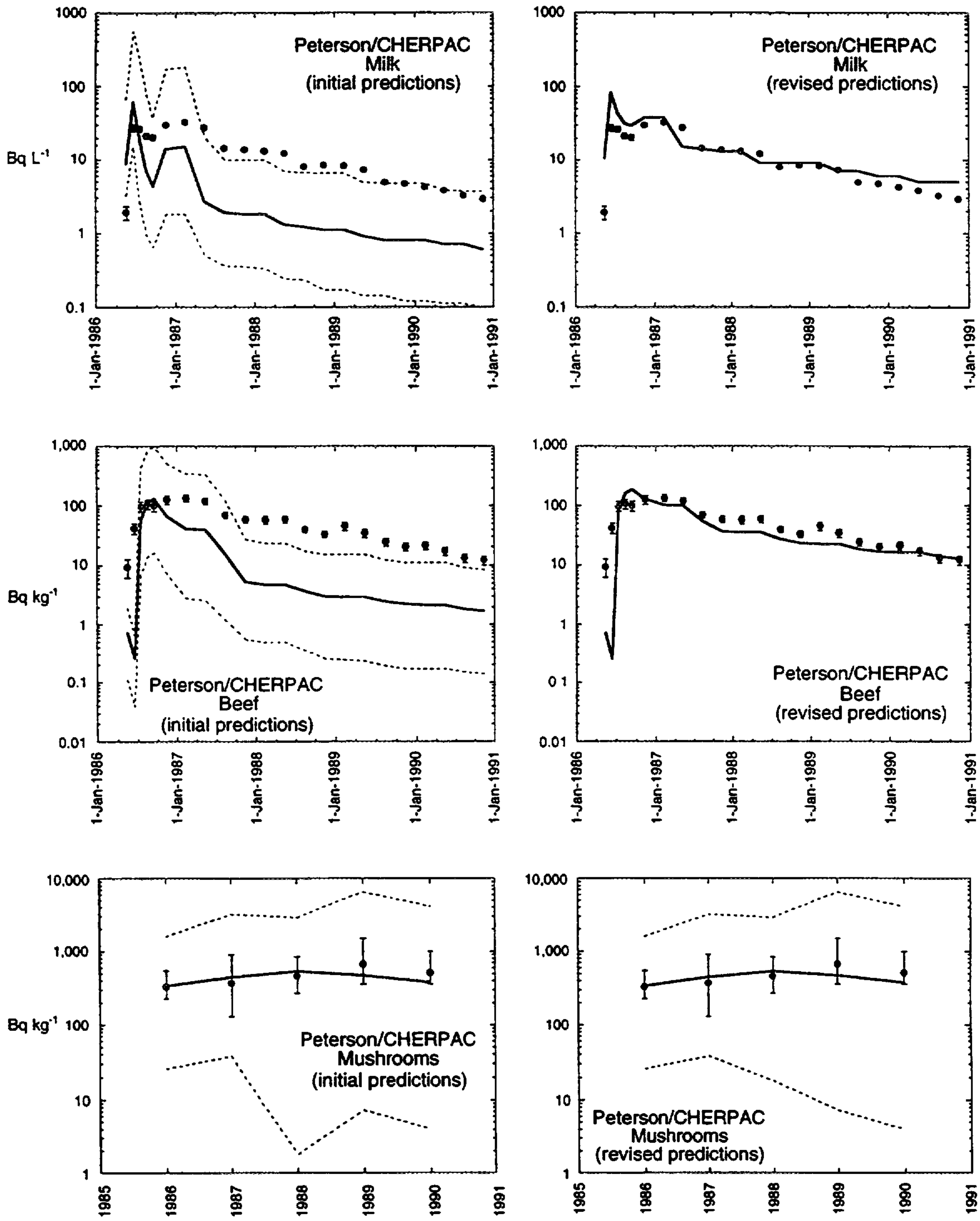

FIG. 35. Comparison of initial (left) and revised (right) predictions for milk (top), beef (center), and mushrooms (bottom) for Peterson/CHERPAC.

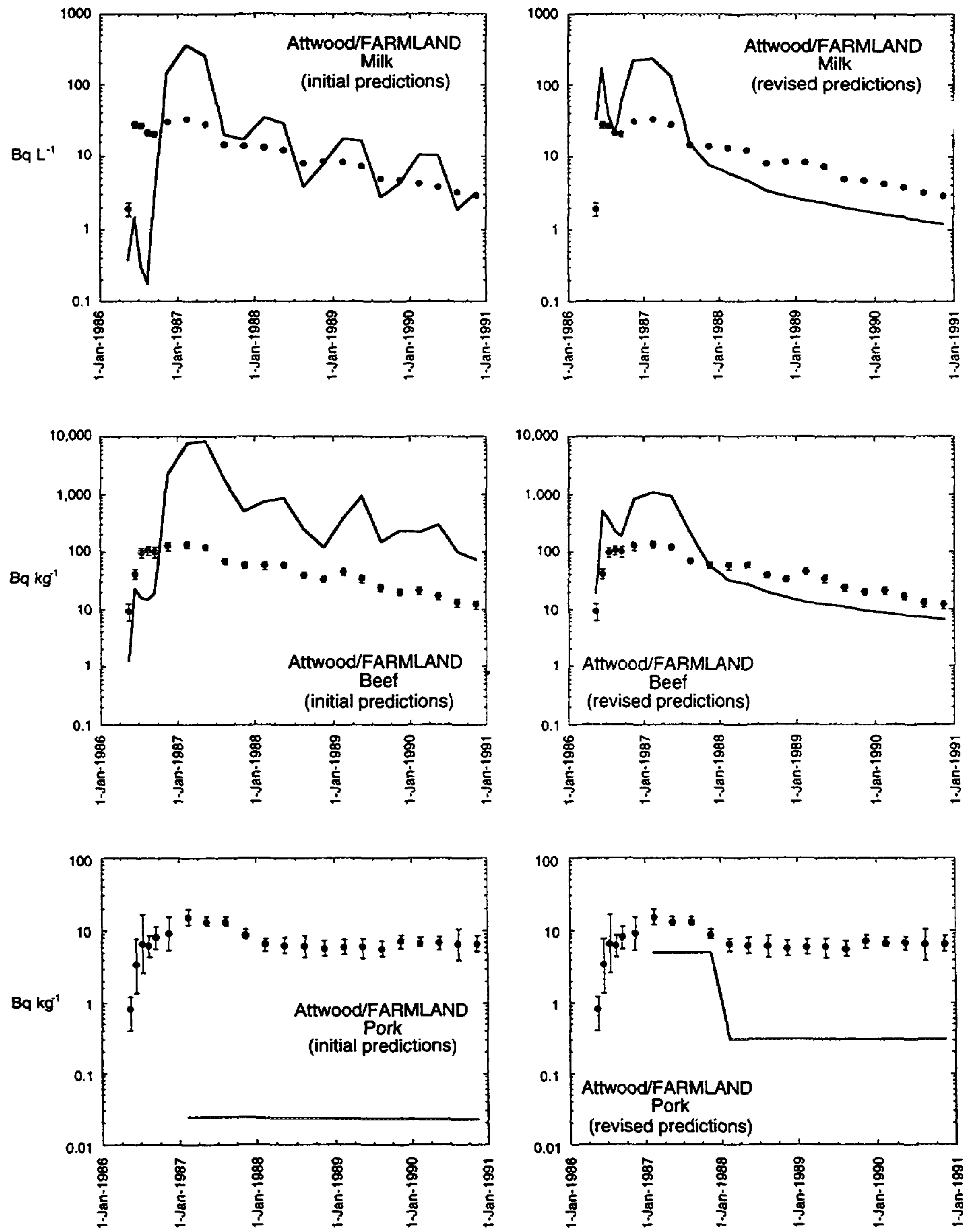

FIG. 36. Comparison of initial (left) and revised (right) predictions for milk (top), beef (center), and pork (bottom) for Attwood/FARMLAND.

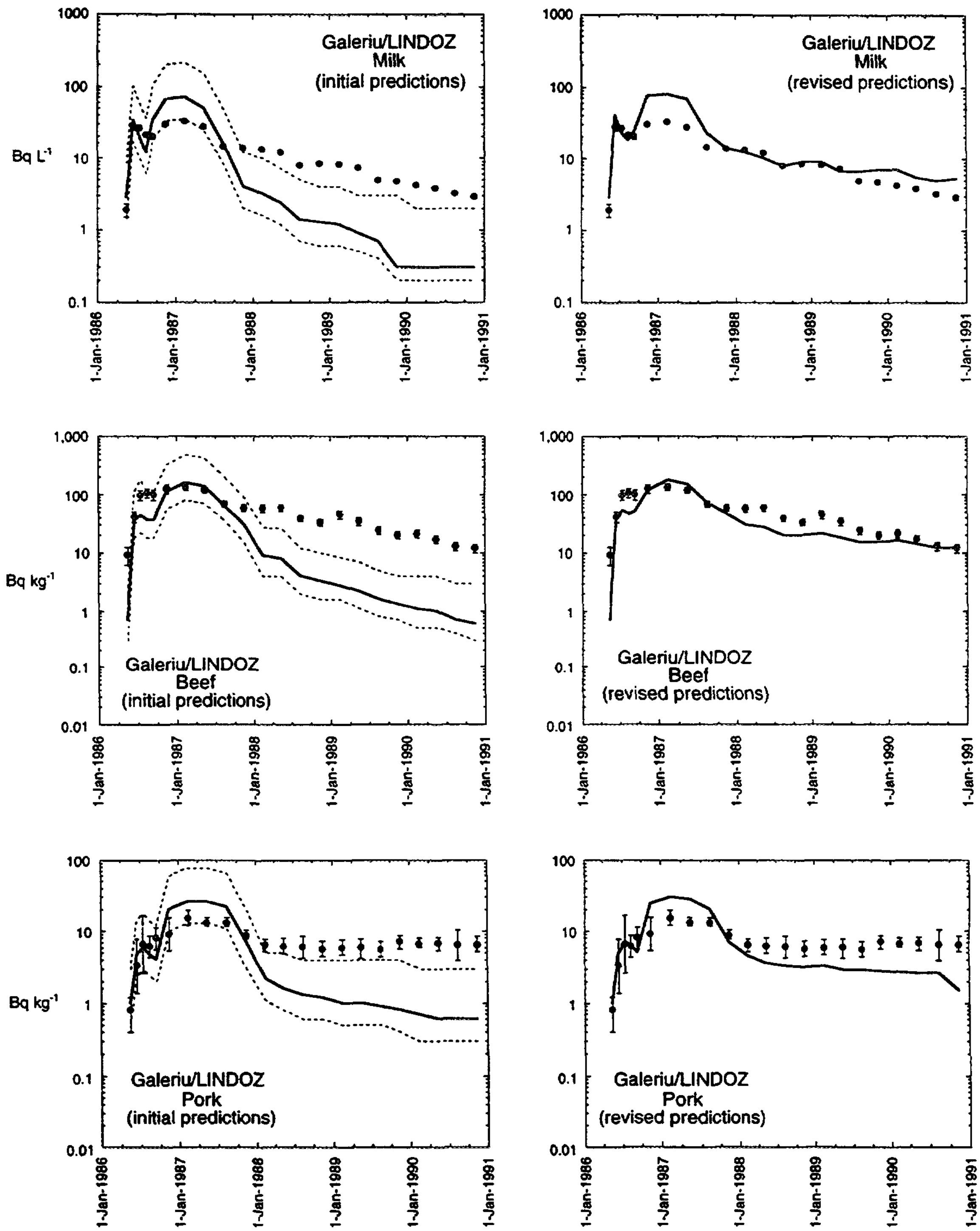

FIG. 37. Comparison of initial (left) and revised (right) predictions for milk (top), beef (center), and pork (bottom) for Galeriu/LINDOZ.

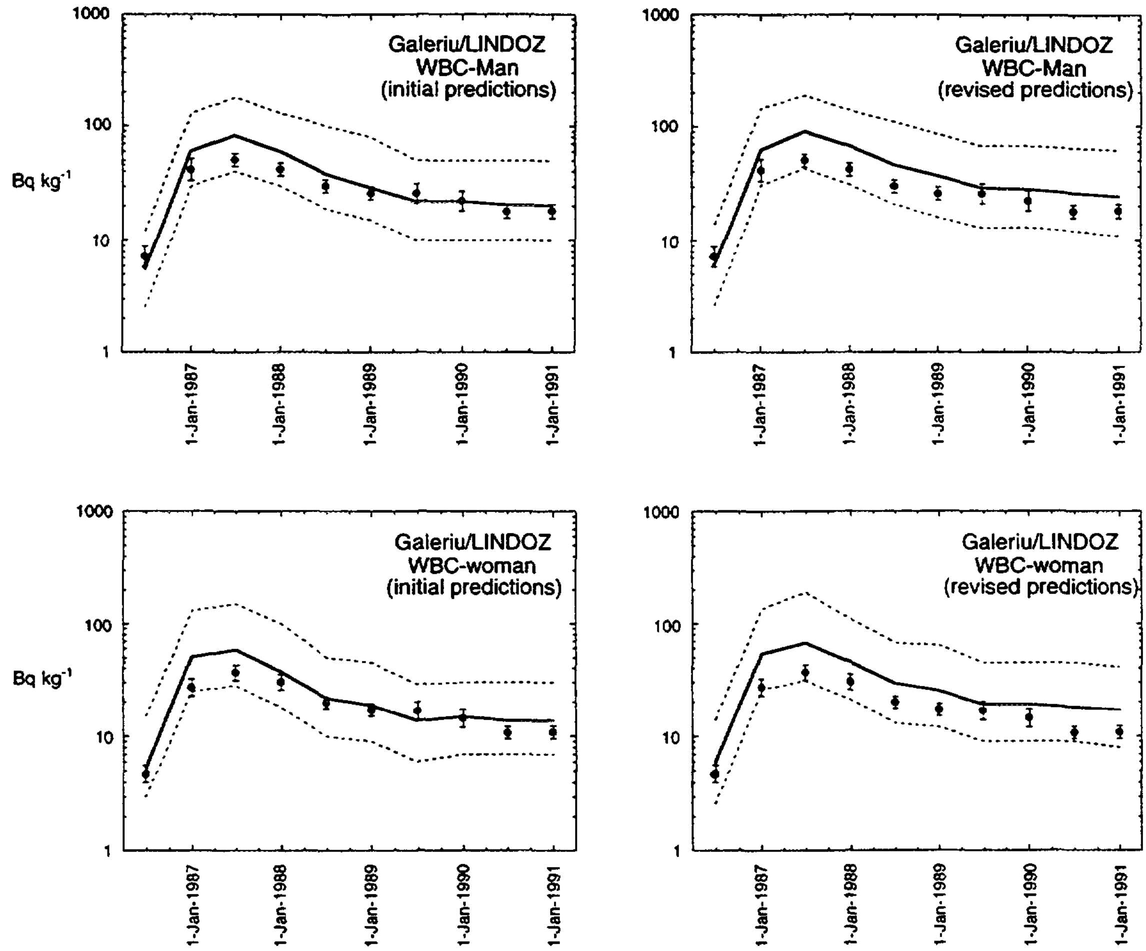

FIG. 38. Comparison of initial (left) and revised (right) predictions whole body concentrations for men (top) and women (bottom) for Galeriu/LINDOZ.

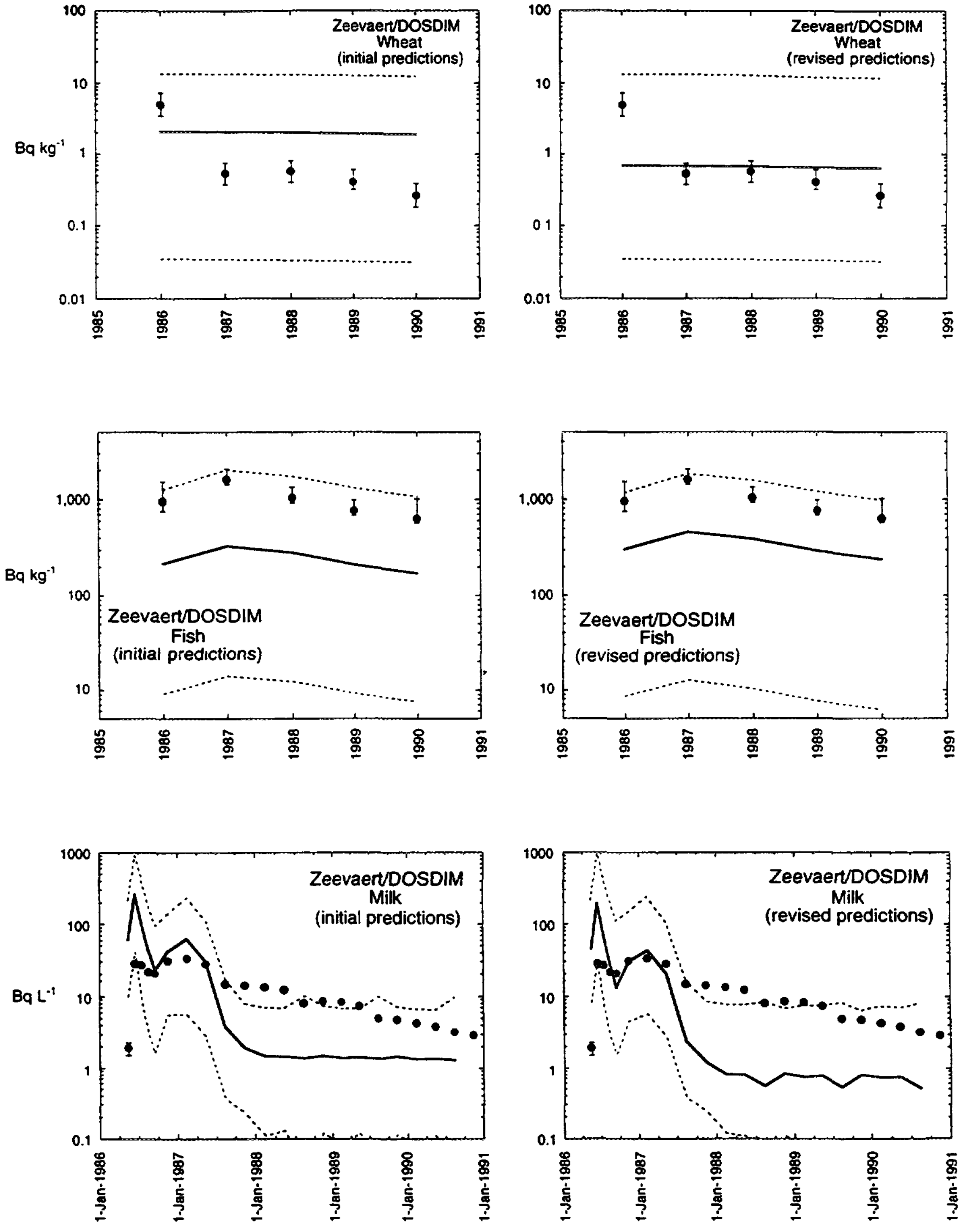

FIG. 39. Comparison of initial (left) and revised (right) predictions for wheat (top), fish (center), and milk (bottom) for Zeevaert/DOSDIM.

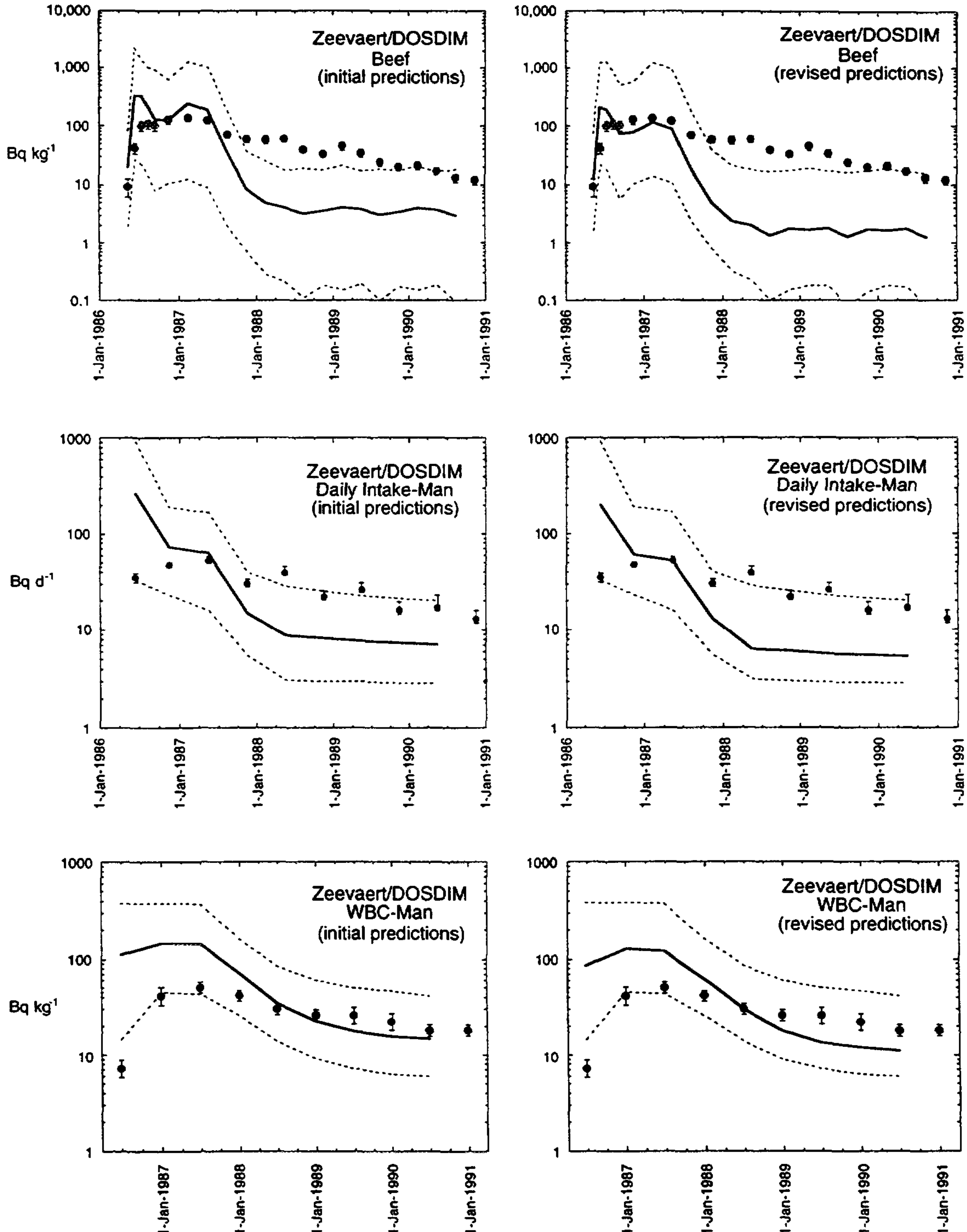

FIG. 40. Comparison of initial (left) and revised (right) predictions for beef (top), daily intake for men (center), and whole body concentrations in men (bottom) for Zeevaert/DOSDIM.

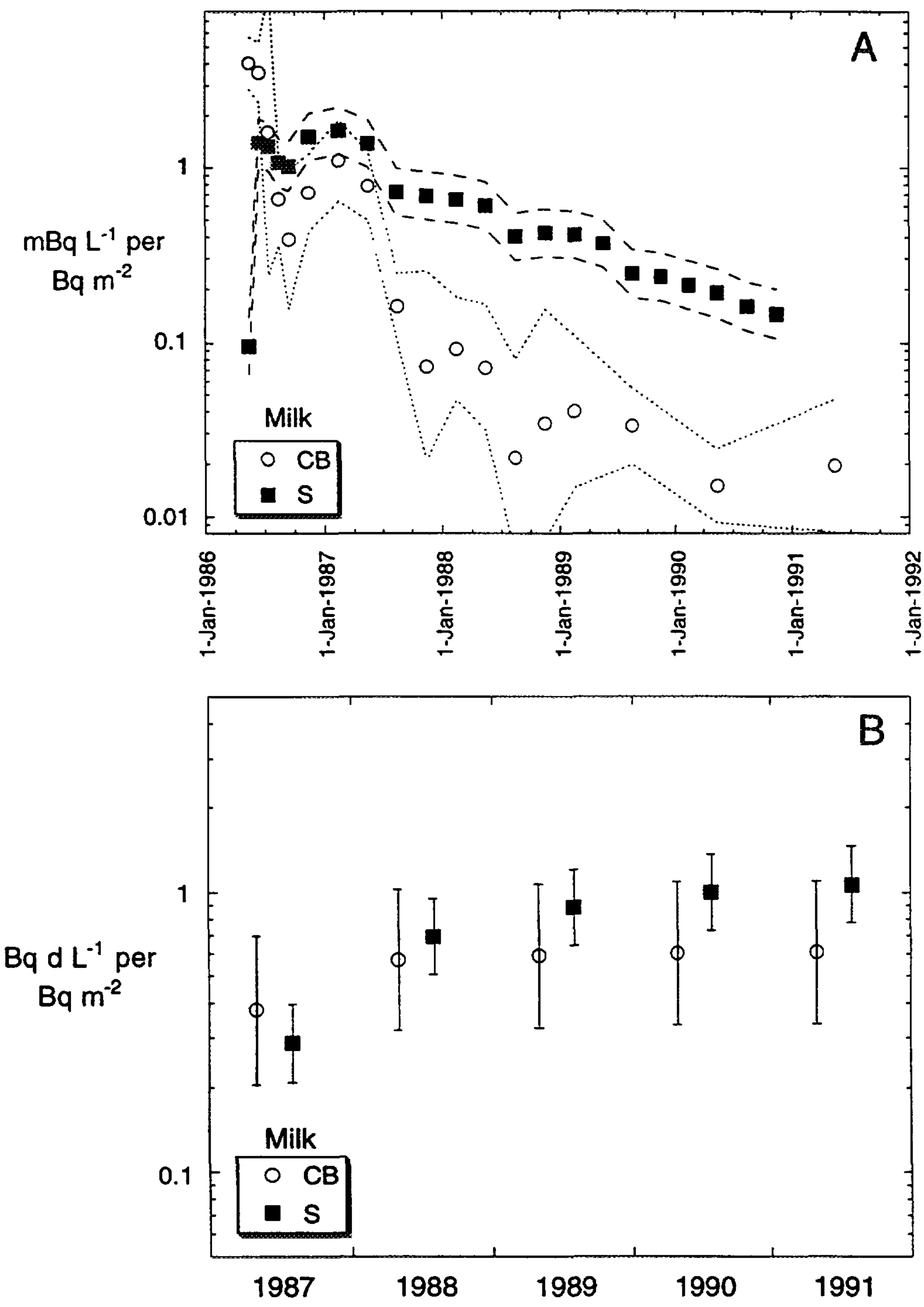

FIG. 41. Comparison of ^{137}Cs concentrations in milk for Central Bohemia (CB) and southern Finland (S). Shown are (A) the observations normalized for total deposition and (B) the cumulative time-integrated concentrations normalized for total deposition (shown for 1, 2, 3, 4, and 5 years post-accident). The 95% confidence limits are indicated as lines (A) or bars (B).

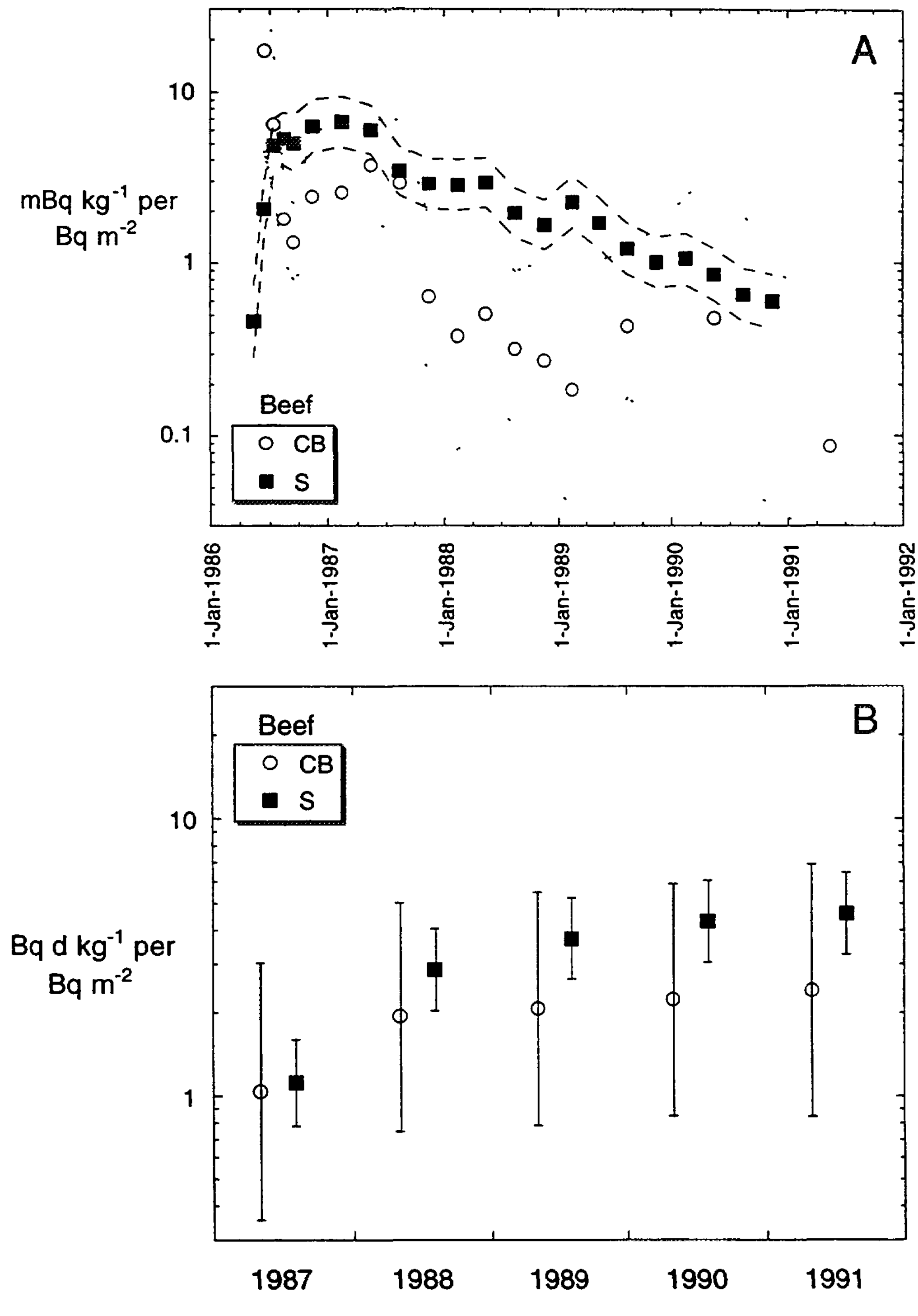

FIG. 42. Comparison of ^{137}Cs concentrations in beef for Central Bohemia (CB) and southern Finland (S). Shown are (A) the observations normalized for total deposition and (B) the cumulative time-integrated concentrations normalized for total deposition (shown for 1, 2, 3, 4, and 5 years post-accident). The 95% confidence limits are indicated as lines (A) or bars (B).

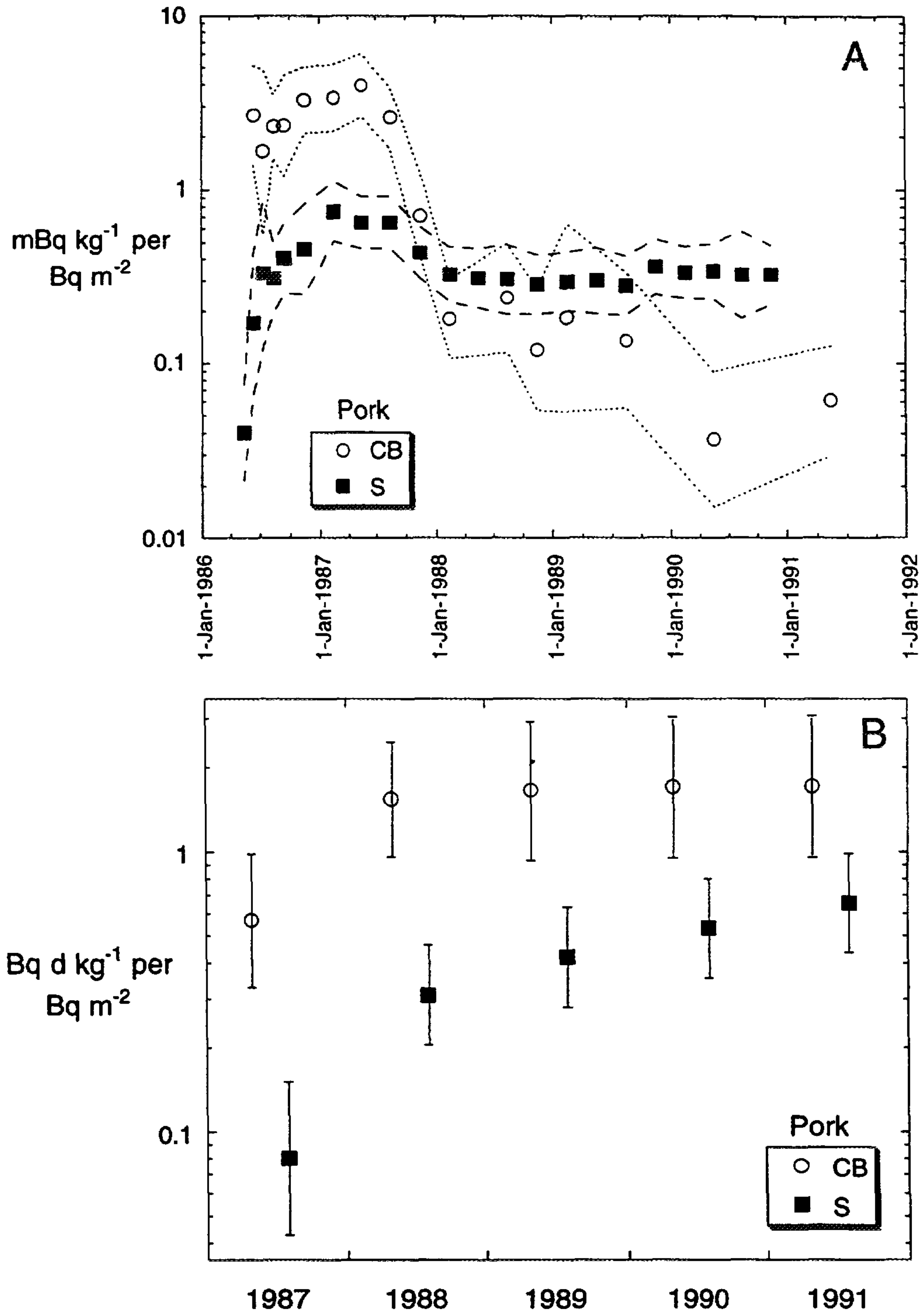

FIG. 43. Comparison of ^{137}Cs concentrations in pork for Central Bohemia (CB) and southern Finland (S). Shown are (A) the observations normalized for total deposition and (B) the cumulative time-integrated concentrations normalized for total deposition (shown for 1, 2, 3, 4, and 5 years post-accident). The 95% confidence limits are indicated as lines (A) or bars (B).

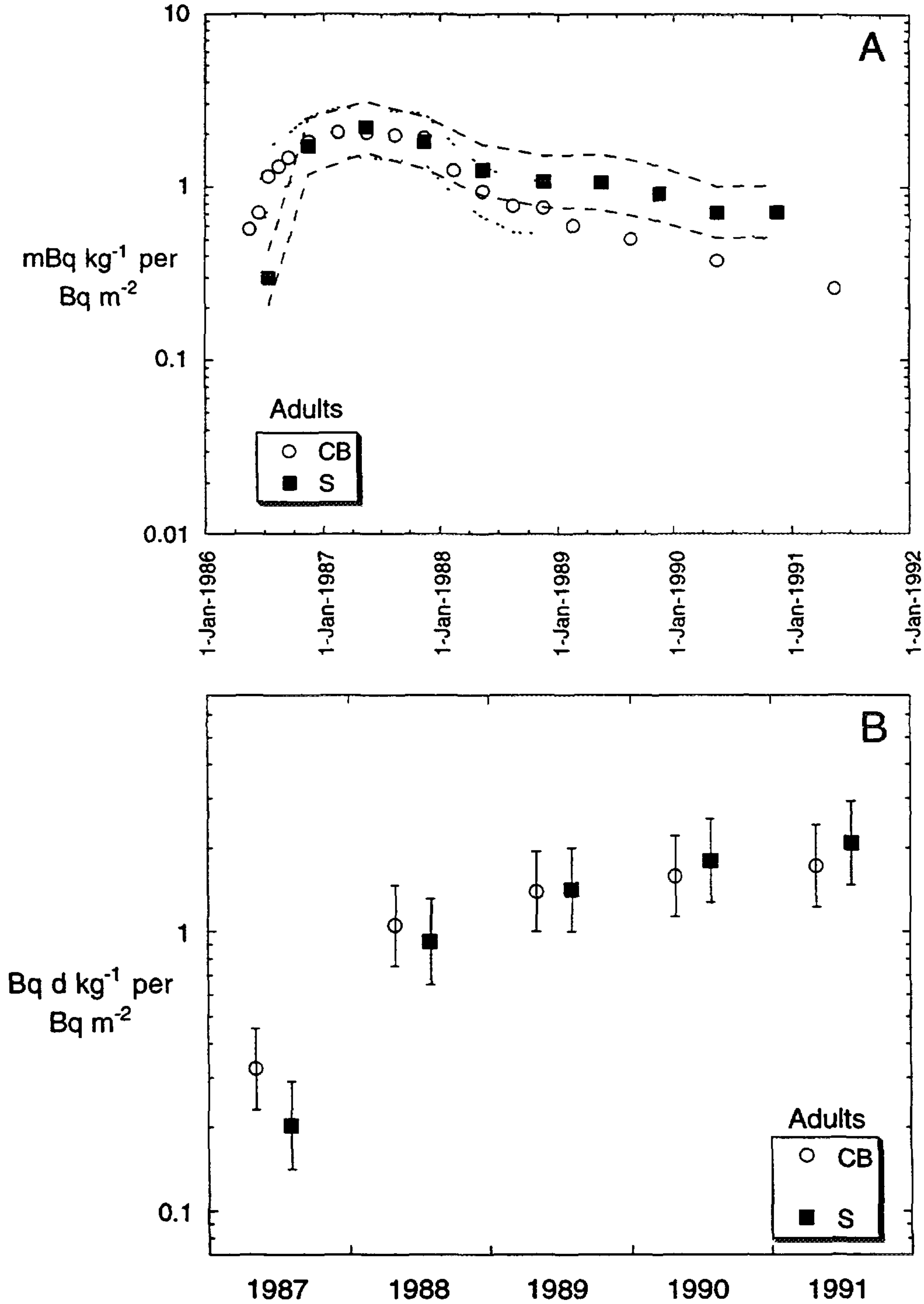

FIG. 44. Comparison of whole body concentrations of ^{137}Cs for Central Bohemia (CB) and southern Finland (S). Shown are (A) the observations normalized for total deposition and (B) the cumulative time-integrated concentrations normalized for total deposition (shown for 1, 2, 3, 4, and 5 years post-accident). The 95% confidence limits are indicated as lines (A) or bars (B).

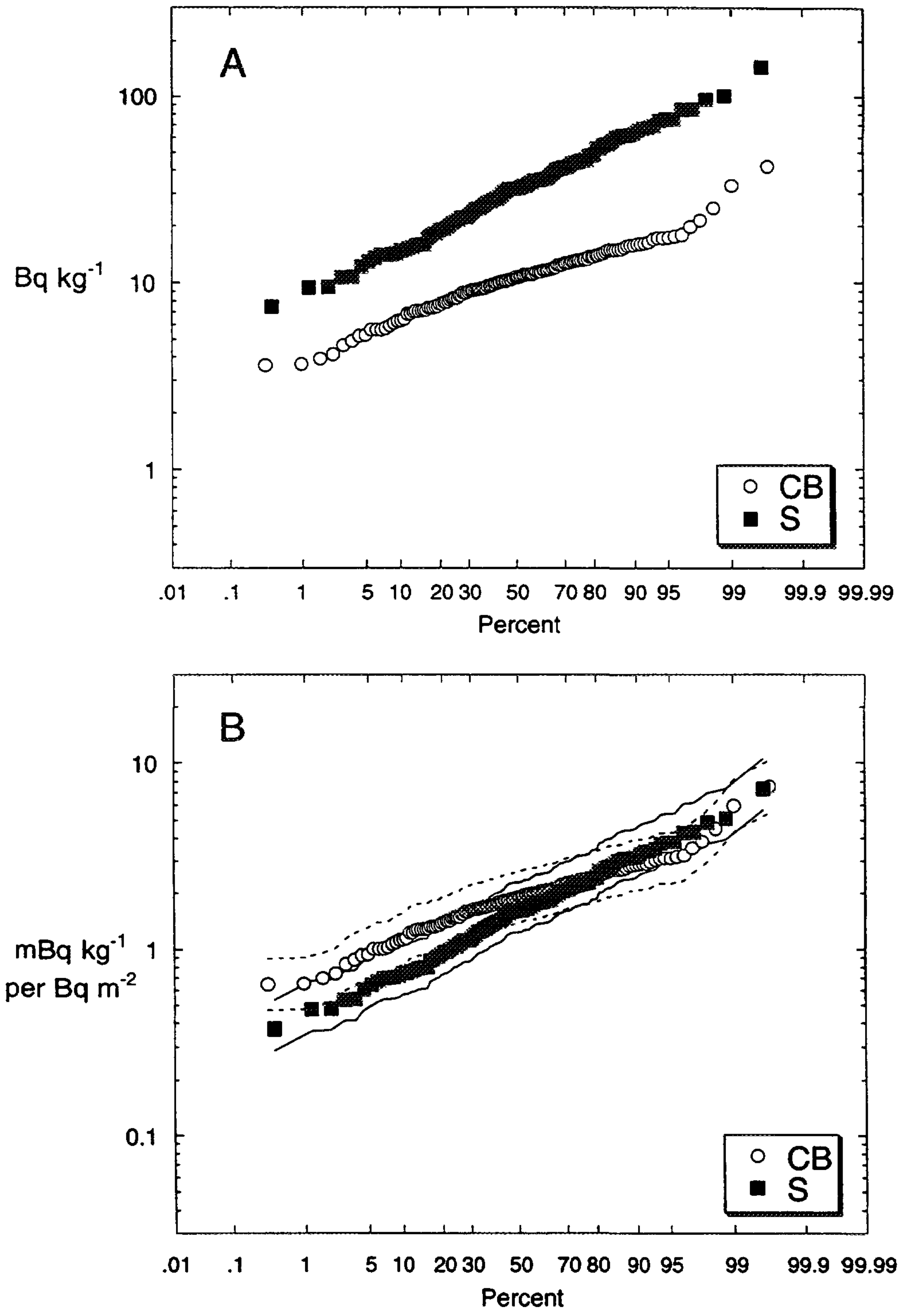

FIG. 45. Comparison of distributions of whole body concentrations of ^{137}Cs for adults (males and females) in Central Bohemia (CB) and southern Finland (S) for 1987. Shown are (A) the observations and (B) the observations normalized for total deposition. Confidence limits on the normalized observations represent only the uncertainty in the total deposition. Observations for CB are for the second quarter of 1987; observations for S are for December 31, 1987.

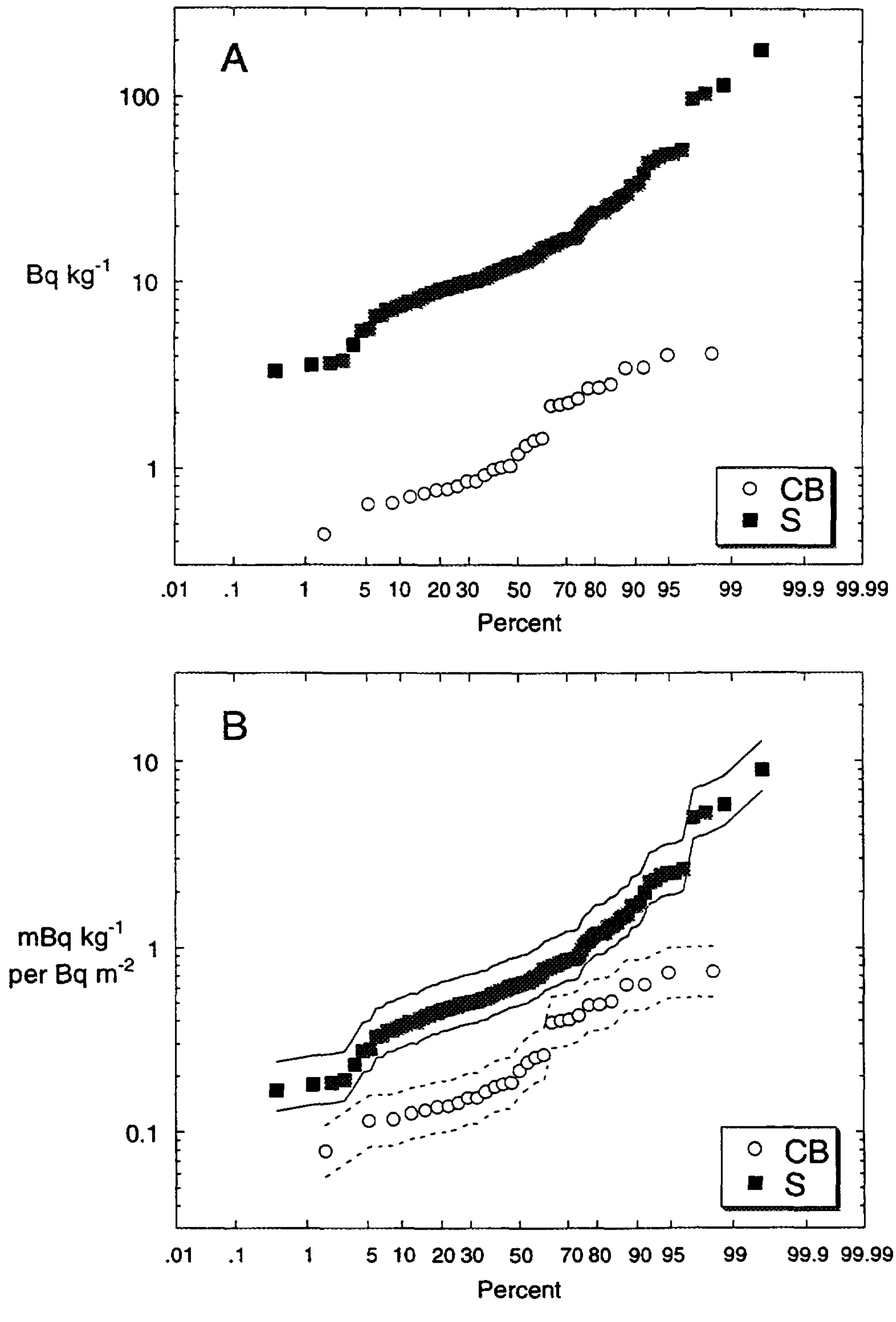

FIG. 46. Comparison of distributions of whole body concentrations of ^{137}Cs for adults (males and females) in Central Bohemia (CB) and southern Finland (S) for 1990. Shown are (A) the observations and (B) the observations normalized for total deposition. Confidence limits on the normalized observations represent only the uncertainty in the total deposition. Observations for CB are for the fourth quarter of 1990; observations for S are for December 31, 1990.

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Appendix I

DOCUMENTATION AND EVALUATION OF MODEL VALIDATION DATA USED IN SCENARIO S

A. Rantavaara, H. Arvela, M. Suomela

I.1. INTRODUCTION

The scenario on Chernobyl-derived environmental radiocaesium in southern Finland in the years 1986-2036 was used for model testing in the IAEA/CEC Co-ordinated Research Programme on the Validation of Environmental Model Predictions (VAMP). This report gives the scenario description and the observed values of the test quantities, and their derivation from radiocaesium measurement data. Also radiation doses of the test persons are estimated.

The modelling task was to assess both the amount of deposited ^{137}Cs and its concentrations in foodstuffs, animal feeds and the human body in the test region during the specified time periods. The test area comprised nine southernmost provinces of Finland, an area of 176 000 km^2 with a population of 4.3 million (Fig. I.1). The test persons were 20 year old adults and a child, ten years old when the deposition occurred. Three time periods were considered, namely the first twelve months since the deposition at the end of April 1986, 4.6 years (until 31.12.1990), and 50 years.

The test region is characterized by varying environmental and food production conditions. Domestic products from agriculture and also products from aquatic and terrestrial seminatural ecosystems contribute to the diet of people. The weather conditions of southern and middle boreal zones add variation and some complexity to the scenario. The year has four seasons, the growth period is short but intensive, and field crops yield one harvest per year. The northern boreal zone and also the southwestern archipelago were outside the test area. The pathways related either to reindeer or to coastal brackish water fishes were not included in the modelling tasks.

Input information (Section I.2) for the test scenario includes measured concentrations of ^{134}Cs and ^{137}Cs in ground level air, and deposition densities based both on rain water collection and ground contamination data. General information on the test region, population, and production of foodstuffs is also given.

Most radioactive fallout received in Finland after the Chernobyl nuclear accident originated in the first major release and spread over the test region between April 27 and 29, 1986. Most radioactive material was deposited with heavy showers which caused an uneven areal distribution (Fig. I.2). Deposition continued with varying intensity until May 12. At the end of April the growing season had not yet begun in Finland. Estimation of the mean deposition density was one of the modelling tasks. To avoid a biased starting point for foodchain assessments due to modellers' own deposition estimates, the mean deposition density of ^{137}Cs in each subregion used in the scenario was given as input information.

The model validation test was started as a blind test. All regional information in the scenario description was coded, and the first maps of subregions were schematic to hide the actual test area. The blind test idea was gradually cancelled in the course of the exercise. The geographical region S was revealed after deposition estimates were made. At the same time, sources of information in the open literature became available to the modellers. After the blind test phase, communication was encouraged between modellers and the compiler of the scenario description at the Finnish Centre for Radiation and Nuclear Safety (STUK) to avoid unnecessary misinterpretations of input information. Clarifications and additional information provided in the course of model calculations are included in the present scenario description.

Test data (Section I.3) include observed values for the endpoints of model calculations and their evaluation. The observed data include deposition, concentrations in animal feeds and in foodstuffs of agricultural and wild origin, human intake and whole body contents. For radiation dose comparisons (Section I.4) the following pathways were assessed: ingestion, inhalation, and external radiation from the cloud and from ground contamination. The ingestion pathway was further divided into food types to compare their relative importance to the dose. The internal dose was estimated from measured whole-body contents and from intake of foodstuffs and inhaled air. For all test quantities and dose estimates, the arithmetic mean and its 95% confidence interval were calculated for the entire region S.

Choosing a large region in Finland for a test scenario offered some advantages. The origin of consumed food was generally known. Finland is the northernmost country in the world which is almost self-supporting for agricultural produce. Foodstuffs of wild origin are domestic, too. The ready access to comprehensive statistical information on the population and on production of foodstuffs was another advantage.

Producing all radioactivity data at one institution guaranteed comparability of data and facilitated the compilation of the test scenario. STUK delivered the radiocaesium data and other input information to the International Atomic Energy Agency. The approach to environmental measurement programmes at STUK had greatly resembled the content of this kind of model validation tests. The planning of the scenario S started in the middle of the five-year test period. The information on environmental radioactivity in the past was thus necessarily based on existing data. The most challenging features of the test scenario, from a data deliverer's point of view, were the varying environmental pathways and conditions in a large test area, a comprehensive analysis of data and estimation of uncertainties for all test quantities.

I.2. DESCRIPTION OF TEST SCENARIO S

I.2.1. INTRODUCTION

This scenario involves the assessment of ^{137}Cs body content and of the total radiation dose due to ^{137}Cs in the environment to people living in an area of varying environmental conditions.

The scenario can be seen as being in two parts:

(1) a model test in which predictions of ^{137}Cs body content and concentrations in environmental materials can be compared with observed values in the test area; and
(2) a model comparison in which predictions of the total dose from ^{137}Cs in the test environment are compared and analysed.

Both rural settlements and urban areas are included in the test region, and pathways contributing to dose may include those from both terrestrial and aquatic environments.

I.2.2. ASSESSMENT TASKS

I.2.2.1. General

The following subsections contain a description of the calculational endpoints required in this test scenario. The quantities to be predicted are separated into two groups: The first group consists of quantities for which measurements exist and against which model predictions can be tested, the second group consists of quantities (e.g. radiation dose) which can only be predicted but not tested. The latter are included because they are the most common and useful endpoints in radiological assessments. For each quantity, a 95% confidence interval (2.5% and 97.5% lower and upper bound estimates, respectively) should be given to quantify the expected uncertainty in the result. It is anticipated that these values will be *subjective* confidence intervals, given the nature of the data provided for this scenario.

For the quantities requested in Sections I.2.2.2 and I.2.2.3, modellers are required to estimate the *arithmetic mean* for the time-periods specified and for the entire region S, and a 95% confidence interval thereof.

I.2.2.2. Calculations for model testing

The calculations in the model testing part should be performed for three average representatives of the population of S, i.e., an adult woman (age 20 in 1986), an adult man (age 20 in 1986), and a child (age 10 in 1986). The term 'test persons' refers to these three categories.

I.2.2.2.1. Total deposition

Estimate the average ^{137}Cs deposition (wet and dry) over the entire region S (Bq m^{-2}). Estimate the total ^{137}Cs and ^{134}Cs inventory of the test region due to the Chernobyl accident after the passage of the contaminated air (Bq).

I.2.2.2.2. ^{137}Cs concentrations in food products

Estimate the mean contamination of the following food products produced in S:

- Leafy vegetables (Bq kg^{-1} f.w.)
- Cereals (wheat and rye; Bq kg^{-1} f.w.)
- Milk (Bq L^{-1})
- Beef (Bq kg^{-1})
- Pork (Bq kg^{-1})
- Game (small game and big game; Bq kg^{-1})
- Mushrooms (wild, edible mushrooms, *Boletus* and *Cantharellus* types; Bq kg^{-1} f.w.)
- Wild berries (wild, edible berries, *Vaccinium* type; Bq kg^{-1} f.w.)
- Freshwater fish (average of predatory, non-predatory, and intermediate feeding type species; Bq kg^{-1}).

Concentrations are requested for products prior to preparation for human consumption, averaged over the specified time-periods and the entire S region. For milk, beef, and pork, estimates of the mean ^{137}Cs concentrations are requested for the months May to September 1986 and for the fourth quarter of 1986 through the fourth quarter of 1990. For leafy vegetables, cereals, game, berries, and mushrooms, estimates of the mean ^{137}Cs concentrations are requested for the main harvest, picking season, or hunting season for the years 1986 to 1990. For leafy vegetables, estimates are also requested for the months May to September 1986. For freshwater fish, estimates of the mean ^{137}Cs concentrations are requested for the second half of 1986 and the annual catches of 1987 to 1990.

I.2.2.2.3. Human intake

Estimate the mean ^{137}Cs intake per day (Bq d^{-1}) of the test persons (woman, man and child) for the month of June 1986, the 4th quarter 1986, and the 2nd and 4th quarters of 1987 through 1990, averaged over the S region.

I.2.2.2.4. ^{137}Cs concentrations in animal feeds

Estimate the mean ^{137}Cs concentrations in pasture vegetation, barley, and oats (Bq kg^{-1} f.w.) for the harvests in 1986, 1987, 1988, 1989, and 1990, averaged over the S region.

I.2.2.2.5. Whole-body content

Mean Body Content. Estimate the mean ^{137}Cs concentration in the body of the test persons (Bq kg^{-1}) in region S at June 30 and December 31 for the years 1986 through 1990.

Statistical Distribution of Body Content. Estimate the distribution of adult whole-body concentrations of ^{137}Cs (Bq kg^{-1}) in the population as a complementary cumulative distribution function (CCDF) and the 95% confidence interval of this distribution for 31 December, 1987 and

1990. Examples of CCDF functions can be found in IAEA publication Safety Series No. 100 [I.1]. Note that the fractiles of a CCDF are equal to 1-p, where p is a fractile of the cumulative distribution function CDF.

I.2.2.3. Calculations for comparison of dose predictions

In this part of the scenario the 'test persons' are adults (average of men and women) 20 years old in 1986. Estimates are requested of the mean dose (mSv) to the test persons from the following pathways:

- external exposure due to ^{137}Cs from the Chernobyl cloud
- external exposure due to ^{137}Cs ground deposits
- inhalation of ^{137}Cs from the Chernobyl cloud
- inhalation of resuspended ^{137}Cs
- ingestion of ^{137}Cs
- all pathways (total dose from ^{137}Cs).

The term 'dose' refers to the sum of the effective dose from external exposure in a given period and the committed effective dose from radionuclides taken into the body in the same period. Dose estimates for all pathways except external and inhalation exposure from the Chernobyl cloud are requested for the periods 27 April 1986 to 30 April 1987, 27 April 1986 to 31 December 1990, and 27 April 1986 to 27 April 2036. For each time period, also show the percentage contributions of the three main food items contributing to the ingestion dose and the percentage contributions of the three main exposure pathways contributing to the total dose.

For models not designed with a fixed set of dose conversion factors, the use of the following factors for the dose predictions of the *test persons* (adults), as used in case of Scenario CB, is recommended [I.2-I.4]:

- Inhalation (Sv Bq^{-1}): 8.6×10^{-9}
- Ingestion (Sv Bq^{-1}): 1.4×10^{-8}
- External radiation
  - cloud (Sv m^3 h^{-1} Bq^{-1}): 9.3×10^{-11}
  - deposition (Sv m^2 h^{-1} Bq^{-1}): 1.3×10^{-12}

I.2.3. INPUT INFORMATION

I.2.3.1. Measurements of environmental ^{134}Cs and ^{137}Cs in the test area

I.2.3.1.1. Air concentrations

The radioactive plume spread over the test region between 27 and 29 April 1986. Between 30 April and 1 May, winds from opposite directions removed the plume from S the territory. Another plume from the reactor accident reached the test region during the second week of May 1986. Additional details about the radioactive plume are described by the Finnish Centre for Radiation and Nuclear Safety [I.5].

Ground level air was sampled continuously with a high-volume air sampler at station AIR2 from 27 April 1986 and with another type of sampler at station AIR1 from 28 April 1986 onwards (Fig. I.3).

At station AIR2 air was sampled at a height of 1 meter above ground through a glass fibre filter at a rate of 750 m^3 h^{-1}. The filter material was Whatman GF/A, with an area of 0.26 m^2. The corresponding face velocity was 0.9 m s^{-1}. At station AIR1 the air flow rate was 150 m^3 h^{-1}, and the filter was Whatman GFA/A with an area of 0.06 m^2.

The filters at both stations were changed twice a week to avoid overloading the filters and to ensure the retention of particulate radionuclides.

The stations AIR1 and AIR2 are located in sub-region POP8 (Fig. I.3), and therefore the measurements may not necessarily be representative for the entire test region. Measurements of total activity in air from ten stations of another monitoring network [I.6] showed significantly lower concentrations outside the subarea POP8 and the southern half of POP7 than at stations AIR1 and AIR2. During 27 April - 1 May 1986 the total activities in air at stations in subareas did not exceed 2% of those measured at AIR2. The uncertainty of this upper bound estimate is ± 100% (2σ).

The sampling sites are briefly described in the next section in connection with deposition sampling. Station AIR1 is located at the same place as DEP1, and AIR2 corresponds to DEP9.

The concentrations of ^{134}Cs and ^{137}Cs in air (mBq m^{-3}) up to the end of May 1986 are given in Tables I.I and I.II for stations AIR1 and AIR2, respectively. The concentrations have been corrected to the midpoint of the sampling period. The uncertainty connected with air concentrations in subarea POP8 and the southern half of POP7 is ± 40% (2σ).

During 9-12 May 1986, an atmospheric aerosol sample was collected at station AIR1 using 11-stage impactors. The aerodynamic diameter size range covered was 0.03-16 μm. A bimodal mass size distribution was found, but ^{137}Cs-activity size distribution was unimodal. The modal parameters are given in Table I.III [I.7].

Hot particles were identified by autoradiography in air filters collected at stations (other than AIR1 or AIR2) in subarea POP8 after 26 April. Most of the spots did not contain enhanced amounts of radiocaesium. However, in about 20% of the analysed particles, enhanced radiocaesium activity was also found. The total number of particles per 1000 m^3 air varied during 27 April - 1 May 1986 (Table I.IV).

High-altitude air samples were collected during the period 28 April - 12 May 1986 whenever it was expected that approaching air masses might contain radioactive substances. The aircraft was also equipped with instruments for measurement of external radiation. Thus the distribution and dimensions of a radioactive cloud could be determined [I.5].

I.2.3.1.2. Ground contamination [I.8]

Several successive surveys of external gamma radiation were performed in the test region since the spring of 1986. Both sensitive GM-counters and gamma-spectrometers were used for measurements.

The original measurement results and the vertical distributions for radiocaesium in soil were used to estimate the radiocaesium deposited in 1986 for a grid covering the test region. The minimum detectable surface activity of ^{134}Cs was 100 Bq m^{-2}. The distances of measuring routes in the areas of highest deposition were 20-30 km and in subarea POP6 about 50 km. Based on these data, ^{137}Cs deposition to different sub-regions (Figs I.4-I.6) has been calculated (Tables I.V-I.VII). This information mostly concerns rural areas (e.g. forests, agricultural land). It does not necessarily represent urban areas.

Further explanation of Table I.VII and Fig. I.6 on fish areas is given in Section I.2.3.3.4. The uncertainty connected with ^{137}Cs deposition by subareas is about ± 20% (2σ).

I.2.3.1.3. Total deposition

Total deposition was collected continuously at 11 stations in the test region starting in early spring of 1986. The surface areas of the samplers were 0.05 or 1 m^2. Collectors are made of stainless steel. They are placed at a height of 1.1 m above the ground and are provided with wind shelters. Most of the collectors were emptied monthly. After every emptying, the collectors were rinsed with dilute nitric acid and distilled water, and the rinsing solutions were added to the sample. If there had been no rain during the sampling period, the collector was rinsed carefully to collect the dry deposit for analysis.

After the Chernobyl accident, the sampling periods at stations DEP1 and DEP9 were initially one day, later a few days, and thereafter one or two weeks.

The locations of the sampling sites in the test region are shown on the map in Fig. I.3. Four of the samplers, namely those at stations DEP1, DEP3, DEP6 and DEP10, are placed on cultivated grass-covered areas or lawns. Samplers at stations DEP2, DEP5 and DEP9 are surrounded by flat, open areas covered by wild surface vegetation. Most other stations are at the edge of open fields surrounded by large forest areas.

The monthly amounts of deposited ^{134}Cs and ^{137}Cs are given in Table I.VIII [I.9]. Observations from stations DEP1 and DEP9 from the period of more frequent sampling in 1986 are also included in the table.

The uncertainty connected with deposition data by POP-areas can be $\pm$ 90% (2σ).

I.2.3.1.4. Soil samples: Vertical profiles

The vertical distribution of radiocaesium in surface soil was determined for different uncultivated soils in the test region in the years 1986 - 1989 (Table I.IX, Fig. I.7). Altogether 60 samples were taken, usually during August - October. The sites are grouped into 'forest soils', 'uncultivated mineral soils', and the group 'unknown', which means either of the two specified groups. Forest sites, especially those of 1989, represent typical forests based on mineral soils.

The sites were flat, with minimum runoff, and the radiocaesium activities found are assumed to give the total accumulated fallout. The sampling depth most often exceeded 15 cm, which means that the samples also contained most of the ^{137}Cs from nuclear weapons fallout, estimated to average 1.8 kBq m^{-2} in the test region at the beginning of 1986.

Some of the samples were taken using a spade. The surface area of these samples varied generally between 0.017 and 0.09 m^2. Most of the forest soil samples were taken using a cylindrical tube 7 cm in diameter.

The samples were cut into layers in the laboratory. Contamination of deeper layers from radiocaesium in surface soils was avoided as far as possible. In cutting the soil layers to be analysed, the thickness of sections was kept approximately the same for the samples of uncultivated mineral soil fields. For forest soil samples from 1988-89, the natural soil horizons were considered. The layers analysed represented surface vegetation plus litter and humus, leaching layer, deposition layer, and subsoil. However, it was not always possible to separate the two horizons next to humus soil from each other, and the bottom soil (sand or gravel) was sometimes cut into several sections.

Fractions of ^{134}Cs and ^{137}Cs found in layers from the surface (0 cm) downward are given as percentages in Table I.IX.

I.2.3.2. Protective measures

In the spring of 1986, some recommendations involving intervention were given to the farmers and to the public in general:

During 7-15 May:

Recommendation to postpone the open field sowing of lettuce, spinach and other fast-growing vegetables.

During 7-26 May:

Recommendation not to allow cows out on pasture. The farmers delayed the grazing of 99 ± 1% (2σ) of dairy cows.

For protection of special occupational groups the following recommendations were given:

10 May:

Farmers should use respiratory protection in dusty soil cultivation work.

Summer 1986 to the end of 1990:

Recommendations were given to limit the possibility of high consumption of wild fish (game fish) in subareas FISH4 and FISH5. A retrospective follow-up study from 1990 revealed that due to these recommendations, consumption rates of wild produce in general decreased in subareas of S (Table I.X) [I.10].

In December 1986:

Recommendations were given on the use of peat for cultivation of greenhouse vegetables in 1987. The content of radiocaesium in horticultural peat was checked and in some cases it was decreased by decontamination. The intent was to eliminate ^{137}Cs content exceeding 100 Bq kg^{-1} in greenhouse vegetables in 1987. Most (98 ± 1% (2σ)) vegetable producers followed the advice of the authorities, and follow-up measurements during the harvest season confirmed this.

I.2.3.3. Environmental information

I.2.3.3.1. Meteorological Characteristics

Rainfall observations were made daily at 373 stations in the test region beginning 26 April 1986 [I.11]. The total rainfall amounts were measured between 06 UTC (or GMT) on the given day to 06 UTC on the following day. They are given in mm d^{-1} for the period 26 April - 31 May 1986 in Table I.XI. The regional locations of the stations are shown in Fig. I.8. (As the daily rain observations for 373 stations over 35 days resulted in more than 13000 records, they are not reprinted in this document. Table I.XI shows only some sample records. However, the complete data are available on diskette.)

On 29 and 30 April 1986 there was a widespread occurrence of showers in the test region. Due to the scattered nature of the rainfall, large local differences occurred in the daily rainfall amounts. The last remains of snow in shaded forest areas were melted by the showers.

I.2.3.3.2. Topography

The test region is rather flat: The major part of it is characterized by small-scale variations in topography, with low hills and ridges alternating with valleys and lake basins. Lowlands prevail in subregions POP7 - POP9 (Fig. I.4). Eskers (long ridges of gravel from glacial deposits) and lakes characterize the landscape of central subregions POP1 - POP6. Less than 20% of the total test area lies below 50 m altitude. Most basins in subareas POP1 - POP6 are in a zone at an elevation of less than 90 m. A few hills or mountains of about 200 m in height are found in these subareas [I.12].

I.2.3.3.3. Climatic Conditions [I.12]

The duration of the snow cover in open fields is between four and six months. The mean snow period is 1 November to 30 April. The maximum water equivalent of snow occurs from 15 March to 1 April. The distribution of water equivalent as a function of time can be approximated by a triangular shape, with a maximum of 100-150 mm.

Ground frost usually stops between the middle of April and the middle of May. The average date of ice break-up in lakes varies between 30 April and 10 May, and that of freeze-up between 15 and 30 November. In the spring of 1986, most lakes were open before 27 April.

The sum of effective temperature (the sum of daily average temperatures exceeding 5 °C) varies in the test region between 900 and 1350 °C on the basis of 30 years' statistics. The mean temperature of the growing season is 12-13 °C. The length of growing season is 160-180 d. The ranges of the average monthly temperatures in the test region are given in Table I.XII.

Precipitation is received rather evenly during all four seasons. However, rain deficiency may occur at the beginning of the growing season. The annual precipitation in the test region generally varies between 450-750 mm. During periods of low rainfall, irrigation is used, especially in subareas AGR16 (deficiency in rainfall 80-100 mm in May - July) and in AGR3, AGR11 and AGR14 (deficiency in rainfall 60-80 mm) (Fig. I.5). Irrigation of fields is most common for vegetable production, but it is usual also in cultivation of cereal crops. Local surface water systems are used as sources of irrigation water.

The best climatic conditions for growing plants are in the southwestern and southernmost coastal areas which belong to the hemiboreal zone. The periods given above for ground frost, ice break-up, etc., include the change from south to north, as well as the variation of effective temperature sum, the length of the growing season, etc. Additional climatologic information is available in the Finnish Meteorological Institute Monthly Bulletin (in Finnish and Swedish).

I.2.3.3.4. Inland waters [I.12, I.13]

Roughly 10% of the surface area is covered by water. Variation in subareas POP1 to POP9 is shown in Table I.XIII. The test area is divided into six main drainage areas, FISH1 to FISH6 (Fig. I.6), which again are divided into 67 subareas by watercourse divides. The average ^{137}Cs fallout on land in the main drainage areas is given in Table I.VII.

Typical of the test region are lake and river watercourses, in which short river sections or channels join one lake basin to another. River watercourses are typical of the subareas FISH1, FISH2 and FISH6. Areas FISH3, FISH4 and FISH5 contain most of the lakes.

The average depth of the lakes is 7 m. About 2.5% of the lake area is deeper than 30 m, and 60% is shallower than 5 m. Small lakes are typically shallower than 3 m. The surface area of the lakes varies between less than a hectare to several hundreds of square kilometers. About half of the total water volume belongs to the thirty largest lakes (extending over more than 100 km^2). Altogether, ponds comprise less than 0.5% of the total water volume of all lakes.

In subarea FISH4 the soil is mainly till, bogs are scarce. In subarea FISH5 a high proportion of clay occurs in the southern land areas, bogs are found only in northern parts of the area. The largest subarea, FISH3, differs from the others by having moraine soils, but it also shows features similar to those of the northern parts of subareas 4 and 5. All these areas are crossed by numerous esker chains and covered with a discontinuous till blanket. Extensive mires are to be found in the north of these regions.

The low calcium content in the bedrock and topsoils, combined with the extensive peatlands, causes the lake water to be low in nutrients, relatively acidic, and high in humus content. About 5% of all the lakes are acidic, some of these are naturally acidic, yellowish or brown humic lakes. The transparency of the lakes is usually to depths of a few meters. The shortage of light limits the biological productivity in the watercourses, but the major controlling factor is the poor nutrient supply. Biological productivity in the lakes varies: algae in open water areas produce plant material in amounts between a few kilograms and a few tons per hectare per season. The average sedimentation rate in all lakes is 0.3 mm a^{-1}.

Most of the lakes (>80%) are oligotrophic, especially those appearing in moraine and esker areas. Naturally eutrophic lakes (<20% of the lakes) are found in clay areas of subareas FISH1, FISH2 AND FISH5. Very few of the important fishing lakes are eutrophic, however.

Evaporation decreases from south to north. A typical value for evaporation for a lake in the south is 500 mm a^{-1} and in the north 350-450 mm a^{-1}.

Runoff to the watercourses from drainage areas FISH3, FISH4 and FISH5 is typically about 5-7 L s^{-1} km^{-2}. About two-thirds of the precipitation evaporates. Regulation of the water level changes the water balance, especially in the spring in subarea FISH6, but has little significance in the other areas. Underground in- and outflow can be significant in areas of eskers. Some characteristics of different drainage areas are given in Table I.XIV, and data on 70 lakes in the test area for some chemical parameters and suspended solids are given in Table I.XV and Figs I.15 and I.16. The water residence times in material of 20 individual lakes vary between 20 and 2200 days [I.14].

Concentrations of ^{134}Cs and ^{137}Cs in bulked water samples from drainage areas FISH1, FISH2 and FISH6 and from three subareas of FISH3, FISH4 and FISH5 since the spring of 1986 are given in Table I.XVI. Average potassium contents of the same water samples are given in Table I.XVII [I.15-I.17]. Monthly surface water temperatures in lakes of average depths in the test area are given in Table I.XVIII.

About 30 fish species are found in the test area. The most predominant species are perch (*Perca fluviatilis*), pike (*Esox lucius*), vendace (*Coregonus albula*), roach (*Rutilus rutilus*), whitefish (*Coregonus lavaretus*), bream (*Abramis brama*), and burbot (*Lota lota*). Annual catches of fish categorized as predators, non-predators and intermediate feeders are given in Table I.XIX [I.18].

I.2.3.3.5. Forests [I.12, I.19]

Area of forests as a percentage of the total land area varies in the test region (Table I.XX). The typical soil in forests is podzol. The surface of land is covered by a thin humus layer, which is mainly raw humus. The next layer is the A horizon, from which the soluble nutrients are leached and accumulated in a deeper layer, the B horizon. The surface soil is acidic. The bottom soil, the C horizon, is sand or moraine.

The types of forest vegetation give an indication of the nutritional status and moisture content of the soil. Mesic and submesic heath forests are usual, the corresponding vegetation types being Myrtillus (MT, 33% of forests) and Vaccinium (VT, 27%). The extreme types, rich Oxalis-Myrtillus type (OMT, 21% together with leafy groves), and dry or very dry, or Calluna (CT, 12%) and Cladina (CT, 7%) type heath forests are also found.

Coniferous trees, spruce (*Picea abies* L.) and pine (*Pinus sylvestris* L.), are the dominant trees in 90% of the forest land. Deciduous trees such as birches (*Betula pubescens* and *Betula pendula* Roth.), aspens, poplars (*Populus*), and alders (*Alnus*) are most often only pioneer species of the natural vegetation succession which occurs following a fire or other damage to the forest. At a later stage they are replaced by conifers. On an average, deciduous trees predominate on about 10% of the forest land.

The area of peatlands is continually decreasing as draining programmes dry out the thin peat, but peatlands still cover vast areas, especially in the northern test region (Table I.XXI). The drainage area in 1986-88 was 70000 ha. Less than half of the forestry land is undisturbed.

Human influence has changed the natural mineral and water balance of soils. The measures include systematic draining of peatlands for forestry, introduction of clear felling, thinning, forest soil melioration methods (e.g. ploughing as a means of regenerating forests), and drain cleaning. As an example, the areas of forest land treated by different measures in 1988 are given:

–	Clear felling	76000 ha
–	Thinning	201000 ha
–	Fertilization	
	- Mineral soils	45000 ha
	- Peat lands	13000 ha
–	Ploughing	122000 ha

I.2.3.4. Agriculture

I.2.3.4.1. Practices by season [I.20, I.21]

The sowing period covers the whole of May. In the spring of 1986, sowing in production areas AGR1 to AGR17 (Fig. I.5) took place as indicated in Table I.XXII. Before sowing the fields (which are ploughed in autumn) are harrowed to a depth of 7 to 10 cm. The depth of sowing is 5 to 6 cm.

For application of chemical fertilizers, equipment for combined sowing and fertilizing has been developed. Fertilizer is placed between seed rows below the level of the seed bed, where the soil is moister than on the surface. This method facilitates better dissolution of fertilizers, and the deeper location of the plant nutrients encourages roots to grow deeper into moist soil instead of remaining close to the surface where they may dry out [I.22].

Fields in the test region must be ditched in order to drain excess water, as the yearly precipitation is greater than the evaporation. Ditches are especially important in spring, to drain the runoff from snow- and ice-melt as quickly as possible so that soil cultivation and sowing can begin [I.22].

Grasslands used for silage making are usually cut for the first time in June. Before autumn, two or at most three new cuttings for silage may be made. Haymaking usually occurs during the two last weeks of June and the first three weeks of July.

The pasture season for dairy cows normally lasts from 10 May to 20 September, except for subareas AGR2, AGR6, AGR7, AGR8, AGR12 and AGR17, where it lasts from 15 May to 15 September. The change from indoor feeding to grazing and vice versa is gradual, lasting a couple of weeks. Beef cattle usually do not graze, and only 3-4% of beef originates from cows which graze like dairy cows. The forage of both dairy and beef cattle varies with the season. During the feeding of fresh grass, the need for additional feeds is less than in winter (see paragraph 'Production and use of feeds', Section I.2.3.4.3) [I.23, I.24].

The feeding of poultry and pigs has almost no seasonal variation because the feeds are mainly mixtures available at regional fodder factories.

The height of winter rye sprouts at the end of April is 10-13 cm, varying from year to year. The plant stand is dense. Seasonal development of the leaf area index for spring cereals and silage grass was computed using a dynamic model for water and nitrogen-limited growth, assuming the actual weather conditions during the growing season of 1986. The leaf area indices (LAIs) as a function of the Julian day 1986, together with the effective temperature sums (ETSs) for the same period, are given in Figs I.9-I.14 for nine locations (shown in map of Fig. I.9) [I.25].

The harvesting of cereals starts during the last week of July (rye) and lasts until the first three weeks of September. The growth period is 97-106 days for spring wheat, 95-101 days for oats, and 84-100 days for barley, varying with varieties sown [I.21].

Potatoes and root vegetables for the whole year use are normally harvested during the first three weeks of September. However, early varieties of vegetables and potatoes for summertime use are harvested from the end of June [I.21].

Ploughing starts at the beginning of September and goes on until late October, except in the case of land intended for winter cereals (all rye, part of wheat), which must be sown during the last two weeks of August and the first two or three weeks of September. The depth of ploughing varies between 15 and 22 cm, the most common depth being 20 cm.

Grasslands are cultivated either for hay, pasture, or silage. The main plant species used are timothy (*Phleum pratense*), meadow grass (*Festuca pratensis*) and clovers such as *Trifolium pratense, Trifolium hybridum* and *Trifolium repens*. Depending on the plant mixture, grasslands with a clover stand are ploughed every 2 to 3 years, with a timothy stand every 3 to 4 years, and with meadow grass, etc., every 3 to 5 years [I.24].

I.2.3.4.2. Cultivated soils

Land use in agriculture is shown in Table I.XXIII. Proportions of different soil types in the ploughed layer and in sub-soils for 17 production areas are given in Table I.XXIV. The average pH in the ploughed layer is given in Table I.XXV. Acidity varies with soil type (Table I.XXVI) [I.26].

The soil types for cereal cultivation are usually chosen as follows [I.20]:

- Winter wheat: best are heavy clay soils;
- Spring wheat: clayish soils fairly rich in humus, not peaty soils;
- Rye: all soil types are possible, best are light mineral soils, worst are mull and peat lands;
- Barley: all soils except for those with low pH, most often finer fine sand or silt soils are chosen;
- Oats: best are mould soils, also relatively poor growing conditions are acceptable, as for example peaty soils.

I.2.3.4.3. Production and use of feeds [I.24, I.27, I.28]

The main roughages for cattle are hay, pasture, and silage complemented with other fodder plants such as kale, leaves of sugar beets, marrow kale (*Brassica oleracea*) and potatoes. For silage, different hay plants (timothy, meadow fescue, etc.), and to a minor extent clovers (*Trifolium* sp.), are used. Leaves of beets, kale, and marrow kale are used as raw material for silage, other feeds are used directly.

The average milk yield per cow in different agricultural areas is given in Table I.XXVII, and the monthly yield in per cent of annual yield in Table I.XXVIII. During grazing in May - June, dairy cows need additional fodder grain or concentrates, approximately 0.5 kg per each kg of milk exceeding a 20-kg daily production. In late summer the same additional feed is needed for daily production exceeding 15 kg. The main additional feed of dairy cows during grazing is concentrate, including fodder grain, byproducts of the food industry, molasses from sugar beet pulp, wheat bran, etc. The minimum daily portion of concentrate is 0.5 kg. Hay is given during a gradual change from indoor feeding to grazing and vice versa. Hay (several kg per day) is also given during dry periods in summer when the pastures do not produce enough grass. During the period 7-26 May 1986, about one per cent of dairy cows were fed new grass. Cows did not graze, but were fed the fresh grass indoors. Beef cattle usually do not graze, but the seasonal feeding of fresh grass reduces the use of other feeds.

Industrial feeds for cattle are processed mainly from fodder grain coming from each agricultural production area. The grain mixtures used for cattle contain at least one-third barley or oats. Annual yields as well as yields per hectare of hay and silage are given in Tables I.XXIX and I.XXX. The feed utilization by dairy cows, beef cattle, and heifers is given in Tables I.XXXI-I.XXXIII. Amounts of feed in these tables are given in kg of product, i.e., for the same form in which the feed is used. Dry matter contents of these feeds are as follows: silage, 22%; hay, 83%; pasture, 20%; feed grain, 86%; complete feed, 88-90%; concentrate, 88-90%. 'Other' includes swede, dry matter 12%; sugar beet, dry matter 23%; potato, dry matter 22%; and molasses or treacle, dry matter 90%.

The annual production of cereal grains and potatoes is given in Table I.XXXIV. Barley and oats are produced mainly for feeding cattle, pigs and poultry. The delay between harvesting and distribution of cereals in feed mixtures varies from a few months to about a year.

Besides mineral constituents, the feed mixtures of pigs consist mainly of domestic cereals (barley, wheat and oats), domestic or imported meat meal and bone meal (1-5%) and marine fish meal (2-3%), and the by-products of the sugar industry (1-5%). Since the beginning of 1990, imported soya protein has mainly replaced fish meal in feeds for pigs. Portions of feed constituents are varied in order to achieve an optimal raw protein concentration. Altogether, of the feeds utilized for pigs, 30% are the feed mixtures described above, 59% are fodder grains (mainly barley), and 10% are protein concentrates. In 1986, some 20% of the pork consumed originated on farms where whey is given to the pigs. Whey can be a constituent of the industrial feed mixture or it can be given in some other form. It contributes to the protein and carbohydrate fractions of the feed. The use of whey as a feed for pigs decreased substantially (to a few percent of pork production) towards the early 1990s.

A pig typically weighs 90-100 kg before slaughtering (carcass weight 75-78 kg). Feeding lasts 20 weeks. During the last month the feed consists of cereals (70%, of which 70% is barley, to which wheat and oats are added), crushed soya (7-15%), some meat and bone meal, and peas [I.28 and I.29].

Feed mixtures for broiler meat production contain about 70% cereals (barley, wheat and oats), meat and bone meal, and fish meal (1-5% each). Other constituents do not contribute to the radiocaesium content of the feed. The feed of laying hens does not differ essentially from that of broilers.

All feed grain is domestic. During the time period considered in this scenario, the imported raw materials of feeds did not contain ^{137}Cs in greater concentrations than were found in domestic cereal grains, fish meals, and meat and bone meals.

I.2.3.5. Production of foodstuffs [I.27]

Cultivation is intensive, and basic foodstuffs beyond local needs are produced in the test region. Production figures for foodstuffs of animal origin are given in Table I.XXXV.

Eggs consumed in the test region are produced mainly in subregions AGR2, AGR14 and AGR16. Most poultry farms are situated in the grain and forage producing areas, especially in AGR16.

Annual yields of cereal grains and potatoes are given in Table I.XXXIV and yields per hectare in Table I.XXXVI. Annual yields of vegetables and fruit produced commercially in different subareas are given in Tables I.XXXVII and I.XXXVIII. yields per hectare for vegetables grown in the open are given in Table I.XXXIX and yields per m^2 for greenhouse vegetables in Table I.XL. Produce from private gardens is not included in the tables, but it is estimated to represent about 15% of the consumption of fresh forms of vegetables grown outdoors [I.30].

Early vegetables grown in the open, especially leek and chive, originate to a large extent from the southwestern part of the country, outside the S region. Production conditions in this area correspond to those in the most southwestern agricultural area of S.

In 1986, 30% of the expected rye yield was lost, and the deficient amount was imported. Imported rye contained ^{137}Cs of 5 Bq kg^{-1} or less. Most cultivars of cereal crops are of domestic breeds, suitable for a short growing season and cool climate.

Fruit vegetables produced in greenhouses are sufficient to cover 70% of consumption. Tomatoes are harvested during April to September and greenhouse cucumbers during March to October. Due to the high production costs, tomatoes and cucumbers are imported during the darkest and coldest season of the year. In the winter of 1986-87, the ^{137}Cs concentration in imported fruit vegetables did not exceed 2 Bq kg^{-1}. Lettuce distributed commercially is grown in greenhouses and amounts to about 7% of the consumption of leafy vegetables.

Peat is extensively used as a growing medium for greenhouse vegetables (55% of tomato, 45% of cucumber, and practically all lettuce). The other main growing medium is rock wool. Peat collected in the spring of 1986 was monitored for radiocaesium. Partial decontamination of horticultural peat eliminated ^{137}Cs contents exceeding 100 Bq kg^{-1} in greenhouse cucumber, tomato and lettuce in 1987. The most contaminated peat lots were rejected by the peat industry. Additional measures were taken by vegetable producers, who often had to use peat from their own agricultural subarea.

Horticultural peat is changed periodically depending on the species being cultivated. For cucumber, peat is changed each harvest year, while for tomatoes the same peat is used for one or two years. At least two practices were common for lettuce at the end of the 1980s: (1) The peat is not changed for several years; a layer (a few cm thick) of new peat is added on the prepared peat layer from the previous year. (2) The whole peat layer is changed every second year. The first practice is more common than the second [I.31].

In greenhouses, automatically controlled watering and fertilization is used in large production units throughout the test area. However, about 60% of tomatoes and cucumbers are produced commercially in relatively small greenhouses with more traditional watering and fertilizing. Air conditioning can be automatically controlled. In all systems, outdoor air flows in during several hours of the day in the warmest days of May to August [I.31].

In the production of field-grown vegetables, the test area is self-supporting to a degree of 85-90%. The most important species are carrot, cabbages and onion, all of which are also stored.

Growing berries for home use is common in the whole test area. The degree of self-sufficiency is about 90%. Domestic apple production accounts for about 7% of the fruit consumption.

Radiocaesium contents of imported fruits, vegetables and other produce were on the average no higher than the mean contents in the produce from the test area. They can be concluded from the countries of origin given with the contributions to consumed amounts in Table I.XLI [I.32]. Practically no foodstuff samples exceeded the information limit of 100 Bq ^{137}Cs $kg^{-1}{}_{f.w.}$ used by the Customs Laboratory in 1986 [I.33].

I.2.3.6. Sources of household water [I.14]

About 40% of the population uses surface water, mainly as treated by public water supply plants. The remainder mainly utilize ground water. The source of untreated water for the most densely populated subarea POP8 is a large lake in subarea POP2. Other subareas take raw water from natural surface water basins relatively close to the population centres. The most common treatment for water purification is aluminium-sulphate precipitation.

I.2.3.7. Hunting [I.18, I.34]

Most hunters work in agriculture (40%) or in industry (20%) [I.12]. Different subareas of the test region contribute to the annual game bag as given in Table I.XLII.

Hunting of waterfowl normally starts on about 20 August, of hares on 1 September, and of moose animals on 15 October. The hunting season for moose ends by mid-December and for all others by the end of February the following year. The beginning of the hunting season for terrestrial game birds varies between 20 August and 1 October. Most of the game meat is received during the first 6 weeks of the season for waterfowl and the first 2 months for moose animals.

Moose (*Alces alces*) is the most important game animal, contributing 80% to the annual game bag. The next most important species are hare (*Lepus* species, 6%), waterfowl (6%), white-tailed deer (*Odocoileus virginianus*, 5%) and terrestrial birds (3%).

I.2.3.8. Collecting of natural products [I.35]

Wild berries (e.g. blueberry, *Vaccinium myrtillus*, and lingonberry, *Vaccinium vitisidaea*) and mushrooms are most often picked from the region near to home. However, some 15% of the amounts consumed are distributed commercially and are picked mainly from subregions POP3, POP5 and POP6. Wild berries and mushrooms from areas of lowest deposition outside the S region contribute about 10% of the consumption in the S region.

Harvests of mushrooms and wild berries vary to a great extent from area to area and year to year. Large quantities of mushrooms were found in the whole region in 1988, whereas in 1989 the harvest was poor.

I.2.3.9. Fishing [I.18, I.34]

Recreational fishing involves about 10^7 man days annually. The main season lasts from May to the end of September. In winter, when lakes are ice-covered, 11% of the catch is taken, with perch being the main fish caught.

In 1986 the fishing of small perch declined for some time. In 1988, the total freshwater fish catch was about 15% smaller than in 1986.

The normal catch from the lakes is 5-10 kg ha^{-1} [I.36]. Information on the catch of 1986 is given in Table I.XIX. This includes contributions of different fish species (divided into three groups with different feeding habits) to the catches of a whole area as well as the contributions of different fishing areas to the total freshwater catch.

Annual mean ^{137}Cs concentrations in other-than-freshwater fish (e.g. marine or imported) are given in Table I.XLIII [I.37-I.44].

I.2.3.10. Food distribution

The food produced in each subarea is sufficient for consumption in that subarea, except in the case of subarea POP8, for which the main production subareas are sources of basic foodstuffs. Organization of foodstuff distribution causes additional changes in the origin of food consumed in the test area, especially in the case of processed cereals, meat products and milk.

Delays in the distribution of foodstuffs vary with food category and, for cereals, on the last year's harvest. In 1986, the cereals from the new harvest were used for the first time on 1 November. Due to considerable failure of crops in 1987, domestic grain from 1986 was consumed until the beginning of 1988 [I.45]. For liquid milk products, the delay between milking and consumption varies from 1 to 6 days. Meat is distributed a few weeks after slaughtering.

Conserved fish, meat, vegetables and fruits, as well as mushrooms, are usually consumed within six months or less. Conserved food amounts to up to 20% of the annual consumption of each food type mentioned here [I.46-I.48].

I.2.3.11. Population information

I.2.3.11.1. Age, dwellings and industrial structure [I.34, I.49]

Information on the industrial structure, dwelling types and the proportion of the population from urban areas in the test region is given in Table I.XLIV. The average size of a household in the test region is 2.5 persons.

Dwellings are normally built to be well-insulated with tight fitting doors and windows, especially those constructed after the first energy crisis in the 1970s (about half of the dwellings). The mean number of floors in blocks of flats is 4.6 (range 2-13). The number of summer cottages is estimated at 300,000 (Table I.XLV), and the time that they are occupied at 30 days per year. Suggested shielding factors (including occupancy factors) for calculation of external radiation doses are 0.18 for one-family houses and 0.47 for multi-storey houses [I.50].

Average time spent outdoors by people over 10 years old is given in Table I.XLVI [I.51]. The age distribution of the population by 5-year intervals in the region on an average is given in Table I.XLVII. The populations of subareas POP1 to POP9 by age (three groups) and sex is shown in Table I.XLVIII.

I.2.3.11.2. Food consumption

The diet of adults (Table I.XLIX) corresponds to about 10.5 kJ (2500 kcal) and 13.0 kJ (3100 kcal) energy intake for women and men, respectively, when supplemented with fats, sugar and beverages [I.30, I.46-I.48]. Consumption rates of foodstuffs for children are given in Table I.L [I.52].

The consumption of milk includes all liquid milk products, ice cream and curd. The figures for fish are for gutted fish (without head and bones). Fat is not included in the figures for meat, whereas the same amount of bones as in normal cooking is included in consumption rates [I.53]. For game meat, however, the consumption rate of the edible part of meat (without bones) is given. Figures for potatoes, vegetables, and fruit correspond to product weights. For wheat used for human food, the reduction in whole grain ^{137}Cs concentration due to fractionation of Cs during milling was 0.5 in 1986 [I.54].

The diet has some seasonal variation. Consumption rates are temporarily increased during harvest seasons of different produce and during fishing and hunting seasons.

I.3. DATA FOR MODEL TESTING

I.3.1. RADIOCAESIUM MEASUREMENTS

I.3.1.1. Gammaspectrometric sample measurements [I.55, I.56]

I.3.1.1.1. Measurement system

Radiocaesium measurements in environmental samples were carried out using low-background, high-resolution gammaspectrometric systems. The detectors were either germanium or lithium drifted germanium semiconductors. Their relative efficiencies varied between 20-40%, and energy resolution at 1.33 MeV was between 1.7 and 2.2 keV. Multichannel analysers of 4096 or 8129 channels measured gamma radiation for the energy ranges 30-2000 keV and 30-2700 keV, respectively. Energy calibration and resolution were measured and recorded weekly using standard procedures.

The cylindrical background shields are of 12-14 cm thick lead, covered inside with thin cadmium and copper sheets to reduce the X-ray background of the sample spectra. To decrease the background radiation from airborne radioactivity, aged, clean air was slowly blown through the shields during measurements in the acute phase of fallout in the spring of 1986. At that time rather frequent checks of background intensity were made. Normally background measurements of several days duration are carried out a few times a year, and short checks occasionally more often.

A 0.6 litre Marinelli beaker and a 30 ml cylindrical container were the usual sample geometries. The volume and density of the sample were allowed to vary. An almost cylindrical beaker of one litre was used for fresh or dried samples, when a volume between the two primary geometries was needed.

For the efficiency calibration of detectors, monoenergetic single nuclide standards in a water matrix were used. Some milligrams of carrier element of each of the radionuclides was added in solutions to keep the standards stable. The calibration procedure gives both peak and total efficiencies, which are needed for calculation of coincidence summing corrections. The estimate of the error of efficiency calibration was $\leq$ 4%.

I.3.1.1.2. Analysis of gamma spectra

The spectrum analysis programme GAMMA-83 was developed at STUK for low-activity environmental samples [I.57]. The stiffness in fitting the Compton background can be adjusted for each spectrum. The peak identification can be improved with parameter choice for individual spectra. Minimum size of the peak accepted for analysis can be chosen. The peak search and further calculations can have preset integrated peak areas as threshold values. The IAEA's comparison spectra have been used to test both the peak search and peak area calculation routines. The most demanding, very complicated air filter spectra during the early phase of the fallout situation in 1986 were also checked manually. All gamma spectra are checked by an expert on gamma spectroscopy before further use of results.

Coincidence summing corrections are a routine of the programme. For the one litre beaker geometry, which was used only in 1986, the coincidence correction was made manually. Correction is essential for precise determination of ^{134}Cs, which was used for the estimation of the content of Chernobyl-derived ^{137}Cs in environmental samples. The measured ^{137}Cs content also included traces of nuclear weapons test fallout, which were subtracted from the measured ^{137}Cs using the activity ratio ^{134}Cs/^{137}Cs. For the Chernobyl fallout distributed in Finland, this ratio was 0.52 on October 1, 1986 [I.58].

I.3.1.1.3. Error of determination

Measurement error included one standard deviation according to a Poisson distribution. For nuclides with several photopeaks, the error was a weighted quadratic sum of relative standard deviations (R.S.D.) of the integrated peak areas used for determination of a radionuclide. In the total error the calibration error was also included. However, it was significant only in connection with small R.S.D.s. For sample measurements used as test data, a general goal was not to exceed 5% total error for ^{137}Cs. In the first months of the extended surveillance this was not achieved, mainly due to samples measured fresh, without preconcentration. Since 1987 measurement errors were often well below 5%.

I.3.1.1.4. Limit of detection

Contents of ^{134}Cs or ^{137}Cs smaller than detection limits were found in a minor part of the foodstuff samples. The detection limit was derived from the threefold standard deviation of the main photopeak background, and it varied between about 0.5 Bq kg^{-1} to 3 Bq kg^{-1} fresh weight.

I.3.1.1.5. Pretreatment of samples for measurement

Environmental samples were measured either fresh, dried at 105 °C, or dry-ashed at 400-450 °C. Non-liquid samples were homogenized for the measurement. Most fresh samples were measured in 1986 after a remarkable extension of sampling programmes. Preconcentration of radiocaesium by drying or ashing the sample was seldom needed in the first year after deposition, but it was used after that. The ashing at ≤450 °C did not cause losses of radiocaesium.

After the end of April 1986 the following sample types of importance to the scenario were analysed for ^{134}Cs and ^{137}Cs: pelletized air filters, evaporated and dry ashed rain water (wet and dry deposition) and surface water, dried and sieved soil (Ø < 2 mm), fresh or dried grass, fresh, dried or ashed milk, and other foodstuff samples of both agricultural and wild origin. Altogether the ^{137}Cs data used directly for the scenario was a result of somewhat more than 10^4 sample measurements. Of these 85% were measurements of foodstuffs.

I.3.1.1.6. Intercomparison tests

STUK has traditionally participated in intercomparison tests organized by the IAEA, and in the 1980's and 1990's also in the tests of the Nordic Nuclear Research Programme and the U. S. Environmental Protection Agency [I.55, I.58, I.59]. Related to the measurements used for the scenario, the following intercomparison samples were analysed: Milk powder IAEA-321, clover IAEA-156, grass IAEA-373, soil IAEA-6 and IAEA-375, and air filter, milk and water samples provided by the EPA.

I.3.1.2. Sampling programmes

I.3.1.2.1. Ground-level air, deposition [I.5, I.9, I.60, I.61]

Continuous sampling of ground-level air and wet plus dry deposition in the spring of 1986 are described in Section I.2.3.1. Data for samples from rain water collectors were not used for estimation of test quantities for deposition due to the small number of sampling locations.

After the first findings of the Chernobyl fallout, air samples were taken several times a day in Helsinki and Nurmijärvi (stations AIR1 and AIR2). In the beginning of May daily samples were taken, and after mid-May the frequency was reduced to normal, twice a week, at all stations. During the five year test period some new air sampling stations were installed in Finland. Data from the new air monitoring station AIR3 (Viitasaari) (Fig. I.3) was also used for dose estimation from resuspended material in ground-level air.

I.3.1.2.2. Animal feed [I.37, I.41, I.43, I.62]

Pasture vegetation was surveyed in May 1986 at sixty farms (Fig. I.17). Sampling was repeated a few times in May in most of the locations. The grass samples were cut to a height of about 5 cm to avoid contamination with soil [An unpublished study].

After the spring of 1986 pasture vegetation was not surveyed in a representative way, and only sporadic observations are available. Two experimental farms delivered samples of pasture vegetation until autumn 1986. Some data were also obtained from experiments on silage vegetation.

Oats and barley are grown mainly for feed, but also to a minor extent for human food. Their sampling was similar to wheat and rye (next section).

I.3.1.2.3. Foodstuffs [I.16, I.17, I.54, I.63-I.68]

The regular sampling of foodstuffs was remarkably extended after the first observations of fallout radionuclides in milk at the end of April 1986. Dose assessment and potential need for intervention concerning especially wild food types, were the first reasons for a comprehensive surveillance. Further analysis and the use of data for estimation of the seasonal dynamics and long-term trends of ^{137}Cs in foodstuffs was made possible with relevant design of the programme and with quality-assured documentation and analysis of samples. No samples of unknown origin were measured. The continuity of sampling improved the usefulness of the measurement results.

The sampling of foodstuffs was adjusted annually, and more often in 1986. The number of ^{137}Cs measurements decreased gradually after 1987, partly by measuring combined samples, and also by reducing the number of samples (Fig. I.21). The number of measurements in individual data sets is given in connection with the observed values for test quantities (Section I.3.2).

When significant changes were made to the sampling plan or practice, the persons responsible for sampling at outside organizations or enterprises often contributed as experts to the planning. STUK had direct contact with all deliverers of samples when needed, for example when sample information was insufficient or when samples for a regular programme were not received at the laboratory at planned times. Written instructions with a list of contact persons at STUK were given to all sample takers.

(a) Milk, beef, pork and cereal grains

Maps of sampling areas (Figs I.18-I.20) give a view of the areal representativeness of the samples of milk, meat and cereals. The representativeness for production was best for milk, 30-40 per cent of production.

For areal beef samples the information on origin of samples became more exact after 1986. The purpose was to have a list of municipalities of origin for each combined sample. Pork samples were composed of a few hundred small pieces from different animals. It was the responsibility of the slaughterhouses to see that the combined sample was representative for locations producing most meat.

Cereal grains were sampled by the regional branches of the State Granary. Samples were taken in connection with receiving cereals from the farms. In 1986, both farm-specific and areal samples were taken. Later, mostly combined regional samples composed of a varying number of individual samples were collected from annual harvests. In all years of the study, part of the samples were from known municipalities.

(b) Garden produce, wild berries and mushrooms, game and fish

The analysed vegetables and fruit, wild berries and mushrooms, game meat and freshwater fishes were all farm- or site-specific samples, taken in different provinces as far as possible. Some types of these products come to the food-market mostly from a limited area, and their sampling was focused towards the same regions. Vegetables grown for own households in kitchen gardens were also considered.

(c) Foodstuffs analysed for intake estimation

In addition to foodstuffs analysed for model testing, also fruit vegetables, root vegetables, apples, peas and beans, poultry meat, sheep meat, eggs and seafish were studied. Human intake via ingestion was analysed for all meaningful components of the diet. Estimation of intake for different dietary subgroups both regionally and by composition of diet was thus made possible.

I.3.1.3. Survey of environmental gamma radiation

A countrywide survey of environmental gamma radiation and fall-out levels in Finland was performed in autumns 1986 and 1987. The measurements were made by means of sensitive Geiger counters and a gamma spectrometer placed in cars. During driving, a total of 19 000 km, the instruments were continuously taking measurements, the results thus represent average radiation levels of each of about 1000 route sections measured. The final dose rates and deposition estimates were calculated from the spectrometric measurements of ^{134}Cs. The deposition calibration is based on comparison at calibration sites between measurements in an immobile vehicle and soil samples obtained at a short distance from the road.

The coordinates of the centres of the sections were used for production of radiation maps. Using an interpolation procedure, a rectangular grid (8 km × 8 km) of values was generated from an irregularly spaced set of points. The grid values were used for calculation of dose rate and mean ^{137}Cs deposition levels for the 458 Finnish municipalities, of which 383 were in the area S. [I.8]

I.3.1.4. Whole-body counting of ^{137}Cs

I.3.1.4.1. Method of measurements

Subjects were measured with the IRMA 1 counter in Helsinki or with the mobile IRMA 2 counter used for studies elsewhere in Finland [I.69, I.70]. Each year measurements were taken in winter time, mainly from November to April. According to Finnish legislation, the personal result was given to each participant.

The IRMA 1 whole-body counter, installed in an iron room, uses a multidetector scanning technique. The subject lies on a bed in the middle of a circular frame, on which holders for four NaI(Tl)-crystals (diameter 12.7 cm, height 10.2 cm) are installed. During a scan measurement, the frame on which the detectors are installed is driven at constant speed along the subject in a horizontal direction. The scanning time is normally 30 minutes for a scanning length of 170 cm. The minimum detectable activity (MDA) for ^{134}Cs and ^{137}Cs was 30 Bq when the nuclides were measured separately. This method also permits the profile distribution of the radionuclides in the body to be determined. Before measurement with this counter, each subject took a shower and dressed in clean pyjamas to avoid external contamination.

The IRMA 2 mobile whole-body counter is a measuring device which employs modified chair geometry. The background shield is made of two components, the chair and detector shields. A high purity germanium semiconductor detector (HPGe) was used in all measurements. The relative efficiency of this detector was 27 per cent, and the resolution was 1.95 keV, as determined by the

1.33 MeV gamma ray of ^{60}Co. The measurement time was usually 1000 seconds and the corresponding MDA for ^{137}Cs about 50 Bq. Whenever possible, the people to be measured first took a shower or at least changed into clean pyjamas.

The quantitative calibration of the whole-body counters was carried out using phantoms filled with appropriate radionuclides of known activity. The calibration factors, as a function of the weight of the phantom, were calculated separately for ^{134}Cs, ^{137}Cs and ^{40}K.

The results of the Nordic intercomparison study indicated that with both of the whole-body counters, the results of measurements of the ^{137}Cs reference phantom were within 5 per cent of the theoretical value [I.59].

I.3.1.4.2. Measurement programme

Due to the protective recommendations given in Finland, signs of ^{134}Cs contamination in people first became evident in June, 1986. This nuclide indicated that the fallout originated in the Chernobyl accident [I.71]. The measured activities were very near the MDA value.

In 1986, the number of people invited for measurements from different parts of Finland was 380 [I.71]. The measurements of this group were started in November 1986 and continued in 1987. By the end of December 1986, 96 persons had been whole-body counted. Of these, 24 were children aged 5-14 and the rest were adults aged 15-65. The number of people measured in 1987 was 160, of which 132 were adults [I.72]. The size of the group was to be restricted to a minimum mainly due to additional costs of the measured persons which the laboratory was responsible for. The persons were selected from the population register by the Research Institute for Social Security at the Social Insurance Institution. The sampling method chosen was stratified random sampling where the strata were provinces and the sample size was self-weighting. The purpose of measuring this group was to investigate the variation of ^{134}Cs and ^{137}Cs body burden in people residing in different fallout regions in Finland so that the internal radiation dose of the Finnish population could be estimated.

In 1988 an additional group of 180 people from the Helsinki area was selected in the same way [I.73]. The Helsinki area, which belongs to the region of lowest deposition density of ^{137}Cs, had been excluded from the first selection to limit the number of people measured from this region. The region was well represented in the whole population group chosen in 1986, and the situation in the Helsinki area was well known since a Helsinki reference group of 26 people had been whole-body counted annually since 1965 [I.69]. The additional 180 people were added to the original 380 members of the population group. In 1988, 212 people from the whole population group were whole-body counted. Of these, 178 were adults. The corresponding figures were 161 and 127 in 1989 [I.70].

To ensure that a sufficient number of people would be measured annually, a third additional random sampling was done in 1990 [I.70]. The size of that sample was 500 people. In 1990 the population group measured included the original group, the additional group from the Helsinki area, and finally the group sampled in 1990. Altogether 323 people were whole-body counted in 1990. Of these, 272 were adults.

From these groups, people (aged 5-65) living in the test area were selected for calculation of mean ^{137}Cs body contents. The number of persons included in the calculations each year is given with the ^{137}Cs body burdens in Section I.3.2.6.

I.3.2. DERIVATION OF QUANTITIES FOR MODEL TESTING (OBSERVED DATA)

I.3.2.1. General methodology

I.3.2.1.1. Types of ^{137}Cs data

The test quantities and the radiation doses derived for comparisons are means for the test area during the given time periods, with 95% confidence intervals of the means. In calculating the means from primary results of ^{137}Cs measurements, information on areal distribution of the population, production of different foodstuffs, and areal deposition densities were considered. Other variables included in calculations are specific to sample types. For whole-body measurements, fish, game meat and greenhouse vegetables, the primary data were assumed to represent the whole test area or its subregions. Other data were checked for the difference in the mean deposition densities of ^{137}Cs, weighted for sampling density and for production.

Treatment of data, especially the estimation of uncertainties, was often dependent on the method of sampling or on combination of samples for the activity measurement. The following types of ^{137}Cs data were included in the calculation of observed values for model testing:

- Areal survey data for environmental gamma radiation were used for estimation of ^{137}Cs deposition (see Section I.3.2.2).
- Time series representing individual collecting stations, measured for ground-level air and pasture grass (from May 1986). The method of estimation was based on regression fitting with the least-squares method, either of primary or log-transformed data.
- ^{137}Cs contents in random site-specific samples of different vegetables, mushrooms, game animals or wild berries, taken from known locations, and fishes from known lakes. Also results of whole-body measurements belong to this category, with respect to the method of data treatment. Theoretical means and confidence intervals were derived using log-normal statistics. Censored observations for non-detectable ^{137}Cs contents were replaced by detection limits of the measurements.
- ^{137}Cs contents in combined samples representing known subregions of the test area, such as samples of milk received by a dairy from the whole supply area, cereal grain samples from different purchase areas of the State Granary, and samples of beef and pork from supply areas of slaughterhouses. Both cereal grains and meat represent a number of known or unknown municipalities, which do not cover the supply areas as a whole. When estimating the uncertainty of the mean ^{137}Cs content, the error of the ^{137}Cs determination, and information on the representativeness of the sample were taken into account.

I.3.2.1.2. Data for site-specific samples

The data for random site-specific samples were usually log-normally distributed; this was checked with graphical printouts of most subsets of data used in calculation of the test quantities. Data sets included some censored observations, mostly for low-activity samples measured fresh in 1986. Sample-specific or roughly estimated detection limits were used for calculation of the mean and 95% confidence limits from the log-normal distribution. After 1986 the samples were preconcentrated for measurements, and the measuring times were long enough to reduce the number of censored observations close to zero.

The calculation of the mean and the 95% confidence interval was based on the log-likelihood equations reviewed by Beauchamp et al. [I.74], as was suggested for VAMP. The SAS programme for the use of the equations was made available by G. Brandt [I.75, I.76]. For uncensored data the estimates of μ and σ^2 are

$$\hat{\mu} = \frac{1}{n}\sum_{i=1}^{n} \ln(x_i) \tag{1}$$

and

$$\hat{\sigma}^2 = \frac{1}{n-1}\sum_{i=1}^{n} (\ln(x_i)-\hat{\mu})^2. \tag{2}$$

The mean of x was estimated by

$$E(x) = \exp(\hat{\mu}+\frac{\hat{\sigma}^2}{2}). \tag{3}$$

The approximate 95% confidence interval of the mean is

$$C.I. = \exp\left(\hat{\mu}+\frac{\hat{\sigma}}{2}\pm 1.96\sqrt{\frac{\hat{\sigma}^2}{n}+\frac{(\hat{\sigma}^2)^2}{2(n+1)}}\right). \tag{4}$$

For data sets including censored observations due to nondetectable ^{137}Cs contents, the maximum likelihood estimates for μ and σ were obtained by finding the values that maximize the log-likelihood function

$$L(\mu,\sigma) = -n\ln\sigma-\frac{1}{2}\sum_{i=1}^{n}(\frac{\ln(x_i)-\mu}{\sigma})^2+\sum_{j=1}^{k} r_j\ln(F_j)+constant, \tag{5}$$

where

$$F_i = \int_{-\infty}^{\xi_i}\Phi(t)\,dt,$$
$$\xi_i = (D_i-\mu)/\sigma,$$
$$\Phi(t) = (2\pi)^{-\frac{1}{2}}e^{-\frac{t^2}{2}}$$

and

n = number of uncensored observations,
r_i = number of censored observations under the detection limit,
D_i = Detection limit,
k = number of detection limits.

An estimate for $Var(\hat{\mu}+\hat{\sigma}^2/2)$ can be obtained from

$$var(\hat{\mu}+\frac{\hat{\sigma}^2}{2}) = (s.e.(\hat{\mu}))^2+(\hat{\sigma}\,s.e.(\hat{\sigma}))^2+2\hat{\sigma}cov(\hat{\mu},\hat{\sigma}), \tag{6}$$

where the standard errors and covariances are calculated as described by Beauchamp et al. [I.74]. The proposed asymptotic 95% confidence interval for the mean is

$$C.I. = \exp\left(\hat{\mu}+\frac{\hat{\sigma}^2}{2}\pm 1.96\sqrt{var(\hat{\mu}+\frac{\hat{\sigma}^2}{2})}\right). \tag{7}$$

Some means for site-specific data sets were corrected for biased sampling concerning production-weighted deposition. These were data for game meat, wild berries and mushrooms, and several field-grown vegetables and fruit, analysed for estimation of dietary intake.

The ratio of measured ^{137}Cs content divided by local deposition, the transfer factor (TF), was used for calculation of means and confidence intervals for some sample types (milk, cereals, wild berries, mushrooms, game meat). In these cases the samples were assumed to represent production conditions rather than the ^{137}Cs contents in the whole year's production. The mean content and its confidence interval were obtained by multiplying the mean and the C.I.s of the TF by production-weighted deposition.

I.3.2.1.3. Data for combined regional samples

Sampling areas did not cover the test area as a whole. The municipalities outside the sampling areas were considered using the transfer factor for ^{137}Cs as a temporary quantity and taking into account either deposition and soil type, or only deposition densities in all municipalities, in calculation of the mean. The bias in areal representativeness of foodstuff data was thus systematically corrected.

For estimation of confidence intervals for combined regional samples, both the error of ^{137}Cs determination (2 × R.S.D.) and uncertainties related to sampling were used. The evaluation of the representativeness of the sampling varied by sample type, as explained in the following sections. Quantitative estimates for uncertainties from different sources were combined by quadratic summing, when the variables did not correlate with each other. Other types of uncertainty were treated as additive quantities (Equation 8). Also, different uncertainties related to data sets including a small number of measurement results were added directly.

I.3.2.1.4. Combination of confidence intervals

For model testing or dose comparisons quantities were derived, which were functions of independent or dependent variables. The uncertainty of different variables may include both random and systematic error terms. For functions $f(x_1,...,x_n)$ or $f(x_1',...,x_n')$ of two or more independent variables x_i or dependent variables x_i' the combined confidence intervals were calculated from

$$\Delta f = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i}\right)^2 (\Delta x_i)^2 + \left(\sum_{i=1}^{n} \frac{\partial f}{\partial x_i} \Delta x_i'\right)^2}, \quad (8)$$

where Δ's are the differences between estimated means and lower or upper confidence bounds.

I.3.2.1.5. Production statistics

All statistical information was given in the scenario description for the year 1986. Some fluctuation between years both in meteorological conditions and production of feed and foodstuffs occurred in 1986-1990 [I.27, I.77-I.80]. It was the choice of modellers wether to keep to the scenario description or to consider real meteorological conditions and annual yields. To achieve realistic estimates, e.g. for comparison with whole-body measurements, the annual variation in production was considered in treatment of the test data. Otherwise the input information given to modellers in Section I.2 was used in the treatment of the test data.

A significant loss of harvest followed unfavourable weather conditions in 1987. Cereal grains, vegetables and fruit were produced 20-50% less than in 1986. The bag of small game was 20-40% lower than in 1986. In 1988-1990 the production of different foodstuffs, including wild products, varied between a 40% decline and a 200% increase compared to 1986. The most important agricultural products in daily use varied significantly less, around 10-30 percent in both directions of the figures for 1986. The production-weighted deposition densities in the test area for different food types varied very little, usually a few percent or less in the five-year period. This shows that changes in production would not explain possible discrepancies between observed data and results of model calculations.

I.3.2.2. Deposition estimates through environmental gamma radiation

The results for the mobile survey of gamma radiation and fallout levels, carried out in 1986 and 1987, were used for estimation of the mean deposition received in the area S [I.8]. All activity values were corrected for radioactive decay to 1 May 1986. The activity includes all Chernobyl-derived ^{137}Cs deposited in area S.

The areal integration over the test region gave the following deposition inventories: 3.5×10^{15} Bq for ^{137}Cs and 2.1×10^{15} Bq for ^{134}Cs. The mean deposition densities were 19.9 kBq ^{137}Cs m^{-2} and 11.9 kBq ^{134}Cs m^{-2}.

In estimation of the uncertainty, the representativeness of the measured road sections and the calibration sites of the mobile survey, the systematic calibration error of measurements, and analysis of vertical soil profile samples from the calibration sites were considered. The partly subjective estimate for the 95% confidence interval is 30% around the means.

The 'observed values' of the deposition were actually given to the modellers in the scenario description as average deposition densities of different subregions. For subregions of the test area the mean deposition densities were calculated using the results of the mobile gamma survey for individual municipalities.

I.3.2.3. Animal feeds

Measured ^{137}Cs contents for pasture vegetation from the spring of 1986 declined with time following an exponential curve. Regression fitting gave the mean and C.I.s of the mean for May-July 1986. The extensive surveillance of pasture vegetation was cancelled after the level of ^{137}Cs in milk was estimated to be low enough not to require intervention. After July 1986 the data from monitoring of the Finnish nuclear power plants and sporadic observations from a feed study [I.62] were used to derive very rough estimates for later years (Table I.LI). Uncertainties for pasture vegetation are great due to unrepresentative samples after July 1986. The sampling sites of later grass samples did not represent the feed of dairy cows in the entire region S. The soil types at these sites were clayish soils, whereas coarser mineral soils with higher root uptake of ^{137}Cs than from clays were common in the main production areas of milk.

Calculations for barley and oats are explained in connection with cereal grains in the next section. Observed ^{137}Cs contents in cereal grains used for feed (Table I.LI) show some fluctuation. This was probably caused by varying growth conditions (Figs I.22 and I.23). The fraction of oats produced in peat soils may also vary annually and increase variation in ^{137}Cs contents during the test period 1986-1990.

I.3.2.4. Food products

I.3.2.4.1. Years 1986-1990

(a) General

This scenario differs from STUK's previous assessments when dealing with Chernobyl-derived radiocaesium only. For calculation of the test quantities for different foodstuffs and dietary intake for 1986-1990, about 200 sets of ^{137}Cs data were analysed. For all site-specific samples and for regional samples of pork, log-normal statistics were applied to primary ^{137}Cs concentrations to obtain means and confidence intervals. For combined regional samples, usually the mean and C.I.s were first estimated for subregions. Different sources of uncertainty related to representativeness of samples were considered. Measurement error of regional samples was always included in total confidence intervals as 2 × R.S.D. The mean for the test area S was a production-weighted mean of the means for subregions.

(b) Vegetables and fruit, game and fish

Private farmers, commercial gardens, fishermen and hunters delivered local samples of vegetables and fruit, freshwater fish and game meat. Private pickers sent samples of wild berries and mushrooms, each of which represented one forest. Annual data sets for ^{137}Cs in these products were log-normally distributed. The arithmetic means and the 95% confidence intervals were calculated with the methods of log-normal statistics. No censored observations due to detection limits of measurements were among the data for fish or wild terrestrial products, whereas data for vegetables and fruit included some observations lower than the detection limit, especially in 1986.

Leafy vegetables included cabbages and lettuce. Lettuce contributed seven per cent to the consumption of leafy vegetables; it was mainly produced in greenhouses using peat as a growing medium. Also different cabbages were partly grown under cover at least until July.

^{137}Cs contents in greenhouse leafy vegetables were all treated as one annual data set per harvest year, for which the mean and confidence intervals were calculated using log-normal statistics. For vegetables and fruit grown outdoors, the transfer factors and their distributions were used. The mean TF and its confidence intervals were multiplied by production-weighted deposition for each type of produce (Table I.LII). The slow decrease of ^{137}Cs concentrations was caused by contaminated peat used as growing medium for a part of production.

For fish, the ^{137}Cs data were divided into subgroups by fishing region, by the type of feed of different fish species, and by the size of the lake (less than or above 1 km^2). Means and confidence intervals of the ^{137}Cs contents were calculated using statistics for log-normal distributions. Examples of probability distributions for fish are given in Fig. I.24. Means for subsets of data were weighted for regional fish catches in 1986 when the mean for all fish from the region S was calculated by Equation 9 (Table I.LIII). Confidence intervals for subregions were combined using Equation 8.

$$C_S = \frac{\sum_{ij} G_{ij} * C_{ij}}{\sum_{ij} G_{ij}}, \qquad (9)$$

where

C_S = Mean concentration of ^{137}Cs in fish from area S (Bq kg^{-1}),

G_{ij} = Catch (kg) of group i (i=1,2,3) in subarea j (j=1,...,6),

C_{ij} = Mean concentration in group i from subarea j.

In big game, both moose (calves and adults) and white-tailed deer were included. Fifteen species of small game animals were hunted for food. They were divided into six subgroups for estimation of the mean ^{137}Cs content in small game. Annual transfer factors and annual regional hunting statistics were used for all subgroups formed. TF-data for big game and part of the small game data were treated with log-normal statistics. For some subgroups of small game, the number of annual measurements was small, and medians and ranges were used in estimation. Mean deposition weighted for annual game bag by groups of game animals was used with annual estimates for TF (Equation 9) (Table I.LIV).

$$C_S = \frac{\sum_i TF_i * G_i * D_{Si}}{\sum_i G_i}, \tag{10}$$

where

C_S = Mean concentration of ^{137}Cs in small or big game from area S (Bq kg^{-1}),
TF_i = Transfer factor for group i (i=1,2,3 for big game; i=1,...,6 for small game) from area S,
D_{Si} = Mean deposition in area S weighted for annual game bag of group i,
G_i = Game bag (edible fraction) of group i in S (kg).

Both for catches of fish and annual game bags, the edible fractions were derived from statistics which were given in kilograms of total catch or in numbers of hunted animals [I.18, I.68].

Treatment of data for wild berries and mushrooms resembles the calculations for game meat, except for statistics. No comprehensive statistics for annual amounts of picked berries and mushrooms were available. The information given in the scenario about the use of mostly local forests for picking was used. The mean deposition connected with transfer factors was weighted for population density to obtain annual means and C.I.s for ^{137}Cs concentrations. The origin of the commercially distributed fraction of products was also considered (Tables I.LV and I.LVI).

(c) Milk, beef and cereal grains

The most accurate production statistics were available for milk, when sample types chosen for the test were compared. Both annual production in all municipalities of the test area and percentage of milk received at the regional dairy from each municipality were available. Using the deposition densities from the nationwide external gamma activity survey [I.8], the transfer parameters from deposition to milk (m^2 kg^{-1}) were calculated for each sample measured.

For the first year after deposition, the TF's for areas outside the sampling areas (Fig. I.18) were chosen on the basis of areal ^{137}Cs distribution. This means that often the TF's for the nearest sampling area to a municipality were used. After the grazing season of 1987, soil types of cultivated fields were used for grouping the areas where the same transfer factors were applied. The mean ^{137}Cs concentration for the whole test area was the production-weighted mean for the subregions (Equation 11). The concentrations were further integrated over the time periods defined for the test, and divided by the length of each period to achieve the mean concentration [I.54].

$$C_S = \frac{\sum_{ij} TF_i * D_{ij} * P_{ij}}{\sum_{ij} P_{ij}}, \tag{11}$$

where

C_S = Mean concentration of ^{137}Cs in milk from area S (Bq L^{-1}) during a sampling interval,
TF_i = Transfer factor in subregion i, which comprises the sampling region i,
D_{ij} = Mean deposition in municipality j (in subregion i) (j=1,...,371),
max(i) = number of sampling regions in a year,
P_{ij} = Production of milk in municipality j (in subregion i).

For the content of ^{137}Cs in milk, the following sources of uncertainty were accounted for: the statistical counting error (2 × R.S.D) of individual sample measurements, uncertainty from representativeness of the sample in relation to weekly milk production in the supply area of the dairy (10%, added directly to the measurement error), and range of transfer factors around the mean during the sampling period in question. The constant error of 10% concerning the representativeness of milk in the silos of the dairy was not estimated higher, because the written instructions for sample takers emphasize the proper timing of sampling. Milk from the whole supply area must have been received to the silos before sampling, carried out in two days weekly. Confidence intervals for the mean of the whole test area were obtained by quadratic summing, weighting for production, from the C.I.s of the means for subregions (Table I.LVII).

The mean ^{137}Cs concentrations in milk from the whole test area decreased gradually with time in 1987-1990. The most distinct decline was found each year in early summer after the grazing had started. The milk from central and northern parts of the area showed slower decrease rate than the milk from southern areas where clay soils with efficient fixation of radiocaesium are most common [I.54, I.63]. The decrease with time of the mean ^{137}Cs concentrations in milk from the test area also reveal the importance of milk originating from other than clayish regions.

For beef the representativeness of the individual (bulked) samples concerning the production in sampling regions had to be assessed. Inside each sampling area, the production of beef versus land area was approximately equal. Random sampling (5000 times) from the cumulative areal distribution of deposition was used to simulate the actual sampling [I.1] in estimation of the uncertainty related to varying deposition (95% confidence interval). The locations of origin for a combined beef sample were not always known, but the number of individual animals was given. The varying production conditions and biological variability among animals were assumed to cause a 50% uncertainty in individual samples. This uniform distribution (±50%) was combined with the cumulative deposition distribution of each sampling area in the random sampling runs. Measurement error 2 × R.S.D. was added by quadratic summing with the relative C.I. from the random sampling. For each measured sample the total uncertainty was estimated. The arithmetic means and confidence intervals of the mean were calculated for each sampling area and for all specified time periods. The production-weighted mean for the whole test area was calculated and C.I.s combined using quadratic summing as for milk.

The ^{137}Cs concentrations in beef (Table I.LVIII) were four to five-fold compared to concentrations in milk throughout the five-year period. The actual origin of beef may differ from the origin of milk, as the farms tend to specialize.

For pork each combined sample from some hundreds of animals was collected gradually during a couple of days. This was possible, when sampling was connected with samplings for food hygiene, necessary for pork. The feed of pork was not entirely local, and it may have contained imported feed constituents of varying origin. Therefore, log-normal statistics were used for calculation of means and confidence intervals (Table I.LIX).

The mean concentrations of ^{137}Cs in pork reached maximum values in the first quarter of 1987 and declined thereafter. Since the beginning of 1988 the contents showed some fluctuation but no decrease. The reason for constancy may be the ^{137}Cs contents in the cereals used for feed, which did not decline either. Also ^{137}Cs in imported feeds such as meat meal may have added to the ^{137}Cs content of feed [I.28]. The use of milk as feed was insignificant in this context [I.81].

For a part of the regional cereal samples the municipalities of origin were known. Mostly annual transfer factors were used in calculation of production-weighted means. Confidence intervals were derived by considering the range of transfer parameters and also the error from unknown origin of samples in the sampling region. This error term related to varying deposition was derived from cumulative frequency distribution for deposition density of a sampling area by random sampling (Table I.LX).

(d) Weather conditions in 1986-1990

Varying growing conditions often prevail in Finland, so also during the five years test period. Effective temperature sums for eleven locations in 1986-1990 reveal 1987 as an exceptionally cold summer, whereas the summer 1988 was very warm (Fig. I.23). The results for some sample types reflect these differences. For example in wheat and rye, wild berries and big game the ^{137}Cs contents indicate enhanced ^{137}Cs uptake from soil to field crops and wild plants in 1988, and low uptake in 1987.

I.3.2.4.2. Years 1990-2036

For the 50-years ingestion dose estimates, predictions for ^{137}Cs contents in foodstuffs were needed. The observed values for test quantities were used for approximation of the exponential change in contents after 1990. Data collected at STUK for the same sample types between 1960 and 1986 were used for comparison [I.82] (with a list of earlier reports). Mostly the data for nuclear weapons fallout indicated the slowest decline to be expected, due to annual deposition from the stratosphere in the years when the data were collected. The years 1963 and 1964, when the ^{137}Cs peaked in most foodstuffs, gave a relevant starting point for estimation of decline of contents. The faster component was derived from decline of the test quantities during 1987-1990. Towards the end of the 50-year period, the half-lives of ^{137}Cs contents were assumed to be longer, and especially for terrestrial wild produce, close to the half-life of radioactive decay. For freshwater fish, estimates for half-lives of ^{137}Cs concentrations were made at STUK using post-Chernobyl data [I.83].

I.3.2.5. Human intake

Dietary ^{137}Cs received by the test persons (man, woman and child) was estimated using the consumption rates given in Section I.2.3.11.2, Tables I.XLIX and I.L. For children, the consumption rates of groups of foodstuffs, given for different age groups, were divided into the same categories which were used in the diets of adults. The contributions of individual food species in the children's diet were in the same proportions as in an average adult's diet.

The scenario was not planned to include variability of consumption rates, and all the test quantities were means for the test area. Arithmetic means of consumption rates were used for men, women and children (average of consumption by boys and girls) of different ages.

Calculation of the mean concentrations of ^{137}Cs in several foodstuffs at the time of production was part of the modelling test. Outside the model validation exercise were potatoes, other-than- leafy vegetables, garden berries, domestic and imported nonberry fruit, poultry meat, eggs and other-than-freshwater fish. Information for estimation of contribution to the intake from drinking water was given in Section I.2. Some minor foodstuffs in the Finnish diet, such as lamb's meat and edible offals, were not named, but their consumption rates were added to a relevant foodstuff of the same type, considering also the known radiocaesium contents. Mean ^{137}Cs concentrations for food types which were not included in the test were calculated from measurement results with the same methods as the concentrations for foodstuffs included in the test. For some of the minor food species, only a limited number of measurement results were available, and the treatment of data was simplified accordingly.

The form and pretreatment of the analysed foodstuff samples (edible fraction or the whole product) and definitions of quantities used in dietary surveys and food balance sheets were considered in intake estimation. Several intake-reducing factors were included in calculations as far as quantitative information was available. Subjective estimation concerning some usual household practices was also used.

Consumption rates for the edible fraction were given for fish and meat in the scenario description. For potatoes, vegetables and fruit, the product weights were given, and the consumption rates were therefore corrected for mass losses during preliminary cleaning and peeling for cooking.

Radiocaesium losses during household cooking and industrial processing of food were analysed in Finland after 1986 [I.84]. The studies were aimed and planned to give correction factors for national use. Factors were used for processes in the dairy and milling industries, for processed meat and fish, conserved vegetables and fruit, and for household cooking. Losses during milling of rye were taken from a German study [I.85]. For mushrooms, no corrections were made for parboiling. To keep the diet simple enough for modellers but still reliable for estimation of dietary intake of radiocaesium, species of mushrooms that do not need to be parboiled were chosen for the scenario. The species given in the scenario corresponded to the mean radiocaesium concentration in edible fractions of the most common wild edible mushrooms in Finland.

After the summer of 1986, recommendations to reduce the consumption of freshwater fish were given to maximum consumers of freshwater fish. The recommendations were adjusted concerning area and fish types each year in 1986-1992 in order to cut the highest dietary intakes and keep the highest individual doses lower than 5 mSv a^{-1}. Very probably a considerable part of households refused freshwater fish entirely for some years. The interview survey of 1990 indicated significant changes in the diet due to the Chernobyl fallout [I.10]. The survey results given in the scenario description (Section I.2.3.2, Table I.X) were used to suggest average intake-reducing factors.

Delays in distribution of foodstuffs vary by the type of food. The slowest foods to consumption are cereals, between some months and one year, depending on the last year's harvest. For milk the delay is only a few days, for meat between a few days and three or four weeks except for conserved or processed food, for which the delay may be months or years. The fraction of conserved meat with respect to the total consumption of meat is small. The same holds for fish.

Seasonal changes in the diet were considered on a quarterly basis for freshwater fish, game meat, garden produce, wild berries and wild mushrooms. Use of other foods of the same category was corrected to keep the total daily consumption constant. At the most, the daily consumption of freshwater fish increased 80% and of game meat more than 100% during a quarter of a year. Deep-freezing evens the seasonal changes in the diet, especially when use of vegetables and fruit is concerned.

Dietary intake of ^{137}Cs from different foodstuffs has been calculated from the measured values for different types of food from equation

$$I_{ft} = f_r * f_s * f_{Ch} * cn * C, \qquad (12)$$

where

I_{ft} = intake of caesium through a type of food (Bq d^{-1}),
f_r = reduction factor from food processing, including mass loss,
f_s = seasonality factor when consumption varies during the year,
f_{Ch} = Chernobyl reduction in consumption rate due to government recommendations, public information etc.,
cn = consumption of food (kg d^{-1}),
C = concentration of ^{137}Cs in a food type (Bq kg^{-1}).

Total intake was calculated as

$$I_{tot} = \sum_{sp} I_{sp} \qquad (13)$$

and the error as

$$\Delta I_{tot} = \sqrt{\sum_{sp} (\Delta I_{sp})^2}. \qquad (14)$$

In estimation of the confidence intervals for the mean dietary intake, only the uncertainty in ^{137}Cs concentrations has been taken into account. Variation in the composition of the diet was excluded, as the test quantities were means for the whole area S.

In estimation of the long term dietary intake of adults for the years 1991-2036, the individual components of the diet were analysed separately. The same consumption rates for adults were used as in the first years. The intake of energy by adults actually declines with age, which certainly changes consumption of different types of food.

Dietary ^{137}Cs received by all three test persons peaked during the second quarter of 1987 (Table I.LXI). Intake by adults was reduced to a half in about two years, but by children in less than two years. The cause of the varying half-lives was different diet composition. Children consume more milk than women and significantly less freshwater fish than adults. Milk contributed most to the intake by man, woman and child both in the first year and in the years 1986-1990 (Figs I.25-I.27). The variation in intake via milk with time is caused by temporal changes in ^{137}Cs concentration of milk. Milk dominates also the seasonal pattern of total dietary ^{137}Cs received by children. For adults also the seasonal consumption rates for fish are clearly illustrated. In 1986-2036 annual intakes by man show the gradual change from agricultural products to foodstuffs of wild origin as main sources of ^{137}Cs (Fig. I.28).

I.3.2.6. Measured whole-body contents

The mean values of ^{137}Cs body burdens (Bq/kg body weight) at specified times were calculated separately for children, men and women. The individual results were normalized to represent body burdens on July 1 and December 31 for the years 1986-1990. When normalizing, it was assumed that each year the ^{137}Cs body burdens of people belonging to the population group changed with time in the same relative fashion as the mean body burden of the Helsinki reference group. This group consisted of 26 people and was measured four times each year. The method of normalization is described in the references [I.70-I.73]. The arithmetic means and the 95% confidence intervals were calculated assuming that the observations were log-normally distributed (Table I.LXII). The calculation method was the same as for log-normally distributed ^{137}Cs contents in foodstuffs, as described in Section I.3.2.1.

As an example of the distribution of the individual results (Bq/kg), curves showing the complementary cumulative distribution of the results for men at the end of the years 1987 and 1990 are given (Table I.LXIII, Figs I.29 and I.30).

The variation in radiocaesium body burdens within a certain fallout region is due to differences in the individual diet compositions, in ^{137}Cs concentrations of foodstuffs, and in metabolism of the people. Foodstuffs may be consumed within the production area or transported to another area with a different level of ^{137}Cs fallout. For example, the foodstuffs consumed in the Helsinki area, which represents an area with low ^{137}Cs deposition, are produced in various parts of the country. Another explanation for the body burden variations lies in the different amount of freshwater fish, wild berries and mushrooms consumed in different parts of the country. Foods taken from the wilds tend to have higher activity concentrations than agricultural products.

Participation in the study was on a voluntary basis. Therefore the composition and the size of the population group measured varied annually. This may have increased the variation of the annual mean body burdens.

I.3.2.7. Body burdens estimated from dietary intake

For estimation of body burdens from the dietary intake of man, the metabolic model of the ICRP for caesium was used [I.3]. The biological half-lives for a double-exponential function were chosen from later experiments [I.86, I.87], 2 d for the fast component (fraction of total, 0.1) and 85 d for slow component (fraction of total, 0.9). For the upper confidence limit, the parameters were 110 d (fraction of total, 0.9), and for the lower confidence limit, 80 d with an 0.8 fraction for the slow component. The mean biological half-lives found in Finland were close to the chosen value [I.88, I.89]. Uncertainty from intake estimation was combined with metabolic uncertainty to produce the confidence limits (Fig. I.31). For comparison, the body burdens based on whole-body measurements are also shown. Their confidence limits are based entirely on log-normal distributions of individual body burdens.

I.3.2.8. Comparison of the two body burden estimates

The difference between the body burden estimates from whole-body counter measurements and from dietary intake is small, although the confidence bounds do not overlap (Fig. I.31). No subjective estimates of uncertainty due to metabolisms and actual diets were added to the confidence bounds in either of the body burden estimates.

There are dietary subgroups with significantly different ^{137}Cs intakes among the inhabitants of the test area. The confidence bounds of the mean intake estimate are not dependent on dietary subgroups, but only on average consumption of different food types. The size of the population group participating in whole-body counter measurements was limited, which affects its representativeness. However, the relative changes with time of body burdens from whole-body measurements and from dietary intake agree rather well.

In connection with the intake estimation (Section I.3.2.5), some changes in people's diets, not evident in consumption statistics, have been taken into account. A very much discussed issue of spontaneous restriction of consumption of foodstuffs with high concentrations of ^{137}Cs, such as freshwater fish, and mushrooms, was considered only to the degree suggested in Section I.2.3.2 (Table I.X). The change in intake of all wild products was estimated from a retrospective study made in 1990 [I.10], when the ^{137}Cs contents in fish had declined for two years. This may have resulted in a slight overestimation of dietary intake of ^{137}Cs. Even a rather small decrease in consumption of freshwater fish or mushrooms may significantly reduce the intake of ^{137}Cs. People's reactions in neighbouring countries [I.90, I.91] and treatment of the issue of contamination of food in the media certainly caused some concern among the consumers.

I.4. DATA FOR DOSE COMPARISONS

For the first five years after deposition, the effective radiation doses were estimated using measured ^{137}Cs concentrations for the following pathways: external radiation from the cloud ($E_{Ext,\ cloud}$), external radiation from the ground contamination ($E_{Ext,\ ground}$), internal radiation through ingestion ($E_{Int,\ ing}$) and internal dose as a whole E_{Int}).

I.4.1. EFFECTIVE DOSE FROM EXTERNAL GAMMA RADIATION

I.4.1.1. Dose from the cloud

The effective dose from the cloud has been estimated by multiplying the time-integrated concentration of ^{137}Cs in air during the cloud passage with the dose rate factor given in Section I.2.2.3. Time integrals were calculated for the inhalation dose. No shielding factors were used, and the estimate is for outdoor dose (Table I.LXIV). The relative uncertainty of integrated ^{137}Cs concentration is suggested for external dose from the cloud.

I.4.1.2. Dose from ground deposits

The dose received by man due to ^{137}Cs deposited on the ground declines with time because of weathering and migration of radionuclides into the soil. This effect is pronounced in urban areas, where rain effectively washes the contamination from buildings and paved areas.

Buildings give good shielding for radiation from the ground. Especially in the higher storeys of blocks of flats, the dose rate is small compared to the dose rate at ground level outside. The shielding factor for a person living in a typical Finnish flat is on an average 0.18, and for low-rise residential houses it is 0.47. An average Finn spends approximately 85% of time indoors, and this occupancy factor is taken into account in the shielding factors.

The model used for estimation of the effective dose from external radiation due to deposition on the ground is based on the dose rate formula (Equation 15) proposed by Gale et al. [I.92].

$$\dot{E}_{e,g}(t) = s*d_0*(a*e^{\frac{-\ln(2)}{T_1}*t}+b*e^{\frac{-\ln(2)}{T_2}*t}), \qquad (15)$$

where

$E_{e,g}(t)$ = external dose rate per deposition from ground at time t (Sv m^2 Bq^{-1} h^1),
t = time (a),
s = shielding factor from housing,
d_0 = dose factor for external gamma radiation from ground immediately after the deposition (Sv m^2 Bq^{-1} h^{-1}),
T_1 = fast environmental decay halflife (a),
T_2 = slow environmental decay halflife (a),
a = fraction of caesium related to T_1,
b = fraction of caesium related to T_2.

The values used for region S were

d_0 = 1.3×10^{-12} Sv m^2 Bq^{-1} h^{-1} (from Section I.2.2.3),
s = 0.18, flats; 0.47, small houses [I.50, I.93],
T_1 = 1.15 a,
T_2 = 18.8 a,
a = 0.87, urban environment; 0.62, rural environment,
b (=1-a) = 0.13, urban environment; 0.38, rural environment.

The factors a and b, and the half-lives T_1 and T_2 were evaluated by fitting formula (15) to Finnish dose rate monitoring data [I.94]. For urban areas the factors a and b were estimated from the assumption that the dose rate in urban areas is about 1/3 of the dose rate in rural areas after 5 years [I.95].

The integrated dose per deposition at time t is

$$E_{e,g}(t) = \int_{t_0}^{t} \dot{E}_{e,g}(t)\,dt. \qquad (16)$$

No corrections have been made for the shielding effect of the snow-cover during the winter. We have estimated this effect to be well less than 10% for the annual mean external dose from ground to man in region S.

In the calculations we have used the deposition for different municipalities from the nationwide survey made by STUK (see Section I.3.1.3). The housing conditions in region S were also taken into account on a municipal level. As an estimate of the degree of urbanisation, we have used the percentage of people living in blocks of flats in each municipality. The urbanisation level of the total region S according to this is 40%, which is somewhat less than the values of 50-90% given in the scenario description, and based on the numbers of people living in population centres (Table I.XLIV).

The 95% confidence intervals were determined as the 2.5 and 97.5 percentiles of a simple random sampling test [I.1] composed of 5000 runs, where each parameter in the model was chosen randomly from a uniform distribution between mean-20% and mean+20% (Table I.LXIV).

For comparison, external dose from ground contamination was also calculated using the model of UNSCEAR [I.96]. Its main difference from our model is how it deals with migration of ^{137}Cs. It assumes constant relaxation depths during the first month (0.1 mm), the next eleven months (1 cm) and after that (3 cm), whereas our model assumes a continuous movement of ^{137}Cs in the soil. As can be seen, the results differ mainly in the 50 years time period, where the UNSCEAR model gives a very conservative estimate. The UNSCEAR model has been used with our best-estimate parameters as well as with the parameters given by UNSCEAR (Table I.LXIV).

I.4.2. EFFECTIVE DOSE THROUGH INHALATION

I.4.2.1. Method of calculation

The effective dose through inhalation was calculated using the equation

$$E_{Inh}(t) = d*r*f*\int_{t_1}^{t_2} C(t)\,dt, \tag{17}$$

where

E_{Inh} = effective dose received through inhalation during a time period (Sv),
d = dose conversion factor (Sv Bq^{-1}); $d = 8.6 \times 10^{-9}$ Sv Bq^{-1} [I.3]
r = inhalation rate ($m^3\ h^{-1}$),
f = reduction factor for filtration effect of the building; f = 0.5 for indoor doses during the first cloud passage [I.97] (until April 30, 1986) and f = 1 at other times,
C(t) = ^{137}Cs concentration in ground-level air as a function of time (Bq m^{-3}),
t_1 = the date April 27, 1986, at 3 p.m local time,
t_2 = the end of the time period specified for dose calculation, i.e. April 30, 1987; December 31, 1990; April 27, 2036.

I.4.2.2. Subareas of S

For estimation of time-integrated air concentrations of ^{137}Cs, the area S was divided into two subareas. The division was based on existing radioactivity data. Data of the Finnish Meteorological Institute [I.6] for total beta activity of airborne aerosols showed that during the first cloud passage on 27.4.-30.4.1986 the radionuclide concentrations increased substantially only in southern coastal provinces (see Section I.2.3.1.1). Elsewhere in the test area, the ^{137}Cs concentrations in ground-level air did not exceed 2% of the contents at sampling station AIR2 (Nurmijärvi). The subarea of higher air concentrations included provinces POP8, POP4 and the southern half (including half of the population of the province) of the province POP7. Also after the first cloud passage the same division into subareas was used, as it distinguished relatively well between areas corresponding to the average ^{137}Cs deposition received in the surroundings of AIR2 in the south and AIR3 in the north.

I.4.2.3. Time-integrated ^{137}Cs concentrations in air

For estimation of inhalation doses, the measured air concentrations were available for the following sampling stations and time periods:

- AIR1 (Helsinki): 28.4.-7.8.1986, 13.-30.3.1987, 11.-31.8.1987 and 1.1.1992-May 1993,
- AIR2 (Nurmijärvi): 27.4.1986-11.5.1992,
- AIR3 (Viitasaari): 10.4.1989-May 1993.

For estimation of the time-integrated air concentrations, the period of cloud passage was divided into two: 27.4. (3.00 p.m local time) -30.4. and 30.4.-10.5.1986. All periods related to resuspension started on 27.4.1986 and lasted until April 30, 1987, December 31, 1990 and April 27, 2036.

After the cloud passage, or since May 11, 1986, the measured air concentrations were assumed to represent resuspended ^{137}Cs. During 27.4.-10.5.1986, the resuspended fraction of airborne ^{137}Cs was approximated by exponential fitting, based on data for 11.5.1986 and thereafter. Stratospheric fallout was insignificant, when the reasoning of Hirose et al. [I.98] was applied to Finland. The long-term ratio of ground deposition and air concentration approached roughly a constant value, if the air samplers were in a similar type of environment.

The time-integrated air concentrations of ^{137}Cs were estimated for the southern subregion of S using the mean concentrations at sampling stations AIR1 and AIR2. For the period before the activation of station AIR1, the data for it were extrapolated from the first measurements at AIR1 using the relative changes at the station AIR2. After the sampling at station AIR1 was cancelled in August 1986, the station AIR2 represented the southern subregion until the end of 1990.

For the northern subregion, the time integral for the first cloud passage (27.4.-30.4.) was 1% of the integrated air concentration at station AIR2. Concentrations at station AIR3 were used to estimate the dose from the second cloud passage (30.4.-10.5.1986) and from resuspended material until 31.12.1990. The missing data after April 30, 1986, were extrapolated as for the station AIR1 above.

The air concentrations after the five-year period were estimated with least-squares regression, fitted to the log-transformed ^{137}Cs concentrations from the station AIR2. The relative changes found for AIR2 were applied to the air concentrations in both subareas of S. For the northern area the concentrations were corrected to correspond to the activity level of AIR3.

I.4.2.4. Inhalation rates

The whole adult population older than 19 in 1986 in both subareas of S was considered in estimation of the average dose through inhalation. The age distribution, industrial structure, and number of women and men in the area S were assumed to remain constant throughout the period 1986-2036.

The following categories of physical activity were considered separately for women and men in estimation of the inhalation rate of population: sleep, rest, light work and heavy work [I.99]. The age groups were 20-64 years and 65 years or older. After the age of 65 years the work was assumed to be entirely light work.

The mean inhalation rate in the area S was 0.93 m^3 h^{-1}. The inhalation rates in the two subareas did not differ significantly.

I.4.2.5. Doses

The same fraction of time spent indoors was assumed as for estimation of the external dose. Only during the cloud passage 27.-30.4.1986 was the infiltration effect (f = 0.5) considered. The dose conversion factor was the same as the factor derived for another test scenario dealing with Chernobyl fallout (I.2).

In 50 years time, resuspension was estimated to contribute less than 10 per cent to the time-integrated ^{137}Cs concentrations in ground-level air. The uncertainty of dose estimates (Table I.LXV) mainly comes from representativeness of the measured ^{137}Cs concentrations, and it is an entirely subjective approximation.

I.4.3. EFFECTIVE INTERNAL DOSE

I.4.3.1. Dose from measured whole body contents in 1986-1990

The effective dose for ^{137}Cs from whole body measurements was calculated using the dose factor 2.5 x 10^{-6} Sv per (Bq a kg^{-1}) as given by UNSCEAR [I.100]. The internal radiation doses were calculated using the individual ^{137}Cs values expressed as Bq per kg of body weight. The activity time integrals of ^{137}Cs (Bq a kg^{-1}) were calculated using the individual body burdens normalized to the end of the year and assuming that the individual body burdens changed in the same relative fashion as the mean body burden of the Helsinki reference group within the time period considered. In calculation of the committed effective internal dose of ^{137}Cs for the first year after the Chernobyl accident, the dose factor given above was multiplied by the ratio of activity time integrals calculated to infinity and for one year. In this case a factor 4.1 x 10^{-6} Sv per (Bq a kg^{-1}) for calculating the committed effective dose was applied. The metabolic model given in the ICRP Publication 30 was used [I.3].

When the committed dose for the whole period from 26 April 1986 to 31 December 1990 was calculated, the committed dose factor was applied only to the activity time integral for the last year. To get the effective doses delivered in the former years, the activity time integrals for these years were multiplied by the factor 2.5 x 10^{-6} Sv per (Bq a kg^{-1}). To get the committed effective dose for the whole period, the delivered doses from the period from 26 April 1986 to 31 December 1989 were added to the committed dose calculated for the year 1990. The doses were calculated separately for the groups of men and women. The mean values of the male and female group are shown in connection with total doses in Section I.4.4 for the first year and for 4.6 years. The estimation of 95% confidence intervals for the doses was based on log-normal distributions of body-burdens for women and men. The confidence intervals of the means were calculated using Equation 8 and assuming that the addends were independent.

I.4.3.2. Dose from dietary intake

For comparison, the committed effective dose for an average adult was calculated from dietary intakes (mean for women and men) using the dose conversion factor 1.4×10^{-8} Sv Bq^{-1} (Table I.LXVI). The contributions from different food types to the ingestion dose were derived from dietary intakes.

I.4.4. TOTAL DOSE

The total radiation dose for an average adult living in the region S is a sum of doses from inhalation, ingestion and external radiation. The internal dose (inhalation and ingestion) was based on whole-body counter measurements. The inhalation dose was calculated separately to show its contribution to the internal dose. Total dose, like its components, was given as a committed effective dose. The 95% confidence interval of the total dose was a quadratic sum of the confidence intervals for the addends (Table I.LXVII). The doses for the first five years were based on observed values of the test quantities.

For the years 1991-2036 the internal dose was derived using results of the whole-body counter measurements for the last quarter of 1990. The decrease rate of doses was the same as the decrease rate of the estimated dietary intake (Section I.3.2.5). The lower confidence bounds were derived from the results of whole body counter measurements, and the upper confidence bounds were calculated from the upper confidence bounds of the dietary intakes.

TABLE I.I. RADIOCESIUM CONCENTRATIONS IN GROUND-LEVEL AIR AT AIR1 FROM 28 APRIL TO 30 MAY 1986

From		To		Concentration ($\mu Bq\ m^{-3}$)	
Date	Time	Date	Time	^{134}Cs	^{137}Cs
28.4.	17.30	28.4.	18.50	1650000	2760000
28.4.	18.55	28.4.	20.45	1780900	3100000
28.4.	20.50	28.4.	21.55	4200000	7200000
28.4.	21.55	28.4.	22.55	600000	1090000
29.4.	01.55	29.4.	02.50	510000	880000
29.4.	02.55	29.4.	03.55	480000	830000
29.4.	04.00	29.4.	04.50	410000	670000
29.4.	04.55	29.4.	05.50	320000	540000
29.4.	05.55	29.4.	06.50	210000	350000
29.4.	06.55	29.4.	07.50	126000	195000
29.4.	07.55	29.4.	08.50	61000	124000
29.4.	08.55	29.4.	11.10	19500	35000
29.4.	11.10	29.4.	12.10	3600	9400
29.4.	12.10	29.4.	13.10	7000	12600
29.4.	13.35	29.4.	14.25	3900	6400
29.4.	14.30	29.4.	18.50	1880	4200
29.4.	18.55	29.4.	23.35	273000	470000
29.4.	23.45	30.4.	03.50	310000	530000
30.4.	03.50	30.4.	07.05	195000	330000
30.4.	07.05	30.4.	13.25	94000	164000
30.4.	13.25	30.4.	17.40	143000	249000
30.4.	17.45	30.4.	22.00	183000	300000
30.4.	22.05	1.5.	02.00	43000	72000
1.5.	02.00	1.5.	04.00	24400	42000
1.5.	04.00	1.5.	06.00	19900	33000
1.5.	06.00	1.5.	07.55	44000	74000
1.5.	07.55	1.5.	10.00	31000	53000
1.5.	10.00	1.5.	12.15	19600	36000
1.5.	12.15	1.5.	14.15	22000	39000
1.5.	14.15	1.5.	17.45	21700	41000
1.5.	17.45	1.5.	22.25	27000	44000
1.5.	22.30	2.5.	03.50	41000	69000
2.5.	03.50	2.5.	06.55	59000	92000
2.5.	06.55	2.5.	11.50	46000	79000
2.5.	11.55	2.5.	16.55	48000	82000
2.5.	17.00	2.5.	21.30	18700	33000
2.5.	21.30	3.5.	07.30	22900	38000
3.5.	07.30	3.5.	12.20	75000	123000
3.5.	12.20	3.5.	16.15	100000	163000
3.5.	16.15	3.5.	20.15	92000	151000
3.5.	20.15	4.5.	00.15	72000	121000
4.5.	00.15	4.5.	07.40	59000	97000
4.5.	07.40	4.5.	12.10	43000	74000
4.5.	12.10	4.5.	16.50	33000	51000
4.5.	22.55	5.5	08.20	16800	25800
5.5	08.20	5.5.	12.50	22600	36000
5.5.	12.50	5.5.	17.30	17200	27500
5.5.	17.30	5.5.	20.50	9200	14100
5.5.	20.50	6.5.	07.55	6200	11700
6.5.	07.55	6.5.	13.30	6700	12100
6.5.	13.30	6.5.	17.50	8700	13900
6.5.	17.50	6.5.	21.30	4500	8300
6.5.	21.30	7.5.	07.30	4400	7200
7.5.	07.30	7.5.	11.30	3200	7700
7.5.	11.30	7.5.	20.55	6700	11000
7.5.	20.55	8.5.	08.30	5700	8900
8.5.	08.30	8.5.	20.30	7200	13300
8.5.	20.30	9.5.	08.30	11100	18700
9.5.	08.30	9.5.	12.30	12600	21100
9.5.	12.30	9.5.	20.15	13600	22600
9.5.	20.15	10.5.	08.25	6800	12000
10.5.	08.30	10.5.	15.45	23600	45000
10.5.	15.45	11.5.	10.45	2710	4500
11.5.	10.50	12.5.	07.50	3400	6500
12.5.	07.50	12.5.	16.20	3200	6700
12.5.	16.20	13.5.	10.00	1380	2530
13.5.	10.00	14.5.	10.10	340	560
14.5.	10.10	15.5.	09.55	570	1110
15.5.	10.00	16.5.	10.00	650	1110
16.5.	10.00	17.5.	10.00	710	1140
17.5.	10.00	19.5.	10.15	520	1000
19.5.	10.15	21.5.	10.30	1290	2300
21.5.	10.30	23.5.	14.50	610	1060
23.5.	14.55	26.5.	13.55	1250	2240
26.5.	13.55	30.5.	13.05	590	1050
30.5.	13.05	2.6.	14.05	350	560

TABLE I.II. RADIOCESIUM CONCENTRATIONS IN GROUND-LEVEL AIR AT AIR2 FROM 24 APRIL TO 30 MAY 1986

From		To		Concentration ($\mu Bq\ m^{-3}$)	
Date	Time	Date	Time	^{134}Cs	^{137}Cs
24.4.	09.35	28.4.	09.35	950000	1790000
28.4.	09.35	28.4.	15.10	820000	1400000
28.4.	15.10	28.4.	22.10	7200000	11900000
28.4.	22.10	29.4.	08.50	177000	320000
29.4.	09.05	29.4.	15.45	58000	96000
29.4.	15.45	30.4.	09.20	94000	155000
30.4.	09.20	30.4.	15.45	33000	56000
30.4.	15.45	1.5.	15.45	51000	84000
1.5.	16.40	2.5.	15.55	28200	49000
2.5.	16.05	3.5.	13.50	7700	13200
3.5.	14.10	4.5.	14.35	33000	56000
4.5.	14.45	5.5.	15.15	20500	35000
5.5.	15.25	6.5.	15.00	5400	9100
6.5.	15.10	7.5.	13.25	3500	6100
7.5.	13.35	8.5.	14.45	7200	12600
8.5.	14.55	9.5.	14.10	9700	17400
9.5.	14.10	10.5.	13.00	10200	18600
10.5.	14.15	11.5.	15.40	4100	7500
11.5.	15.45	12.5.	14.20	2900	5400
12.5.	14.30	13.5.	13.15	4000	7500
13.5.	13.20	15.5.	09.30	490	940
15.5.	09.30	16.5.	13.05	370	700
16.5.	13.10	19.5.	13.00	1550	2720
19.5.	13.10	21.5.	13.00	1140	1990
21.5.	13.05	23.5.	13.50	640	1150
23.5.	13.55	26.5.	10.40	990	1800
26.5.	10.45	28.5.	10.40	870	1570
28.5.	10.45	30.5.	10.10	430	730
30.5.	10.20	2.6.	10.55	200	410

TABLE I.III. GEOMETRIC MEAN DIAMETERS (AERODYNAMIC) DG_{ae}, GEOMETRIC STANDARD DEVIATIONS SG, AND MODAL CONCENTRATIONS C FOR RADIOACTIVITY SIZE DISTRIBUTIONS AND FOR MASS AND SURFACE AREA SIZE DISTRIBUTIONS OF THE ACCUMULATION MODE FOR AN AEROSOL SAMPLE DURING MAY 9-12, 1986 AT STATION AIR1

	DG_{ae} (mm)	SG	C
Mass	0.44	1.8	15 ($\mu g\ m^{-3}$)
Surface area	0.31	1.8	251 ($\mu m^2\ cm^{-3}$)
Cs-137	0.63	1.8	9 ($mBq\ m^{-3}$)

TABLE I.IV. NUMBER OF PARTICLES IN 1000 m^3 AIR EXCEEDING DIFFERENT ACTIVITY LEVELS

	Activity (Bq)					
Day	>200	>100	>50	>5	>0.5	>0.05
27.4	0.9	3	17	-	900	-
28.4	1.1	9	23	-	3000	-
29.4	0.9	4	6	-	230	-
30.4	0.6	1.4	2.3	-	110	-
1.5	-	-	-	-	-	2

TABLE I.V. ^{137}Cs DEPOSITION IN POPULATION AREAS CORRECTED TO 1 MAY 1986 (MEANS FOR TOTAL AREA)

Population area	^{137}Cs deposition ($kBq\ m^{-2}$)
POP1	39.5
POP2	29.9
POP3	11.4
POP4	18.1
POP5	16.6
POP6	2.3
POP7	22.3
POP8	13.6
POP9	23.2

(Revised version, December 1992)

TABLE I.VI. ^{137}Cs DEPOSITION IN AGRICULTURAL AREAS CORRECTED TO 1 MAY 1986.

Agricultural area	Land area (km^2)	Total area (km^2)	^{137}Cs deposition mean for total area ($kBq\ m^{-2}$)
AGR1	5676.6	7241	6.2
AGR2	14512.0	15028	25.7
AGR3	3075.9	3121	3.8
AGR4	6861.2	7538	26.0
AGR5	5715.8	7350	43.8
AGR6	6889.6	7118	14.5
AGR7	14883.0	17487	27.8
AGR8	16511.3	19954	11.4
AGR9	5106.7	5588	33.5
AGR10	14431.0	19177	13.9
AGR11	4551.6	4709	7.7
AGR12	9363.5	11120	46.6
AGR13	17782.3	21586	2.3
AGR14	10502.5	11123	25.6
AGR15	5346.9	5694	18.5
AGR16	8446.9	8637	16.4
AGR17	6976.5	7151	22.0

(Revised version, December 1992)

TABLE I.VII. ^{137}Cs DEPOSITION IN FISHING AREAS CORRECTED TO 1 MAY 1986

Fishing area	Area (km^2)	^{137}Cs deposition ($kBq\ m^{-2}$)
FISH1	11753	14.2
FISH2	9866	13.1
FISH3	57192	6.8
FISH4	38823	30.2
FISH5	28032	34.4
FISH6	30426	22.5

(Revised version, December 1992)

TABLE I.VIII. RADIOCESIUM IN WET + DRY DEPOSITION

Deposition station	Area of collector (m^2)	Concentration ($Bq\ m^{-2}$) ^{134}Cs	^{137}Cs	From	To
DEP1	0.05	6.20	17.00	280486	290486
DEP1	0.05	570.00	910.00	290486	300486
DEP1	0.05	1000.00	1900.00	300486	010586
DEP1	0.05	52.00	86.00	010586	020586
DEP1	0.05	14.00	29.00	020586	030586
DEP1	0.05	16.00	31.00	030586	040586
DEP1	0.05	8.30	18.00	040586	050586
DEP1	0.05	9.40	19.00	050586	060586
DEP1	0.05	9.20	18.00	060586	070586
DEP1	0.05	8.00	17.00	070586	080586
DEP1	0.05	.	13.00	080586	090586
DEP1	0.05	31.00	54.00	090586	100586
DEP1	0.05	170.00	300.00	100586	110586
DEP1	0.05	8.00	19.00	110586	120586
DEP1	0.05	57.00	110.00	120586	130586
DEP1	0.05	14.00	26.00	130586	140586
DEP1	0.05	.	7.40	140586	150586
DEP1	0.05	3.70	8.60	150586	160586
DEP1	0.05	9.50	22.00	160586	170586
DEP1	0.05	.	.	170586	180586
DEP1	0.05	.	.	180586	190586
DEP1	0.05	.	.	190586	200586
DEP1	0.05	.	10.00	200586	210586
DEP1	0.05	3.70	7.70	210586	230856
DEP1	0.05	13.00	25.00	230586	260586
DEP1	0.05	.		260586	280586
DEP1	0.05	.	6.40	280586	300586
DEP2	0.05	.	34.00	010486	300486
DEP2	0.05	180.00	400.00	010586	310586
DEP3	0.05	2300.00	4400.00	010486	300486
DEP3	0.05	1000.00	1700.00	010586	310586
DEP4	0.05	5100.00	8800.00	010486	300486
DEP4	0.05	1800.00	2900.00	010586	310586
DEP5	0.07	7000.00	12000.00	010486	300486
DEP5	0.07	7000.00	12000.00	010586	310586
DEP6	0.07	950.00	1800.00	010486	300486
DEP6	0.07	850.00	1300.00	010586	310586
DEP7	0.05	640.00	1200.00	010486	300486
DEP7	0.05	970.00	1700.00	010586	310586
DEP8	0.07	11000.00	20000.00	010486	300486
DEP8	0.07	3300.00	6000.00	010586	310586
DEP9	0.05	.	.	010486	290486
DEP9	1.00	900.00	1700.00	290486	300486
DEP9	1.00	2300.00	3900.00	300486	010586

TABLE I.VIII. (CONTD.)

Deposition station	Area of collector (m^2)	Concentration (Bq m^{-2}) ^{134}Cs	^{137}Cs	From	To
DEP9	1.00	180.00	320.00	010586	020586
DEP9	1.00	76.00	150.00	020586	030586
DEP9	1.00	83.00	130.00	030586	050586
DEP9	1.00	19.00	33.00	050586	060586
DEP9	1.00	12.00	21.00	060586	070586
DEP9	1.00	12.00	20.00	070586	080586
DEP9	1.00	17.00	26.00	080586	090586
DEP9	1.00	31.00	57.00	090586	100586
DEP9	1.00	190.00	360.00	100586	110586
DEP9	1.00	35.00	78.00	110586	120586
DEP9	1.00	16.00	38.00	120586	130586
DEP9	1.00	18.00	33.00	130586	150586
DEP9	1.00	5.60	13.00	150586	160586
DEP9	1.00	6.10	14.00	160586	190586
DEP9	1.00	6.40	20.00	190586	210586
DEP9	1.00	7.90	14.00	210586	230586
DEP9	1.00	18.00	40.00	230586	260586
DEP9	1.00	4.30	8.20	260586	280586
DEP9	1.00	3.50	6.10	280586	300586
DEP10	0.05	880.00	1400.00	010486	300486
DEP10	0.05	.	.	010586	310586
DEP11	0.05	3500.00	6300.00	010486	300486
DEP11	0.05	1500.00	2500.00	010586	310586

TABLE I.IX. VERTICAL DISTRIBUTIONS OF ^{134}Cs AND ^{137}Cs IN SOILS OF THE TEST REGION DURING 1986-1989. SAMPLING SITES HAVE BEEN DIVIDED INTO (1) HEATH FOREST SOILS, (2) UNCULTIVATED MINERAL SOILS, AND (3) UNKNOWN (either 1 OR 2)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
		YEAR 1986		
3	1	0-1.5	83.1	82.4
		1.5-3.5	13.9	14.2
		3.5-7	3.0	3.4
		0-2.5	90.5	89.6
		2.5-4.5	8.3	8.6
		4.5-8	1.2	1.7
3	2	0-1.5	88.9	86.1
		1.5-3	7.3	8.4
		3-5	1.8	2.5
		5-8.5	2.0	3.1
3	6	0-2	79.5	79.9
		2-4	20.0	19.6
		4-6	0.5	0.6
		6-8	.	.
		0-2	90.8	9.1
		2-4.5	7.8	8.0
		4.5-7.5	1.4	1.6

TABLE I.IX. (CONTD.)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
3	7	0-3	70.5	68.9
		3-6	19.6	20.8
		6-8.5	9.9	10.3
3	8	0-1.5	92.2	4.1
		1.5-3.5	7.8	8.7
		3.5-6.5	.	2.9
		6.5-9	.	4.3
3	9	0-1	91.3	90.5
		1-2	6.6	6.6
		2-4	1.5	1.8
		4-7.5	0.6	1.1
3	10	0-2	93.9	71.8
		2-4	6.1	10.7
		4-6	.	6.9
		6-8.5	.	10.7
3	11	0-1	76.2	71.0
		1-2.5	21.5	22.0
		2.5-5.5	1.9	4.1
		5.5-8.5	0.4	3.0
2	4	0-2	95.5	92.2
		2-4	2.4	3.2
		4-6.5	1.2	2.3
		6.5-10	0.9	2.2
2	5	0-2	33.8	30.1
		2-5	46.9	47.9
		5-8	19.3	19.2
		8-11	.	1.6
		11-13	.	1.1
		0-2	23.7	23.4
		2-5	57.6	56.4
		5-8	18.7	18.7
		8-11	.	1.2
		11-13	.	0.6
3	13	0-1.5	19.6	19.3
		1.5-3	22.7	23.0
		3-4.5	25.4	24.6
		4.5-6.5	17.2	16.9
		6.5-9.5	10.3	11.2
		9.5-13.5	3.3	3.5
		13.5-18.5	1.5	1.5

TABLE I.IX. (CONTD.)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
		YEAR 1987		
3	14	0-1.5	8.5	66.1
		1.5-3	25.9	26.8
		3-4.5	2.1	2.9
		4.5-6.5	1.5	1.8
		6.5-9.5	1.2	1.4
		9.5-13.5	0.9	0.8
		13.5-18.5	.	0.2
3	15	0-1.5	56.7	54.9
		1.5-3	35.0	34.3
		3-5	5.4	5.6
		5-6.5	1.5	1.8
		6.5-9.5	0.5	1.1
		9.5-13.5	0.4	1.2
		13.5-17	0.5	1.1
3	16	0-1.5	63.5	62.2
		1.5-3	20.6	20.6
		3-4.5	10.4	10.7
		4.5-6.5	4.9	4.8
		6.5-9.5	0.6	0.8
		9.5-13.5	.	0.4
		13.5-18.5	.	0.4
		18.5-22.5	.	0.2
3	17	0-1.5	76.7	71.3
		1.5-3	14.4	13.7
		4.5-6.5	8.9	7.2
		6.5-10.5	.	4.9
		10.5-15.5	.	1.6
		15.5-19.5	.	1.3
3	18	0-1.5	33.0	32.4
		1.5-3	23.3	23.1
		3-4.5	12.4	12.4
		4.5-6.5	10.1	10.4
		6.5-9.5	9.4	9.8
		9.5-13.5	6.6	7.1
		13.5-18.5	5.2	4.8
		YEAR 1988		
1	19	0-1.5	49.7	48.2
		1.5-3	33.8	32.6
		3-4.5	6.9	6.9
		4.5-6.5	4.5	5.8
		6.5-9.5	5.2	6.5
		0-1.5	86.1	85.6
		1.5-3	11.6	12.1
		3-4.5	1.3	1.4
		4.5-6.5	0.5	0.6
		6.5-9.5	0.5	0.3

TABLE I.IX. (CONTD.)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
		0-1.5	82.4	80.5
		1.5-3	11.8	12.5
		3-5.5	3.8	4.7
		5.5-7.5	1.6	1.9
		7.5-10.5	0.4	0.4
		0-1.5	47.1	44.0
		1.5-3	50.2	52.0
		3-4.5	1.3	1.7
		4.5-6.5	0.8	1.4
		6.5-9.5	0.3	0.5
		9.5-13.5	0.1	0.2
		13.5-17.5	0.1	0.2
		0-1.5	79.7	79.6
		1.5-3.5	17.1	17.0
		3.5-5.5	3.2	3.4
		0-1.5	56.2	55.3
		1.5-3	31.5	31.2
		3-4.5	6.4	7.1
		4.5-6.5	5.8	6.4
		0-1.5	39.2	37.6
		1.5-3.5	37.6	37.7
		3.5-5.5	7.4	7.3
		5.5-7.5	3.8	3.8
		7.5-10.5	2.8	2.8
		10.5-14.5	5.3	5.4
		14.5-18.5	3.3	4.4
		18.5-22.5	0.4	1.0
2	19	0-1.5	55.5	54.5
		1.5-3	38.3	39.0
		3-4.5	4.3	4.5
		4.5-6.5	1.3	1.4
		6.5-9.5	0.5	0.6
		YEAR 1989		
1	20	0-1	23.1	20.2
		1-3	52.3	48.0
		3-5	14.7	17.0
		5-7	6.2	9.1
		7-12	3.7	5.7
		0-1	6.6	5.8
		1-3.5	60.3	54.0
		3.5-5.5	20.3	19.8
		5.5-8	10.0	12.5
		8-10	2.7	6.0
		10-12.2	.	1.8

TABLE I.IX. (CONTD.)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
		0-1	16.3	18.7
		1-3	61.1	57.6
		3-5	8.6	13.0
		5-7	4.5	5.5
		7-12	.	2.8
		12-17	.	0.6
		17-22	4.9	1.0
		22-28	4.5	0.9
1	21	0-1	57.8	55.2
		1-3	25.8	25.2
		3-5	5.4	7.3
		5-8.5	6.2	6.8
		8.5-17.5	4.8	5.5
		0-1	55.1	53.7
		1-2	31.4	31.2
		2-10	12.7	14.3
		10-15	0.8	0.8
1	22	0-1.5	23.1	22.3
		1.5-3	43.3	39.7
		3-4.5	21.2	22.2
		4.5-6.5	8.2	9.7
		6.5-9.5	2.5	4.0
		9.5-14.5	1.8	2.0
1	24	0-1.5	40.6	39.2
		1.5-3	40.3	39.6
		3-4.5	11.9	12.7
		4.5-6.5	5.4	6.1
		6.5-9.5	1.6	2.0
		9.5-13	0.3	0.4
		0-1.5	41.0	39.9
		1.5-3	34.5	34.8
		3-4.5	13.7	14.1
		4.5-6.5	6.5	6.8
		6.5-14.5	4.3	4.4
		0-1.5	51.7	51.8
		1.5-3	40.5	39.7
		3-4.5	5.3	5.7
		4.5-13	2.5	2.8
1	19	0-1.5	3.5	3.5
		1.5-3	58.9	56.0
		3-4.5	22.7	23.4
		4.5-6.5	13.6	15.3
		6.5-12	1.4	1.9
		0-1.5	40.5	39.5
		1.5-3.0	16.1	17.3
		3.0-4.5	3.5	3.6
		4.5-6.5	2.6	3.2
		6.5-9.5	1.9	2.3
		9.5-12	0.8	0.8

TABLE I.IX. (CONTD.)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
		0	27.9	26.4
		0-1.5	47.5	45.9
		1.5-3.0	14.6	15.1
		3.0-6.5	4.8	6.0
		6.5-9.5	4.0	5.0
		9.5-13.5	0.6	0.9
		13.5-15	0.5	0.8
		0-1.5	86.3	84.1
		1.5-3.0	9.4	10.6
		3.0-4.5	2.6	3.3
		4.5-13	1.7	2.0
		0-1.5	87.7	84.4
		1.5-3.0	6.4	8.5
		3.0-4.5	4.1	5.0
		4.5-11.5	1.7	2.1
		0	74.6	72.2
		0-1.5	8.9	9.0
		1.5-3.0	8.1	8.4
		3-4.5	5.3	6.1
		4.5-10.5	3.2	4.3
		0	67.9	65.5
		0-1.5	16.7	18.5
		1.5-3.0	3.7	5.2
		3.0-4.5	3.4	3.4
		4.5-6.5	3.1	3.0
		6.5-14.5	3.1	2.7
		14.5-19.5	0.5	0.3
		19.5-22.5	1.6	1.5
		0	38.8	37.6
		0-1.5	31.2	30.0
		1.5-3.0	21.5	22.3
		3.0-4.5	5.5	6.2
		4.5-6.5	1.5	1.7
		6.5-9.5	0.9	1.1
		9.5-13.5	0.5	0.7
		13.5-24	0.3	0.3
		0-1.5	85.8	84.7
		1.5-3.0	10.6	11.6
		3-4.5	1.1	1.4
		4.5-6.5	0.9	0.9
		6.5-9.5	1.2	1.0
		9.5-13.5	0.4	0.2
		13.5-22.5	.	0.3
		0-1.5	67.8	67.4
		1.5-3.0	19.8	21.1
		3.0-4.5	4.7	5.5
		4.5-6.5	2.6	2.3
		6.5-9.5	.	1.3
		9.5-13.5	2.3	1.1
		13.5-25	2.7	1.3

TABLE I.IX. (CONTD.)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
		0	58.5	55.6
		0-1.5	11.1	11.9
		1.5-3.0	8.9	9.5
		3.0-4.5	4.7	5.1
		4.5-6.5	3.4	4.0
		6.5-9.5	3.9	4.0
		9.5-13.5	4.7	4.9
		13.5-24	4.7	5.1
		0-1.5	56.3	57.0
		1.5-3.0	17.9	19.3
		3.0-4.5	8.4	8.4
		4.5-6.5	6.4	6.5
		6.5-9.5	2.2	2.5
		9.5-13.5	2.9	3.9
		13.5-25	5.8	2.4
		0-1.5	76.3	73.4
		1.5-3.0	17.8	20.2
		3.0-4.5	2.8	3.0
		4.5-6.5	1.0	1.4
		6.5-9.5	1.5	1.2
		9.5-14	0.7	0.9
		0	22.1	22.0
		0-4.5	73.8	74.3
		4.5-6.5	2.8	2.8
		6.5-14.5	1.3	0.9
		0	68.3	65.5
		0-1.5	25.2	26.6
		1.5-3.5	3.2	4.1
		3.5-4.5	1.4	1.7
		4.5-10	0.8	1.1
		10-16	1.1	1.1
		0-1.5	60.8	61.7
		1.5-3.0	22.6	22.4
		3.0-4.5	12.7	12.3
		4.5-10	2.5	2.7
		10-16	0.7	0.6
		16-20	0.6	0.3
		0-1.5	88.5	87.5
		1.5-3.0	6.6	6.7
		3.0-4.5	1.6	2.2
		4.5-6.5	1.8	1.9
		6.5-14.5	0.6	0.7
		14.5-19.5	0.4	0.6
		19.5-24	0.4	0.4
		0	82.2	80.6
		0-1.5	10.9	11.2
		1.5-3.0	3.9	5.0
		3.0-4.5	0.9	1.1
		4.5-6.5	0.4	0.5
		6.5-28	1.7	1.5

TABLE I.IX. (CONTD.)

Soil type	Soil site	Layer (cm)	Vertical Distribution (%)* ^{134}Cs	^{137}Cs
1	6	0-1.5	50.9	50.5
		1.5-3	25.5	25.4
		3-4.5	13.6	13.5
		4.5-6.5	5.9	6.4
		6.5-13	4.2	4.2
		0-2	90.0	87.7
		2-3.5	6.8	6.8
		3.5-5	1.2	2.1
		5-8	0.9	2.1
		8-13.5	1.1	1.3
		0	59.1	56.5
		0-1.5	23.0	24.0
		1.5-3.0	7.8	8.3
		6.5-13.5	6.0	6.7
		4.5-6.5	2.4	2.6
		6.5-13.5	1.7	2.0
2	23	0-1.5	45.9	45.0
		1.5-3	23.9	24.5
		3-4.5	10.0	10.3
		4.5-6.5	5.1	6.1
		6.5-9.5	10.5	9.3
		9.5-16.5	4.6	4.7
		0-2	77.2	70.7
		2-3.5	9.2	12.1
		3.5-5	3.7	4.9
		5-8	3.1	3.6
		8-13.5	6.8	8.8
2	24	0-1.5	35.8	35.3
		1.5-3	23.1	23.1
		3-4.5	13.9	14.0
		4.5-6.5	11.5	11.7
		6.5-9.5	8.1	8.1
		9.5-13	7.7	7.8
2	19	0-1.5	77.6	76.8
		1.5-3.0	16.5	16.9
		3.0-4.5	4.0	4.2
		4.5-11.5	1.9	2.2
2	4	0-1.5	80.3	79.6
		1.5-3	13.2	13.1
		3-4.5	2.2	2.4
		4.5-6.5	1.8	1.8
		6.5-9.5	1.0	1.1
		9.5-16.5	1.5	2.1

* Note: Percentages may not always equal 100% due to rounding.

TABLE I.X. CHANGE IN CONSUMPTION HABITS DUE TO THE CHERNOBYL ACCIDENT

Subarea	Decrease in consumption of wild produce (%)
POP1, POP2	36
POP3, POP4, POP5, POP6	13
POP7, POP9	21
POP8	27

TABLE I.XI. SAMPLE RECORDS OF RAINFALL OBSERVATIONS (COMPLETE DATA ARE PROVIDED ON DISKETTE)

Variable	Column
Code of rainfall measuring station	1 - 4
Year	6 - 7
Month	9 - 10
Day	12 - 13
Daily precipitation (mm)*	14 - 18

* Negative values indicate:
- 0.0 = slight rain
- 1.0 = no rain
- 2.0 = no information

Sample Records on Diskette:

```
-----------------
 373 86 05 14  4.6
 373 86 05 15 -1.0
 373 86 05 16  3.1
 373 86 05 17  3.8
 373 86 05 18  0.7
 373 86 05 19 -1.0
-----------------
```

Clarification to the rainfall data on diskette:

In five cases, the rainfall was given as -0.1. These should be converted to 2.0 (missing information).

TABLE I.XII. RANGES OF AVERAGE MONTHLY TEMPERATURES

Month	Average temperature (°C) From	To
January	-12	-4
February	-12	-5
March	-7	-3
April	0	+2
May	+7	+9
June	+12	+14
July	+16	+17
August	+14	+16
September	+8	+12
October	+2	+7
November	-3	+2
December	-7	-2

TABLE I.XIII. TOTAL LAND AND WATER AREAS OF DIFFERENT POPULATION SUBAREAS

Population area	Area (km^2) Total	Land	Water
POP1	19802	17010	2792
POP2	19357	16230	3126
POP3	19956	16511	3444
POP4	12828	10783	2045
POP5	21660	16342	5317
POP6	21585	17782	3803
POP7	23166	22170	996
POP8	10404	9898	506
POP9	27319	26447	872
Sum	176077	153173	22901

TABLE I.XIV. CHARACTERISTICS OF THE MAIN DRAINAGE AREAS

Area	Lake percentage (%)	Total surface area (km^2)	Evaporation from land areas* ($mm\ a^{-1}$)	Total discharge ($m^3\ s^{-1}$)
FISH1	2-10	14760	400-450	118
FISH2	2-10	7135	400-425	59
FISH3	20	52390	300-400	550
FISH4	19	37235	300-400	290
FISH5	12	27100	300-400	210
FISH6	2-5	38755	300-350	319

* Add 50 mm to get evaporation from the lakes.

TABLE I.XV. INFORMATION ABOUT 70 LAKES OR PONDS IN THE TEST REGION S DURING 1980-1991
(TIME SERIES OF INDIVIDUAL BASINS MAY BE SOMEWHAT INCOMPLETE)

Quantity	Unit	N	Min.	Max.	Q1	Median	Q3	Mean	STD	STDERR	SKEWNESS	KURTOSIS
CNR_NC	(mg Pt/L)	3832	0	350	25	40	60	47.6	31.5	0.508	2.085	8.368
CTY_25	(mS/m)	3613	0.32	19	5	5.9	7	6.5	2.5	0.042	1.471	1.960
FE_	(µg/L)	1545	0	5500	100	260	400	299.5	293.0	7.454	5.531	73.103
K_	(mg/L)	94	0.4	3.5	1	1.2	1.5	1.2	0.4	0.046	1.616	6.355
PH_L	(-)	4345	4.2	9.6	6.5	6.9	7.1	6.8	0.5	0.008	0.167	3.055
RE_S	(mg/L)	440	0	26	0.7	1.9	4.3	3.1	3.6	0.172	2.071	5.826

Description of quantities:

CNR_NC = Colour number (nonfiltered)
CTY_25 = Specific conductivity at 25 °C
FE_ = Iron
K_ = Potassium
PH_L = pH of liquids
RE_S = Residue total suspended

Note: N is the number of observations on which particular calculations concerning the quantity are based. The total number of observations is 5020, i.e. there were that many sample sites at which the data were gathered.

TABLE I.XVI. RADIOCESIUM IN SURFACE WATER IN DIFFERENT DRAINAGE AREAS (FISHING AREAS) AND THEIR SUBREGIONS (RSD OF THE ^{137}Cs CONTENTS DOES NOT GENERALLY EXCEED 5%)

Date	Fishing area	Subregion	Concentration (Bq kg^{-1}) ^{134}Cs	^{137}Cs
15-May-86	FISH1		0.53	0.90
	FISH2		0.39	0.66
	FISH3	A	0.34	0.55
	FISH3	B	0.73	1.40
	FISH3	C	0.15	0.28
	FISH4	A	1.60	2.70
	FISH4	B	0.92	1.90
	FISH4	C	1.30	2.20
	FISH5	A	2.00	3.30
	FISH5	B	3.00	5.30
	FISH5	C	1.50	2.80
	FISH6		0.60	1.00
15-Aug-86	FISH1		0.120	0.23
	FISH2		0.068	0.12
	FISH3	A	0.200	0.39
	FISH3	B	0.200	0.37
	FISH3	C	0.052	0.10
	FISH4	A	0.590	1.10
	FISH4	B	0.350	0.65
	FISH4	C	0.520	0.97
	FISH5	A	0.180	0.34
	FISH5	B	0.670	1.20
	FISH5	C	0.340	0.62
	FISH6		0.160	0.30
15-Oct-86	FISH1		0.056	0.140
	FISH2		0.056	0.120
	FISH3	A	0.033	0.073
	FISH3	B	0.140	0.280
	FISH3	C	0.039	0.090
	FISH4	A	0.330	0.650
	FISH4	B	0.160	0.310
	FISH4	C	0.370	0.720
	FISH5	A	0.170	0.380
	FISH5	B	0.460	0.850
	FISH5	C	0.250	0.510
	FISH6		0.200	0.410
15-Mar-87	FISH1		0.0495	0.1080
	FISH2		0.0336	0.0740
	FISH3	A	0.0132	0.0326
	FISH3	B	0.0871	0.1970
	FISH3	C	0.0468	0.1030
	FISH4	A	0.1840	0.4170
	FISH4	B	0.1510	0.3390
	FISH4	C	0.2720	0.5820
	FISH5	A	0.0592	0.1330
	FISH5	B	0.3570	0.7920
	FISH5	C	0.0602	0.1340
	FISH6		0.0912	0.2030

TABLE I.XVI. (CONTD.)

Date	Fishing area	Subregion	Concentration ^{134}Cs	(Bq kg^{-1}) ^{137}Cs
15-May-87	FISH1		0.042	0.0996
	FISH2		0.023	0.0570
	FISH3	A	0.015	0.0410
	FISH3	B	0.064	0.1600
	FISH3	C	0.039	0.0910
	FISH4	A	0.160	0.3900
	FISH4	B	0.074	0.1600
	FISH4	C	0.190	0.4600
	FISH5	A	0.054	0.1300
	FISH5	B	0.240	0.5400
	FISH5	C	0.150	0.3500
	FISH6		0.055	0.1200
15 Aug-87	FISH1		0.028	0.069
	FISH2		0.021	0.054
	FISH3	A	0.015	0.044
	FISH3	B	0.056	0.140
	FISH3	C	0.031	0.084
	FISH4	A	0.140	0.380
	FISH4	B	0.093	0.230
	FISH4	C	0.160	0.390
	FISH5	A	0.055	0.140
	FISH5	B	0.180	0.440
	FISH5	C	0.150	0.360
	FISH6		0.041	0.110
15-Oct-87	FISH1		0.032	0.085
	FISH2		0.021	0.053
	FISH3	A	0.013	0.035
	FISH3	B	0.046	0.120
	FISH3	C	0.021	0.062
	FISH4	A	0.120	0.330
	FISH4	B	0.066	0.180
	FISH4	C	0.120	0.310
	FISH5	A	0.033	0.094
	FISH5	B	0.140	0.370
	FISH5	C	0.099	0.250
	FISH6		0.035	0.093
15-Mar-88	FISH1		0.018	0.057
	FISH2		0.010	0.028
	FISH3	A	0.010	0.038
	FISH3	B	0.014	0.044
	FISH3	C	0.020	0.083
	FISH4	A	0.093	0.300
	FISH4	B	0.044	0.155
	FISH4	C	0.082	0.240
	FISH5	A	0.026	0.083
	FISH5	B	0.092	0.280
	FISH5	C	0.068	0.210
	FISH6		0.030	0.094
15-May-88	FISH1		0.0170	0.054
	FISH2		0.0120	0.037
	FISH3	A	0.0077	0.029
	FISH3	B	0.0240	0.080
	FISH3	C	0.0160	0.050
	FISH4	A	0.0680	0.220
	FISH4	B	0.0380	0.120
	FISH4	C	0.0670	0.220
	FISH5	A	0.0220	0.077
	FISH5	B	0.0770	0.250
	FISH5	C	0.0540	0.170
	FISH6		0.0210	0.070

TABLE I.XVI. (CONTD.)

Date	Fishing area	Subregion	Concentration (Bq kg^{-1}) ^{134}Cs	^{137}Cs
15-Aug-88	FISH1		0.0075	0.028
	FISH2		0.0120	0.039
	FISH3	A	0.0069	0.029
	FISH3	B	0.0270	0.094
	FISH3	C	0.0160	0.057
	FISH4	A	0.0760	0.260
	FISH4	B	0.0550	0.190
	FISH4	C	0.0620	0.220
	FISH5	A	0.0300	0.089
	FISH5	B	0.0730	0.260
	FISH5	C	0.0510	0.180
	FISH6		0.0240	0.082
15-Oct-88	FISH1		0.0140	0.0480
	FISH2		0.0140	0.0480
	FISH3	A	0.0060	0.0270
	FISH3	B	0.0220	0.0830
	FISH3	C	0.0127	0.0484
	FISH4	A	0.0600	0.2080
	FISH4	B	0.0408	0.1490
	FISH4	C	0.0540	0.1900
	FISH5	A	0.0220	0.0860
	FISH5	B	0.0600	0.2200
	FISH5	C	0.0392	0.1430
	FISH6		0.0180	0.0660
15-May-88	FISH1		0.0084	0.036
	FISH2		0.0076	0.031
	FISH3	A	0.0100	0.050
	FISH3	B	0.0110	0.055
	FISH3	C	0.0092	0.038
	FISH4	A	0.0360	0.160
	FISH4	B	0.0220	0.086
	FISH4	C	0.0330	0.140
	FISH5	A	0.0160	0.065
	FISH5	B	0.0400	0.160
	FISH5	C	0.0210	0.090
	FISH6		0.0130	0.058
15-Aug-89	FISH1		0.0064	0.030
	FISH2		0.0063	0.028
	FISH3	A	0.0041	0.020
	FISH3	B	0.0160	0.068
	FISH3	B	0.0160	0.068
	FISH3	B	0.0160	0.068
	FISH3	C	0.0095	0.045
	FISH4	B	0.0310	0.140
	FISH4	C	0.0350	0.170
	FISH5	A	0.0150	0.062
	FISH5	B	0.0470	0.230
	FISH5	C	0.0280	0.130
	FISH6		0.0130	0.063
15-Oct-89	FISH1		0.0110	0.052
	FISH2		0.0055	0.030
	FISH3	A	0.0035	0.020
	FISH3	B	0.0130	0.066
	FISH3	C	0.0098	0.041
	FISH4	A	0.0290	0.150
	FISH4	B	0.0220	0.120
	FISH4	C	0.0310	0.150
	FISH5	A	0.0120	0.056
	FISH5	B	0.0390	0.180
	FISH5	C	0.0220	0.100
	FISH6		0.0100	0.055

TABLE I.XVII. POTASSIUM IN SURFACE WATER IN DIFFERENT DRAINAGE AREAS (FISHING AREAS) AND THEIR SUBREGIONS

Fishing area	Subregion	Concentration of K* ($mg\ kg^{-1}$)	RSD** (%)
FISH1		3.5	7
FISH2		4.4	7
FISH3	A	0.7	27
FISH3	B	1.3	12
FISH3	C	2.3	17
FISH4	A	1.1	14
FISH4	B	1.6	28
FISH4	C	1.8	13
FISH5	A	2.5	15
FISH5	B	1.2	28
FISH5	C	1.7	16
FISH6		2.2	6

* These are means of four to five measurements at different seasons in two years.

** $RSD^2 = \frac{RSD_1^2 + \cdots RSD_5^2}{5}$, RSD means relative standard deviation of the gammaspectrometric ^{40}K determination.

TABLE I.XVIII. MONTHLY SURFACE WATER TEMPERATURES IN LAKES

Month	Temperature (°C)
June	14 - 15
July	17 - 18
August	16 - 18
September	12 - 13
October	6 - 9

TABLE I.XIX. FISH CATCHES IN 1986 AS THE CONTRIBUTION OF DIFFERENT SPECIES TO THE CATCHES OF EACH AREA AND AS THE CONTRIBUTION OF DIFFERENT FISHING AREAS TO THE TOTAL CATCH

Fishing area	Predators (%)	Intermediate species (%)	Non-predators (%)	All fishes (%)
FISH1	32.3	40.2	27.5	8.1
FISH2	34.5	36.0	29.5	2.7
FISH3	31.4	37.8	30.8	39.3
FISH4	31.9	38.7	29.4	22.7
FISH5	33.3	37.3	29.4	19.4
FISH6	35.6	33.6	30.8	7.8

TABLE I.XX. AREAS OF FOREST LAND AS PERCENT OF THE TOTAL LAND AREA

Subarea	Forest land (%)
POP1	65-79*
POP2	87
POP3	84
POP4	76
POP5	87
POP6	88
POP7	57-72*
POP8	65-66*
POP9	78
Mean	78

* indicates the change from south to north

TABLE I.XXI. PEATLAND AREAS.

Subarea	Peatland (ha)
POP1	29300
POP2	35800
POP3	34800
POP4	35300
POP5	29400
POP6	82600
POP7	83500
POP8	10400
POP9	150000

TABLE I.XXII. SOWING TIMES FOR CEREALS IN 1986.

Production area	Start	End	Percentage of Spring cereals sown by May 20 (%)
AGR1	7.5	28.5	50
AGR2	13.5	4.6	45
AGR3	1-4.5	21.5	95-100
AGR4	4.5	31.5	50
AGR5	6.5	30.5	50
AGR6	15.5	10.6	30
AGR7	12.5	9.6	15
AGR8	14.5	-	15
AGR9	10.5	31.5	55
AGR10	7.5	31.5	60
AGR11	7.5	22.5	95
AGR12	10.5	6.6	35
AGR13	15.5	7.6	15
AGR14	9.5	6.6	50
AGR15	7.5	26.5	80
AGR16	8.5	24.5	80
AGR17	13.5	5.6	30

TABLE I.XXIII. LAND USE ON FARMS BY AGRICULTURAL DISTRICTS ON 31 DECEMBER 1985

Agricultural area	Agricultural and horticultural land under cultivation (ha)	Rough grazing and pasturage area (ha)
AGR1	64027	2742
AGR2	258107	6068
AGR3	28806	5651
AGR4	152237	6094
AGR5	66810	4989
AGR6	67156	1652
AGR7	97587	9079
AGR8	149025	11670
AGR9	85276	2843
AGR10	93949	8961
AGR11	72422	2771
AGR12	105616	7789
AGR13	104498	10569
AGR14	174545	6866
AGR15	132857	4559
AGR16	235663	6114
AGR17	104386	3838
Total	1992967	102255

TABLE I.XXIV. PROPORTIONS OF DIFFERENT SOIL TYPES BY AGRICULTURAL AREAS IN 1981-1985 IN PERCENT (P = PLOUGHED LAYER, S = SUBSOIL)

Agri-cultural area	Layer	Number of samples	SaM	FSaM	SiM	ClM	CoSa	Sa	FSa	FFSa	Si	SaCl	SiCl	HCl	GyCl	Gy	LMud	Mo	CPe	LCPe	SCPe	CSPe	LSPe	SPe
AGR2	P	58338	0.9	9.7	0.0	0.0	0.1	1.6	16.1	23.5	7.9	0.6	0.1	0.1	39.9	1.0	0.0	1.2	0.3	1.9	0.7	0.0	0.1	0.0
AGR2	S	2694	0.9	3.9	0.1	0.0	0.1	1.6	16.1	23.5	7.9	0.6	0.1	0.1	39.9	1.0	0.0	1.2	0.3	1.9	0.7	0.0	0.1	0.0
AGR3	P	8365	0.4	3.9	0.1	0.0	0.1	0.5	10.2	16.7	0.5	26.5	1.4	0.2	35.5	0.1	0.2	3.3	0.0	0.3	0.1	0.0	0.0	0.0
AGR3	S	386	.	2.6	.	0.3	0.5	0.3	3.1	1.3	0.8	22.0	0.5	20.5	46.4	0.8	0.5	0.3	.	0.3	.	.	.	.
AGR4	P	43210	0.4	5.2	0.0	0.0	0.0	0.2	8.4	22.9	14.0	17.0	5.4	1.8	10.6	0.2	0.1	12.6	0.0	0.9	0.2	0.0	0.1	0.0
AGR4	S	2786	0.4	1.8	0.1	0.0	0.0	0.3	3.4	5.3	8.1	20.7	8.8	28.4	17.7	0.4	0.3	2.2	0.0	1.7	0.2	0.0	0.1	0.1
AGR5	P	23779	1.3	14.5	0.2	0.0	0.0	0.3	12.9	31.7	24.0	1.5	0.9	0.0	1.3	0.1	0.1	8.9	0.1	1.9	0.1	0.1	0.1	0.1
AGR5	S	1664	1.0	6.3	0.6	.	0.1	0.6	9.2	19.2	35.5	8.1	8.9	0.4	5.4	0.5	0.2	0.8	0.1	2.6	0.2	.	0.1	0.2
AGR7	P	38024	2.0	23.4	0.1	0.0	0.1	0.6	8.9	22.9	23.9	0.0	0.0	0.0	0.1	0.7	0.1	12.3	0.5	2.7	0.8	0.3	0.3	0.3
AGR7	S	1034	2.0	20.5	0.1	0.1	.	0.6	5.8	18.4	36.3	.	0.3	.	1.3	1.7	0.1	3.2	0.5	7.0	0.7	0.3	0.9	0.4
AGR8	P	51720	2.8	26.4	0.2	0.0	0.1	0.8	9.4	20.8	22.6	0.0	0.0	0.0	0.1	0.9	0.1	11.9	0.2	2.4	0.5	0.1	0.2	0.5
AGR8	S	4453	2.4	20.2	0.4	0.0	0.1	0.7	8.7	19.5	32.2	0.1	0.1	0.0	1.8	2.2	0.1	2.3	0.7	6.2	1.3	0.2	0.4	0.4
AGR1&9	P	54916	0.8	14.8	0.1	0.0	0.0	0.3	9.0	27.0	8.8	11.9	2.3	0.7	8.8	0.4	0.5	11.6	0.1	2.3	0.2	0.1	0.1	0.2
AGR1&9	S	2568	0.5	4.6	0.2	0.0	0.1	0.3	5.1	11.1	10.7	17.2	6.8	15.1	21.6	0.8	0.0	1.2	0.4	3.5	0.3	0.0	0.0	0.3
AGR10	P	45487	5.4	60.5	0.1	0.0	0.0	0.8	8.7	5.4	1.2	0.0	0.0	0.0	0.0	0.1	0.1	8.7	0.2	7.7	0.3	0.1	0.4	0.1
AGR10	S	532	8.5	58.3	0.6	0.2	0.4	0.8	7.5	7.0	8.8	0.2	.	.	.	0.6	.	1.3	0.2	5.5	0.2	.	0.2	.
AGR11	P	37974	0.2	3.7	0.1	0.0	0.0	0.2	5.0	13.0	2.0	20.7	4.3	0.1	44.8	0.1	0.5	5.0	0.1	0.1	0.0	0.0	0.0	0.0
AGR11	S	1973	0.3	1.3	0.2	.	0.1	0.2	2.4	2.8	1.2	12.8	4.6	12.0	60.2	0.3	0.4	0.4	.	0.6	0.2	0.2	.	.
AGR12	P	30539	0.7	6.9	0.1	0.0	0.0	0.2	5.1	24.7	46.5	0.3	1.9	0.0	3.2	0.5	0.1	8.9	0.1	0.4	0.2	0.0	0.1	0.1
AGR12	S	297	0.3	1.7	.	.	.	0.3	3.4	11.8	53.9	0.3	9.4	.	12.5	1.3	0.3	1.0	0.3	3.4	.	.	.	.
AGR13	P	35400	1.4	18.9	0.2	0.0	0.0	0.7	17.9	17.8	23.5	0.0	0.0	0.0	0.0	0.9	0.1	11.4	0.5	4.5	1.1	0.2	0.4	0.4
AGR13	S	357	2.5	17.1	.	.	.	0.6	11.2	16.2	40.1	0.6	.	.	1.7	1.4	.	2.8	0.6	3.4	1.1	.	.	0.8
AGR14	P	38859	1.0	7.9	0.1	0.0	0.1	0.8	12.3	29.9	7.5	3.9	1.7	0.1	15.3	0.7	0.6	15.1	0.3	1.9	0.4	0.1	0.1	0.3
AGR14	S	1159	1.1	3.7	0.2	.	0.3	0.7	3.5	9.5	12.6	10.1	9.1	1.5	38.8	3.0	1.8	2.4	0.1	1.3	0.3	.	0.1	.
AGR15	P	47460	0.1	2.3	0.0	0.0	0.0	0.1	3.6	19.7	12.0	24.8	10.3	1.4	16.8	0.1	0.1	8.1	0.0	0.3	0.0	0.0	0.0	0.0
AGR15	S	4087	0.2	1.1	0.0	0.0	0.0	0.1	1.4	5.4	9.2	19.6	17.4	23.1	19.2	0.2	0.0	1.0	0.0	1.3	0.1	0.0	0.1	0.2
AGR16	P	59078	0.7	5.0	0.1	0.0	0.1	0.3	7.2	15.7	3.0	28.2	4.6	0.6	27.8	0.2	0.2	5.5	0.0	0.7	0.1	0.0	0.2	0.1
AGR16	S	1916	1.1	1.6	0.1	0.1	0.1	0.7	2.9	3.3	2.1	29.9	7.2	26.1	23.1	0.1	0.2	0.8	0.1	0.6	.	.	.	0.1
AGR17	P	19252	0.7	7.4	0.0	0.0	0.1	2.3	26.3	25.7	1.4	0.0	0.0	0.0	7.7	1.0	1.3	19.7	0.6	4.5	0.9	0.0	0.1	0.1
AGR17	S	2581	0.8	4.4	0.2	0.0	0.3	2.0	18.4	25.4	2.7	0.0	0.0	0.0	42.1	1.9	0.2	0.5	0.3	0.7	0.1	0.0	0.0	0.0

Meaning of soil type abbrevations:

Coarse mineral soils
- Gravel moraine = GrM
- Sand moraine = SaM
- Fine sand moraine = FSaM
- Silt moraine = SiM
- Gravel = Gr
- Coarse sand = CoSa
- Sand = Sa
- Fine sand = Fsa
- Finer fine sand = FFSa
- Silt = Si

Clay soils
- Clay moraine = ClM
- Sandy clay = SaCl
- Silty clay = SiCl
- Heavy clay = HCl
- Gyttja clay = GyCl

Organic soils
- Gyttja = Gy
- Lake mud = LMud
- Mould = Mo
- Bryales Carex peat = BCPe
- Carex peat = CPe
- Ligno Carex peat = LCPe
- Sphagnum Carex peat = SCPe
- Carex Sphagnum peat = CSPe
- Ligno Sphagnum peat = LSPe
- Sphagnum peat = SPe

TABLE I.XXV. AVERAGE ACIDITY BY AGRICULTURAL AREAS IN PLOUGHED LAYER

Agricultural area	pH
AGR1	5.85
AGR2	5.70
AGR3	6.14
AGR4	5.95
AGR5	5.91
AGR6	5.66
AGR7	5.84
AGR8	5.81
AGR9	5.81
AGR10	5.90
AGR11	5.94
AGR12	5.94
AGR13	5.80
AGR14	5.88
AGR15	5.93
AGR16	6.06
AGR17	5.53

TABLE I.XXVI. AVERAGE ACIDITY OF DIFFERENT SOILS

Soil type	pH	
	Ploughed layer	Subsoil
Sand moraine	5.91	5.91
Fine sand moraine	5.94	5.93
Silt moraine	5.92	5.87
Clay moraine	5.69	5.86
Coarse sand	5.76	5.79
Sand	5.79	5.83
Fine sand	5.89	5.76
Finer fine sand	5.91	5.69
Silt	5.94	6.01
Sandy clay	6.12	6.23
Silty clay	6.06	6.30
Heavy clay	6.08	6.33
Gyttja clay	5.87	5.44
Gyttja	5.46	5.07
Lake mud	5.30	5.05
Mould	5.44	5.37
Carex peat	5.26	5.16
Ligno Carex peat	5.24	5.15
Sphagnum Carex peat	5.23	4.98
Crex Sphagnum peat	5.12	5.02
Lingo Sphagnum peat	5.15	4.84
Sphagnum peat	5.05	4.91

TABLE I.XXVII. AVERAGE YIELD PER COW IN 1986

Agricultural area	Yield/cow (L)
AGR1	4929
AGR2	4658
AGR3	5056
AGR4	4967
AGR5	4945
AGR6	5236
AGR7	5076
AGR8	4985
AGR9	4774
AGR10	5138
AGR11	4516
AGR12	4919
AGR13	5038
AGR14	4622
AGR15	4910
AGR16	4946
AGR17	4721

Average yield per cow in 1986: 4935 L a^{-1}
Dairy cows in 1986: 500700

TABLE I.XXVIII. AVERAGE MONTHLY MILK YIELD IN 1986

Month	Percentage of annual yield (%)
January	7.7
February	6.8
March	7.6
April	8.2
May	9.5
June	10.0
July	9.8
August	9.5
September	8.1
October	7.6
November	7.5
December	7.7

TABLE I.XXIX. YIELDS OF HAY AND SILAGE IN 1986

Agricultural area	Yield (million kg) Hay	Silage
AGR1	52.4	113.4
AGR2	175.7	541.0
AGR3	10.0	11.3
AGR4	71.7	169.6
AGR5	43.3	106.3
AGR6	62.3	421.9
AGR7	101.0	261.5
AGR8	115.8	673.8
AGR9	62.4	111.3
AGR10	83.5	379.2
AGR11	22.1	30.2
AGR12	88.4	168.9
AGR13	102.9	384.8
AGR14	91.5	127.3
AGR15	57.1	119.4
AGR16	53.8	87.2
AGR17	65.4	112.7
Total	1259.3	3819.8

TABLE I.XXX. YIELDS PER HECTARE OF HAY AND SILAGE IN 1986

Agricultural area	Yield (100 kg ha^{-1}) Hay	Silage
AGR1	40.6	257.8
AGR2	42.8	231.2
AGR3	50.0	188.9
AGR4	42.7	257.0
AGR5	42.9	204.4
AGR6	41.8	230.5
AGR7	40.1	205.9
AGR8	39.0	207.3
AGR9	39.7	227.1
AGR10	38.6	251.2
AGR11	42.6	251.5
AGR12	40.4	216.5
AGR13	38.6	211.5
AGR14	40.7	212.2
AGR15	40.2	234.0
AGR16	44.1	256.5
AGR17	44.2	225.5

TABLE I.XXXI. FEED UTILIZATION OF DAIRY COWS BY THE TYPE OF FEED IN 1988

Agric. area	Feed utilization (kg) Silage	Hay	Pasture	Feed grain	Complete feed	Concen-trate	Others
AGR1	5657.4	1240.8	6370.0	1312.3	210.1	226.6	711.2
AGR2	7188.3	882.2	6123.0	938.3	552.2	187.0	604.8
AGR3	6615.0	1322.2	3900.0	1118.7	833.8	319.0	1080.8
AGR4	5770.8	1276.0	5791.5	1294.7	292.6	259.6	968.8
AGR5	6375.6	1018.6	6526.0	1133.0	342.1	192.5	1024.8
AGR6	7515.9	827.2	5453.5	866.8	814.0	191.4	459.2
AGR7	6835.5	1080.2	6389.5	779.9	690.8	170.5	397.6
AGR8	8246.7	869.0	6513.0	830.5	570.9	203.5	229.6
AGR9	5241.6	1425.6	5908.5	1277.1	206.8	202.4	481.6
AGR10	6967.8	1007.6	6448.0	964.7	497.2	172.7	403.2
AGR11	5550.3	1533.4	4504.5	1665.4	139.7	244.2	392.0
AGR12	6161.4	1216.6	6272.5	1229.8	325.6	221.1	492.8
AGR13	6923.7	1104.4	6363.5	995.5	438.9	199.1	308.0
AGR14	5707.8	1262.8	6181.5	990.0	514.8	166.1	509.6
AGR15	5663.7	1331.0	5408.0	1501.5	206.8	221.1	610.4
AGR16	4775.4	1460.8	5304.0	1375.0	264.0	300.3	873.6
AGR17	6463.8	1311.2	3672.5	1221.0	570.9	272.8	548.8

TABLE I.XXXII. FEED UTILIZATION OF BEEF CATTLE BY THE TYPE OF FEED IN 1988

Agric. area	Feed Utilization of beef cattle (kg) Silage	Hay	Pasture	Feed grain	Complete feed	Concen-trate	Others
AGR1	1474.2	847.0	1209.0	1008.7	78.1	41.8	196.0
AGR2	2154.6	466.4	2853.5	727.1	146.3	33.0	520.8
AGR3	812.7	761.2	604.5	1057.1	198.0	62.7	778.4
AGR4	1864.8	822.8	1326.0	903.1	86.9	69.3	442.4
AGR5	1474.2	686.4	2359.5	919.6	103.4	55.0	347.2
AGR6	2627.1	517.0	1904.5	689.7	215.6	49.5	280.0
AGR7	2186.1	596.2	2788.5	706.2	161.7	33.0	95.2
AGR8	2916.9	591.8	2379.0	612.7	209.0	36.3	67.2
AGR9	1083.6	946.0	1079.0	1049.4	47.3	61.6	224.0
AGR10	1997.1	600.6	2411.5	716.1	177.1	35.2	168.0
AGR11	.	.	.	.	.	.	.
AGR12	1354.5	891.0	1339.0	937.2	92.4	67.1	212.8
AGR13	1927.8	699.6	2411.5	751.3	154.0	47.3	168.0
AGR14	1436.4	776.6	1612.0	882.2	183.7	40.7	291.2
AGR15	1430.1	908.6	1527.5	1050.5	23.1	84.7	179.2
AGR16	1266.3	772.2	1547.0	1003.2	71.5	83.6	425.6
AGR17	1222.2	576.4	2067.0	875.6	94.6	88.0	.

TABLE I.XXXIII. FEED UTILIZATION OF HEIFERS BY THE TYPE OF FEED IN 1988

Agric. area	Feed Utilization of heifers (kg)						
	Silage	Hay	Pasture	Feed grain	Complete feed	Concen-trate	Others
AGR1	1820.7	710.6	2151.5	337.7	20.9	20.9	184.8
AGR2	2305.8	490.6	2392.0	281.6	64.9	14.3	263.2
AGR3	730.8	840.4	2606.5	356.4	29.7	18.7	229.6
AGR4	1707.3	721.6	2138.5	349.8	27.5	17.6	280.0
AGR5	1575.0	607.2	2931.5	269.5	36.3	17.6	240.8
AGR6	2639.7	497.2	1976.0	267.3	101.2	18.7	162.4
AGR7	2242.8	609.4	2424.5	225.5	84.7	15.4	84.0
AGR8	2759.4	547.8	2457.0	214.5	67.1	9.9	44.8
AGR9	1474.2	787.6	2164.5	374.0	25.3	14.3	145.6
AGR10	2236.5	600.6	2463.5	246.4	56.1	11.0	151.2
AGR11	176.4	1306.8	2301.0	323.4	5.5	9.9	.
AGR12	1581.3	796.4	2294.5	330.0	37.4	18.7	106.4
AGR13	2053.8	715.0	2340.0	256.3	57.2	25.3	78.4
AGR14	1738.8	730.4	2164.5	304.7	77.0	23.1	201.6
AGR15	1411.2	783.2	2190.5	396.0	17.6	16.5	156.8
AGR16	1486.8	719.4	1826.5	420.2	41.8	36.3	364.0
AGR17	1858.5	761.2	65.0	678.7	223.3	.	235.2

TABLE I.XXXIV. YIELDS OF CEREAL GRAINS AND POTATOES IN 1986

Agric. area	Yield (million kg)					
	Winter wheat	Spring wheat	Rye	Barley	Oats	Potatoes
AGR1	.	6.	1.3	41.5	42.1	15.5
AGR2	0.3	8.6	6.2	215.7	206.6	215.2
AGR3	3.6	28.4	2.5	16.3	11.7	10.7
AGR4	4.4	40.3	5.8	126.2	96.9	46.8
AGR5	0.3	11.5	2.1	50.2	40.7	17.0
AGR6	.	.	1.1	57.4	17.9	44.9
AGR7	0.2	1.0	2.5	51.9	51.1	19.8
AGR8	.	2.0	3.0	88.1	37.3	20.9
AGR9	1.0	13.7	2.2	47.1	47.5	12.2
AGR10	.	4.4	3.2	43.5	47.5	65.1
AGR11	2.2	68.1	9.2	71.8	31.5	7.2
AGR12	2.7	6.5	3.5	65.1	59.3	15.2
AGR13	.	2.1	1.8	53.5	41.2	11.2
AGR14	5.6	29.1	5.6	136.3	141.2	85.9
AGR15	2.5	62.0	3.9	120.8	65.6	8.9
AGR16	32.5	177.9	13.3	251.1	106.4	38.4
AGR17	.	11.0	1.4	124.5	82.3	54.1
Total	55.3	473.5	68.6	1561.0	1126.8	689.0

TABLE I.XXXV. PRODUCTION OF MILK AND MEAT IN 1986

Agric. area	Production of milk (million L)	Production of meat (million kg)					
		Beef	Veal	Pork	Mutton	Poultry	Horse
AGR1	104.0	3.14	0.00	5.40	0.02	0.00	.
AGR2	325.6	16.83	0.12	25.50	0.11	4.12	0.11
AGR3	18.2	0.62	0.00	0.21	0.05	0.00	.
AGR4	134.6	2.25	0.00	3.59	0.00	0.00	.
AGR5	89.5	2.86	0.00	5.28	0.03	0.01	0.02
AGR6	182.2	7.25	0.00	5.53	0.01	0.00	0.06
AGR7	159.4	6.30	0.01	3.93	0.07	0.00	0.09
AGR8	359.4	10.60	0.09	5.93	0.07	0.00	0.10
AGR9	118.4	3.72	0.06	5.86	0.02	0.00	0.01
AGR10	193.2	8.30	0.06	4.66	0.11	0.00	0.08
AGR11	28.0	3.32	0.00	3.42	0.05	0.00	0.12
AGR12	115.1	8.73	0.04	0.59	0.12	3.59	0.06
AGR13	215.1	6.35	0.01	2.24	0.09	0.01	0.03
AGR14	127.1	1.55	0.01	17.80	0.00	9.33	0.01
AGR15	98.2	0.02	0.00	0.02	0.00	0.00	.
AGR16	91.5	14.85	0.08	67.71	0.17	4.99	0.11
AGR17	89.7	6.52	0.01	9.87	0.08	0.01	.
Total	2449.2	103.21	0.49	167.54	1.00	22.06	0.80

TABLE I.XXXVI. YIELDS PER HECTARE OF CEREAL GRAINS AND POTATOES IN 1986

Agric. area	Yield (100 kg ha^{-1})					
	Winter wheat	Spring wheat	Rye	Barley	Oats	Potatoes
AGR1	.	23.7	25.7	26.9	27.7	154.8
AGR2	32.4	33.1	24.9	29.8	30.0	239.1
AGR3	35.7	32.6	31.7	34.6	31.5	152.8
AGR4	33.9	29.9	27.8	29.3	30.0	222.9
AGR5	33.7	29.5	23.7	28.5	27.9	189.4
AGR6	20.0	30.3	21.0	29.3	28.5	187.1
AGR7	15.0	24.9	24.8	26.6	27.5	152.5
AGR8	26.1	28.2	23.2	25.6	25.4	160.8
AGR9	31.9	24.5	24.3	23.8	24.5	174.2
AGR10	33.8	29.5	23.1	27.4	28.8	210.1
AGR11	36.6	36.6	31.6	35.2	31.2	180.8
AGR12	34.1	24.9	23.4	26.8	26.0	138.1
AGR13	.	29.3	21.9	27.6	27.0	159.4
AGR14	39.7	30.7	29.7	30.2	30.6	209.5
AGR15	31.5	29.8	24.1	29.9	30.0	147.8
AGR16	37.0	32.3	29.0	31.8	31.8	153.6
AGR17	.	32.5	28.4	30.0	31.0	216.5

TABLE I.XXXVII. YIELDS OF VEGETABLES BY AGRICULTURAL AREAS IN 1986.

Agric. area	Yield (100 kg) Garden pea	Carrot	White cabbage	Onion	Beet-root	Chinese cabbage	Swede
AGR1	133.4	9399	7116.2	1303.6	322	1249.7	3226.3
AGR2	0.0	9825	6011.4	6603.4	272	1064.7	1697.4
AGR3	42.0	1485	33.0	34291.6	504	26435.9	1442.8
AGR4	22221.1	103388	10468.8	5089.3	3519	36.2	5552.8
AGR5	133.3	6602	2278.6	1279.2	387	30.0	1798.0
AGR6	0.0	1989	1026.5	116.7	292	0.0	966.6
AGR7	124.3	1991	4894.6	952.2	111	201.9	2907.2
AGR8	42.2	4022	1711.4	1640.0	363	5053.8	6317.0
AGR9	152.6	5418	8627.2	799.3	2143	1831.3	5470.7
AGR10	153.7	49266	16691.3	7404.5	351	26184.5	2508.5
AGR11	559.9	10235	1545.5	308.9	255	231.7	891.3
AGR12	143.0	1387	25638.6	830.0	6195	309.1	3345.0
AGR13	18.0	8023	6836.4	5115.6	235	3143.1	3480.3
AGR14	33433.0	103226	20878.5	12348.4	109691	580.8	31318.8
AGR15	6864.3	5569	57262.8	562.0	2476	2624.4	17298.4
AGR16	9447.5	47008	33335.0	14487.7	11613	1965.0	23591.5
AGR17	17.6	6120	17060.0	134.7	262	2618.4	969.1

TABLE I.XXXVIII. YIELDS OF APPLES AND BERRIES BY AGRICULTURAL AREAS IN 1986

Agric. area	Yield (100 kg) Apple	Black currant	Red currant	Goose-berry	Rasp-berry	Straw-berry
AGR1	249.2	243.1	511.5	72.4	293.9	6016.6
AGR2	29.8	383.0	15.8	3.5	10.6	676.8
AGR3	20090.1	297.5	51.3	0.0	45.1	779.2
AGR4	218.1	447.0	144.2	5.6	47.5	2358.2
AGR5	45.3	310.4	82.7	3.0	81.7	4347.0
AGR6	.	194.8	.	.	.	941.1
AGR7	105.1	2795.0	972.6	31.9	124.0	5466.1
AGR8	92.8	4825.3	532.0	22.0	406.1	64195.6
AGR9	191.7	249.2	91.7	5.5	8.6	5519.3
AGR10	429.1	4601.9	3978.3	186.5	411.4	13556.3
AGR11	2735.7	174.6	127.7	0.4	52.2	1808.7
AGR12	175.7	2042.9	915.7	12.0	137.6	2364.1
AGR13	44.9	3738.7	773.8	75.0	359.3	5140.8
AGR14	67.8	376.8	46.6	40.2	4.6	1182.2
AGR15	3242.9	173.2	55.9	16.8	23.3	3181.1
AGR16	5827.2	618.1	436.8	12.7	223.6	11435.6
AGR17	1.2	1922.3	10.4	7.0	43.3	398.6

TABLE I.XXXIX. YIELDS PER HECTARE OF VEGETABLES GROWN IN THE OPEN IN 1986

Agric. area	Yield ($100kg\ ha^{-1}$) Pea	Carrot	White cabbage	Onion	Gherkin	Red beet	Chinese cabbage	Swede	Cauliflower	Leek	Bean
AGR1	29.0	318.6	221.0	141.7	187.3	179.0	101.6	250.1	98.1	154.7	38.9
AGR2	66.6	267.7	349.5	141.4	.	136.2	247.6	188.6	105.1	141.1	.
AGR3	24.7	200.7	110.0	227.7	172.2	209.9	148.1	327.9	114.0	190.5	103.0
AGR4	58.6	371.9	290.8	113.6	122.1	225.6	181.2	315.5	102.7	169.0	19.2
AGR5	31.0	262.0	474.7	104.0	138.4	184.3	150.0	246.3	76.8	161.5	70.0
AGR6	0.0	160.4	197.4	233.3	.	138.8	.	292.9	75.8	80.0	.
AGR7	33.6	201.1	453.2	68.5	176.6	158.5	201.9	252.8	68.8	120.0	20.0
AGR8	11.4	177.2	237.7	100.0	98.4	157.7	216.9	233.1	159.4	126.9	.
AGR9	31.8	258.0	337.0	121.1	118.5	208.1	292.6	362.3	182.6	93.9	61.5
AGR10	32.7	333.1	286.3	125.5	372.7	206.4	230.7	238.9	94.0	113.1	67.5
AGR11	21.7	437.4	309.1	79.2	142.6	170.2	144.8	270.1	97.4	150.6	103.1
AGR12	28.6	203.9	349.3	143.1	82.1	160.9	110.4	200.3	110.4	110.8	53.0
AGR13	7.2	253.9	377.7	147.0	250.3	167.5	200.2	386.7	118.2	143.6	.
AGR14	60.6	376.6	380.3	151.7	223.5	310.3	145.2	385.7	141.0	155.7	65.8
AGR15	52.2	311.1	280.7	98.6	67.8	208.1	127.4	308.9	134.1	137.4	45.5
AGR16	32.6	273.3	342.6	144.3	189.0	351.9	162.4	304.8	113.3	260.0	89.2
AGR17	44.1	229.2	331.9	103.6	240.0	262.3	185.7	206.2	147.8	150.8	100.0

TABLE I.XL. YIELDS OF VEGETABLES GROWN IN GREENHOUSES IN 1986

Agric. area	Yield (kg m^{-2})			
	Tomato	Cucumber	Head lettuce	Gherkin
AGR1	10.2	19.5	2.7	6.5
AGR2	21.0	31.7	2.5	5.4
AGR3	24.2	31.2	3.6	8.1
AGR4	14.3	26.5	2.1	5.9
AGR5	10.7	17.3	3.0	6.1
AGR6	21.7	35.6	10.4	2.4
AGR7	16.1	32.2	3.6	6.3
AGR8	16.2	25.1	2.9	5.4
AGR9	15.2	31.9	3.2	10.1
AGR10	14.8	24.0	2.6	5.2
AGR11	9.5	16.3	2.9	3.9
AGR12	10.5	26.4	2.1	5.3
AGR13	24.3	22.3	3.6	4.6
AGR14	20.3	32.3	2.5	4.1
AGR15	13.3	34.9	3.2	5.0
AGR16	19.1	31.2	3.4	7.6
AGR17	25.1	33.2	1.8	3.1

TABLE I.XLI. CONTRIBUTIONS TO CONSUMED AMOUNTS OF IMPORTED FOODSTUFFS BY COUNTRIES OF ORIGIN

Foodstuff	Country of origin	Contribution to consumption (%)
Leafy vegetables, root vegetables and fruit vegetables		
generally	Spain	14
	Netherlands	5
in 1987/88*	Spain	8
	Netherlands	24
	Sweden	2
	Other European countries	5
Potato		
generally		<1
in 1987/88*	Netherlands	13
Fruit (apples and pears)		
	Central European countries	17
Grain (rye)		
in 1987	USSR	33
in 1988	Germany	25
	USSR	17

* harvest year

TABLE I.XLII. RELATIVE CONTRIBUTION TO THE ANNUAL GAME BAG

Population area	Contribution to the annual game bag (%)
POP1	14.2
POP2	9.4
POP3	9.4
POP4	7.2
POP5	8.9
POP6	7.7
POP7	16.8
POP8	6.2
POP9	20.1

TABLE I.XLIII. ^{137}Cs CONTENT IN FISH OTHER THAN FRESHWATER FISH

Quarter	^{137}Cs content (Bq kg^{-1})
2/86	7
3/86	40
4/86	40
1/87	40
2/87	50
3/87	60
4/87	50
1/88	40
2/88	40
3/88	40
4/88	40
1/89	40
2/89	40
3/89	30
4/89	30
1/90	30
2/90	30
3/90	30
4/90	30

TABLE I.XLIV. POPULATION IN 1985 BY DWELLING TYPES AND BY INDUSTRIAL STRUCTURE (PORTION OF URBAN POPULATION BY TEN PERCENT ACCURACY)

Population area		Industrial structure				Inhabitants living in	
	Degree of urbanization (%)	Econ. active pop. (%)	Agricult. forestry hunting (%)	Industry (%)	Services (%)	Small houses (%)	Blocks of flats (%)
POP1	70-80	46.7	6.1	37.1	48.2	57.1	42.9
POP2	60-70	43.6	10.8	29.0	49.9	71.1	28.9
POP3	60-70	42.9	13.8	25.5	50.0	69.2	30.8
POP4	70-80	45.3	8.1	32.9	49.1	69.1	30.9
POP5	50-60	43.8	15.6	27.8	46.9	73.2	26.8
POP6	50-60	42.1	14.9	24.1	49.3	79.9	20.1
POP7	60-70	45.9	8.1	36.1	47.3	67.0	33.0
POP8	80-90	51.1	1.9	27.0	65.3	41.9	58.1
POP9	50-60	42.1	15.3	30.7	45.9	82.6	17.4

TABLE I.XLV. NUMBER AND PERCENTAGE OF SUMMER COTTAGES AND OTHER RESIDENTIAL BUILDINGS FOR RECREATIONAL USE IN 1989

Population area	Summer cottages Number	Percentage of total (%)
POP1	50765	16.7
POP2	23018	7.6
POP3	21661	7.1
POP4	30147	9.9
POP5	39591	13.0
POP6	16774	5.5
POP7	59809	19.7
POP8	36642	12.1
POP9	25588	8.4
Total	303995	100.0

TABLE I.XLVI. AVERAGE TIME PER DAY SPENT OUTDOORS BY INDIVIDUALS OF OVER 10 YEARS AGE DURING APRIL 1, 1987 TO MARCH 31, 1988

Activity	Average time per day (min)
Walk and life outdoors	13
Hunting	1
Fishing	3
Picking berries	1
Picking mushrooms	<0.5
Jogging, running	2
Cycling	2
Skiing	2
Passive staying outdoor	3
Total	28

TABLE I.XLVII. AGE DISTRIBUTION OF POPULATION ON 31 DECEMBER 1986 BY 5-YEAR INTERVALS

Age group	Women (%)	Men (%)
0-4	6.188	6.891
5-9	6.191	6.877
10-14	5.924	6.634
15-19	6.416	7.108
20-24	7.218	8.002
25-29	7.254	8.099
30-34	7.772	8.676
35-39	8.332	9.418
40-44	6.648	7.410
45-49	5.874	6.311
50-54	5.167	5.379
55-59	5.521	5.402
60-64	5.412	4.534
65-69	4.739	3.303
70-74	4.298	2.650
75-79	3.620	1.939
80-84	2.158	0.938
85-89	0.963	0.340
90-94	0.261	0.077
95-	0.045	0.010

TABLE I.XLVIII. POPULATION DISTRIBUTION BY SEX AND AGE ON 31 DECEMBER 1986

Population area	Total	Population Females	Males	Age distribution (%) 0-14	15-64	65-
POP1	680091	354489	325602	18.3	68.0	13.7
POP2	247995	126051	121944	19.6	67.4	12.9
POP3	256213	131004	125209	19.5	67.5	13.0
POP4	338983	173804	165179	17.7	68.2	14.2
POP5	208726	106750	101976	18.0	67.5	14.5
POP6	177288	89739	87549	19.3	67.2	13.5
POP7	713896	369768	344128	18.5	67.2	14.3
POP8	1200485	632929	567556	18.7	70.0	11.3
POP9	444777	226939	217838	21.0	64.9	14.1

TABLE I.XLIX. CONSUMPTION RATES FOR ADULTS

Foodstuff	Consumption ($g\ d^{-1}$) Average	Women	Men
Milk	720	570	870
Cheese	34	33	35
Beef	56	49	64
Pork	71	54	88
Poultry meat	16	16	16
Game meat	3.8	3.4	4.2
Freshwater fish	12	10	15
Seafish	39	31	47
Egg	30	25	34
Rye	50	42	58
Wheat	122	109	135
Other cereals	33	28	38
Potatoes	180	150	210
Fruit vegetables	44	48	40
Leafy vegetables	40	45	35
Root vegetables	50		50
Pea and bean	10	10	10
Fruit*	250	275	225
Garden berries	43	43	43
Wild berries	9	9	9
Wild mushrooms	3.6	3.6	3.6

* Non-berry fruit

TABLE I.L. MEAN DAILY INTAKE OF FOODS BY DIFFERENT AGE GROUPS OF BOYS AND GIRLS (STANDARD DEVIATIONS OF THE MEANS ARE GIVEN IN PARENTHESES)

Foodstuff	Mean daily intake (g)					
	9-year-olds		12-year-olds		15-year-olds	
	boys	girls	boys	girls	boys	girls
Milk and milk products	726 (330)	704 (313)	820 (380)	712 (321)	945 (460)	605 (322)
Cereal products	146 (74)	125 (67)	203 (159)	150 (88)	225 (122)	158 (101)
Potato	130 (121)	115 (93)	114 (148)	117 (98)	211 (199)	128 (166)
Vegetables	83 (114)	94 (99)	95 (91)	98 (135)	104 (113)	117 (194)
Fruit and berries	183 (258)	231 (190)	220 (242)	268 (232)	211 (235)	239 (185)
Fats	41 (22)	38 (19)	55 (35)	43 (29)	66 (39)	44 (27)
Meat and meat products	112 (97)	98 (70)	143 (137)	92 (72)	186 (169)	119 (134)
Fish and fish products	16 (28)	18 (30)	24 (58)	8 (8)	9 (20)	7 (14)
Eggs	18 (23)	16 (20)	21 (25)	28 (18)	23 (30)	20 (26)
Beverages, sugar etc.	211 (230)	166 (192)	249 (254)	168 (176)	381 (302)	308 (242)

TABLE I.LI. ^{137}Cs CONCENTRATIONS IN ANIMAL FEED (Bq kg^{-1})
(N = Number of measurements)

Time period	Mean	95% confidence interval Lower bound	Upper bound	N
Pasture vegetation[a]				
May 1986	1500	1000	2300	99
Jul 1986	40	10	200	33
Jul 1987	20	10	200	≥3
Jul 1988	10	5	100	4
Jul 1989	4	2	40	≥5
Jul 1990	2	1	20	3
Barley				
Harvest 1986	3.7	2.2	7.0	16
Harvest 1987	0.7	0.5	1.1	15
Harvest 1988	0.7	0.6	0.9	15
Harvest 1989	1.5	1.1	2.1	13
Harvest 1990	-	-	-	-
Oats				
Harvest 1986	8.7	4.4	17.4	12
Harvest 1987	1.7	1.2	2.4	15
Harvest 1988	3.4	2.7	4.4	15
Harvest 1989	5.4	4.3	7.0	13
Harvest 1990	-	-	-	-

[a]) Means are for fine mineral soils with considerable clay fraction, and do not represent the whole territory of S. The confidence intervals include the real mean for S.

TABLE I.LII. ^{137}Cs CONCENTRATIONS IN LEAFY VEGETABLES (Bq kg^{-1})
(N = Number of measurements)

The year of production	Mean	95% confidence interval Lower bound	Upper bound	N
1986	3.3	1.4	8.9	52
1987	2.5	1.4	6.7	30
1988	1.2	0.6	4.4	15
1989	2.7	1.0	3.7	36
1990	0.5	0.2	1.6	26

TABLE I.LIII. ^{137}Cs CONCENTRATIONS IN FRESHWATER FISH (Bq kg^{-1})
(N = Number of measurements)

Time period	Mean	95% confidence interval Lower bound	 Upper bound	N
1986 (2nd half)	940	750	1500	469
1987	1580	1420	2050	1396
1988	1020	920	1330	796
1989	760	680	990	826
1990	630	570	1010	658

TABLE I.LIV. ^{137}Cs CONCENTRATIONS IN GAME MEAT (Bq kg^{-1})
(N = Number of measurements)

The year of hunting	Mean	95% confidence interval Lower bound	 Upper bound	N
Small Game				
1986	220	150	360	97
1987	-	-	-	-
1988	250	170	420	39
1989	230	160	380	53
1990	220	150	340	57
Big Game (Includes also deers)				
1986	250	230	310	255
1987	210	200	270	47
1988	270	250	330	125
1989	250	240	310	167
1990	220	210	290	101

TABLE I.LV. ^{137}Cs CONCENTRATIONS IN WILD BERRIES (Bq kg^{-1})
(N = Number of measurements)

Year of harvest	Mean	95% confidence interval		N
		Lower bound	Upper bound	
1986	110	80	160	122
1987	90	60	150	43
1988	150	100	250	72
1989	130	90	220	47
1990	120	80	220	64

TABLE I.LVI. ^{137}Cs CONCENTRATIONS IN WILD, EDIBLE MUSHROOMS (Bq kg^{-1})
(N = Number of measurements)

Year of harvest	Mean	95% confidence interval		N
		Lower bound	Upper bound	
1986	330	230	550	176
1987	370	130	910	78
1988	460	270	840	135
1989	670	360	1500	44
1990	510	360	1000	63

TABLE I.LVII. ^{137}Cs CONCENTRATIONS IN MILK (Bq L^{-1})
(N = Number of measurements)

Time period		Mean	95% confidence interval Lower bound	Upper bound	N (whole year)
May	1986	1.9	1.5	2.3	440
Jun	1986	27.7	24.9	30.5	440
Jul	1986	26.4	24.0	28.8	440
Aug	1986	21.3	19.4	23.2	440
Sep	1986	20.3	18.5	22.1	440
IV	1986	30.1	28.3	31.9	440
I	1987	32.7	31.1	35.0	298
II	1987	27.5	25.9	29.4	298
III	1987	14.4	13.7	15.3	298
IV	1987	13.8	13.1	14.8	298
I	1988	13.1	12.3	14.0	277
II	1988	12.1	11.4	12.9	277
III	1988	8.0	7.6	8.5	277
IV	1988	8.4	8.0	9.0	277
I	1989	8.2	7.7	8.8	212
II	1989	7.3	6.9	7.8	212
III	1989	4.9	4.7	5.2	212
IV	1989	4.7	4.4	5.0	212
I	1990	4.2	3.9	4.5	200
II	1990	3.8	3.6	4.1	200
III	1990	3.2	3.0	3.4	200
IV	1990	2.9	2.7	3.1	200

TABLE I.LVIII. ^{137}Cs CONCENTRATIONS IN BEEF (Bq kg^{-1})
(N = Number of measurements)

Time period		Mean	95% confidence interval		N
			Lower bound	Upper bound	(whole year)
May	1986	9.2	6.2	13	94
Jun	1986	41	33	50	94
Jul	1986	97	80	116	94
Aug	1986	106	88	125	94
Sep	1986	100	80	121	94
IV	1986	126	105	147	94
I	1987	134	117	154	124
II	1987	120	106	134	124
III	1987	69	61	78	124
IV	1987	58	50	67	124
I	1988	57	48	66	117
II	1988	59	51	67	117
III	1988	39	34	44	117
IV	1988	33	29	37	117
I	1989	45	38	52	78
II	1989	34	29	39	78
III	1989	24	21	28	78
IV	1989	20	17	23	78
I	1990	21	18	24	57
II	1990	17	14	20	57
II	1990	13	11	15	57
IV	1990	12	10	14	57

TABLE I.LIX. ^{137}Cs CONCENTRATIONS IN PORK (Bq kg^{-1})
(N = Number of measurements)

Time period		Mean	95% confidence interval Lower bound	Upper bound	N (whole year)
May	1986	0.8	0.4	1.2	20
Jun	1986	3.4	1.4	7.8	20
Jul	1986	6.6	2.6	17	20
Aug	1986	6.2	4.3	8.7	20
Sep	1986	8.1	5.7	11	20
IV	1986	9.1	5.5	15	20
I	1987	15.0	12	20	37
II	1987	13.0	12	16	37
III	1987	13.0	12	16	37
IV	1987	8.7	7.8	10	37
I	1988	6.5	5.2	7.8	48
II	1988	6.2	5.0	8.1	48
III	1988	6.1	4.3	8.5	48
IV	1988	5.7	4.6	7.4	48
I	1989	5.9	4.7	7.7	29
II	1989	6.0	4.2	7.8	29
III	1989	5.6	4.5	7.3	29
IV	1989	7.2	5.8	8.6	29
I	1990	6.7	6.0	8.0	23
II	1990	6.8	5.4	8.2	23
III	1990	6.5	3.9	10	23
IV	1990	6.5	5.2	8.5	23

TABLE I.LX. ^{137}Cs CONCENTRATIONS IN CEREALS (Bq kg^{-1})
(N = Number of measurements)

The year of harvest	Mean	95% confidence interval Lower bound	Upper bound	N
Wheat				
Harvest 1986	4.9	3.4	7.4	47
Harvest 1987	0.53	0.37	0.74	23
Harvest 1988	0.57	0.40	0.80	11
Harvest 1989	0.40	0.32	0.60	16
Harvest 1990	0.26	0.18	0.39	13
Rye				
Harvest 1986	28	14	45	96
Harvest 1987	2.8	2.0	3.4	12
Harvest 1988	3.5	2.5	4.6	16
Harvest 1989	1.0	0.8	1.4	17
Harvest 1990	1.0	0.7	1.4	10

TABLE I.LXI. HUMAN ^{137}Cs INTAKE (Bq d^{-1})

Time period		Mean	95% confidence interval Lower bound	Upper bound
Man				
June	1986	35	31	39
IV	1986	47	45	51
II	1987	52	49	57
IV	1987	30	28	34
II	1988	39	37	46
IV	1988	22	20	25
II	1989	26	24	30
IV	1989	16	15	20
II	1990	17	16	23
IV	1990	13	12	16
Woman				
June	1986	25	22	28
IV	1986	33	31	36
II	1987	37	35	41
IV	1987	21	20	24
II	1988	26	24	30
IV	1988	15	14	17
II	1989	18	17	21
IV	1989	12	11	15
II	1990	12	11	16
IV	1990	9.5	8.6	12
Child				
June	1986	25	23	28
IV	1986	32	30	34
II	1987	33	31	35
IV	1987	18	17	20
II	1988	19	18	21
IV	1988	13	12	14
II	1989	12	11	13
IV	1989	9.8	9.1	12
II	1990	6.7	6.4	7.6
IV	1990	7.5	7.1	8.9

TABLE I.LXII. MEAN BODY CONTENT OF ^{137}Cs (Bq kg^{-1})
(N = Number of measurements)

Time period	Mean	95% confidence interval Lower bound	Upper bound	N[a]
Man				
Jul. 01, 1986	7.2	5.8	8.9	49
Dec. 31, 1986	41.1	33.0	51.1	49
Jul. 01, 1987	50.4	44.2	57.4	63
Dec. 31, 1987	41.6	36.5	47.3	63
Jul. 01, 1988	30.1	26.3	34.4	70
Dec. 31, 1988	25.9	22.6	29.7	70
Jul. 01, 1989	25.8	21.3	31.3	52
Dec. 31, 1989	22.2	18.3	26.9	52
Jul. 01, 1990	18.0	15.7	20.7	123
Dec. 31, 1990	18.1	15.8	20.8	123
Woman				
Jul. 01, 1986	4.7	4.0	5.6	46
Dec. 31, 1986	27.1	22.8	32.3	46
Jul. 01, 1987	36.7	31.2	43.2	60
Dec. 31, 1987	30.3	25.8	35.7	60
Jul. 01, 1988	19.8	17.5	22.4	83
Dec. 31, 1988	17.1	15.1	19.3	83
Jul. 01, 1989	16.8	14.0	20.1	53
Dec. 31, 1989	14.4	12.0	17.3	53
Jul. 01, 1990	10.7	9.5	12.2	117
Dec. 31, 1990	10.8	9.5	12.3	117
Child				
Jul. 01, 1986	7.0	5.4	9.1	24
Dec. 31, 1986	40.2	31.1	52.1	24
Jul. 01, 1987	34.1	26.1	44.5	17
Dec. 31, 1987	28.1	21.5	36.7	17
Jul. 01, 1988	18.8	14.9	23.6	27
Dec. 31, 1988	16.2	12.9	20.3	27
Jul. 01, 1989	12.6	10.1	15.8	26
Dec. 31, 1989	10.8	8.7	13.5	26
Jul. 01, 1990	9.2	6.8	12.4	35
Dec. 31, 1990	9.3	6.9	12.5	35

[a] The subjects were measured once a year. The same data were used for estimating both the July 1 and December 31 concentrations.

TABLE I.LXIII. STATISTICAL DISTRIBUTION OF BODY CONTENT

Man	Fractile (%)	Body content (Bq kg^{-1})
Dec. 31, 1987	97.5	11.9
	68.0	31.8
	50.0	35.9
	32.0	43.8
	2.5	90.3
Dec. 31, 1990	97.5	3.8
	68.0	10.2
	50.0	12.7
	32.0	16.8
	2.5	101

TABLE I.LXIV. EXTERNAL DOSE FROM ^{137}Cs (mSv)
(UNSCEAR model calculations are given for comparison.)

	Mean	95% confidence interval	
		Lower bound	Upper bound
External dose from the cloud[a]	5×10^{-6}	1×10^{-6}	25×10^{-6}
Ground exposure, best estimate			
Apr. 27, 1986 - Apr. 30, 1987	0.06	0.04	0.09
Apr. 27, 1986 - Dec. 31, 1990	0.19	0.11	0.28
Apr. 27, 1986 - lifetime	0.67	0.35	1.1
Ground exposure, UNSCEAR model with site specific parameters			
Apr. 27, 1986 - Apr. 30, 1987	0.06		
Apr. 27, 1986 - Dec. 31, 1990	0.17		
Apr. 27, 1986 - lifetime	1.0		
Ground exposure, UNSCEAR model with given parameters			
Apr. 27, 1986 - Apr. 30, 1987	0.05		
Apr. 27, 1986 - Dec. 31, 1990	0.16		
Apr. 27, 1986 - lifetime	1.0		

[a] Dose outdoors.

TABLE I.LXV. INHALATION DOSE FROM ^{137}Cs (mSv)

	Mean	95% confidence interval Lower bound	Upper bound
From the cloud	0.2×10^{-3}	0.04×10^{-3}	1×10^{-3}
From resuspended material			
First year	50×10^{-6}	10×10^{-6}	250×10^{-6}
4.6 years	58×10^{-6}	12×10^{-6}	290×10^{-6}
50 years	63×10^{-6}	13×10^{-6}	320×10^{-6}

TABLE I.LXVI. INGESTION DOSE FROM ^{137}Cs, ADULTS (mSv)
(Calculated from dietary intake.)

	Mean	95% confidence interval Lower bound	Upper bound
First year (365 d) = April 27, 1986 - April 27, 1987			
Total	0.23	0.21	0.26
Milk (51%)	0.12	0.11	0.13
Freshw. fish (16%)	0.037	0.030	0.056
Beef (12%)	0.028	0.024	0.033
4.6 years = April 27, 1986 - Dec. 31, 1990			
Total	0.72	0.67	0.84
Milk (36%)	0.26	0.24	0.28
Freshw. fish (31%)	0.22	0.19	0.30
Beef (9.6%)	0.07	0.06	0.08
50 years = April 27, 1986 - April 27, 2036			
Total	1.6	1.3	2.7
Freshw. fish (39%)	0.62	0.33	1.7
Milk (18%)	0.28	0.26	0.31
Wild mushr. (9.4%)	0.15	0.07	0.33

TABLE I.LXVII. TOTAL DOSE FROM ^{137}Cs, ADULTS (mSv)
(Internal dose was calculated from the results of the whole-body counter measurements.)

	Mean	95% confidence interval	
		Lower bound	Upper bound
First year = Apr. 27, 1986 - Apr. 27, 1987			
Total	0.16	0.13	0.20
Internal dose (78%)	0.10	0.08	0.12
External dose (21%)	0.06	0.04	0.09
4.6 years = Apr. 27, 1986 - Dec. 31, 1990			
Total	0.50	0.39	0.62
Internal dose (62%)	0.31	0.23	0.39
External dose (38%)	0.19	0.11	0.28
50 years = Apr. 27, 1986 - Apr. 27, 2036			
Total	1.35	1.0	3.5
Internal dose (50%)	0.68	0.54	2.8[a]
External dose (50%)	0.67	0.35	1.1

[a)] Based on dose estimated from dietary intake.

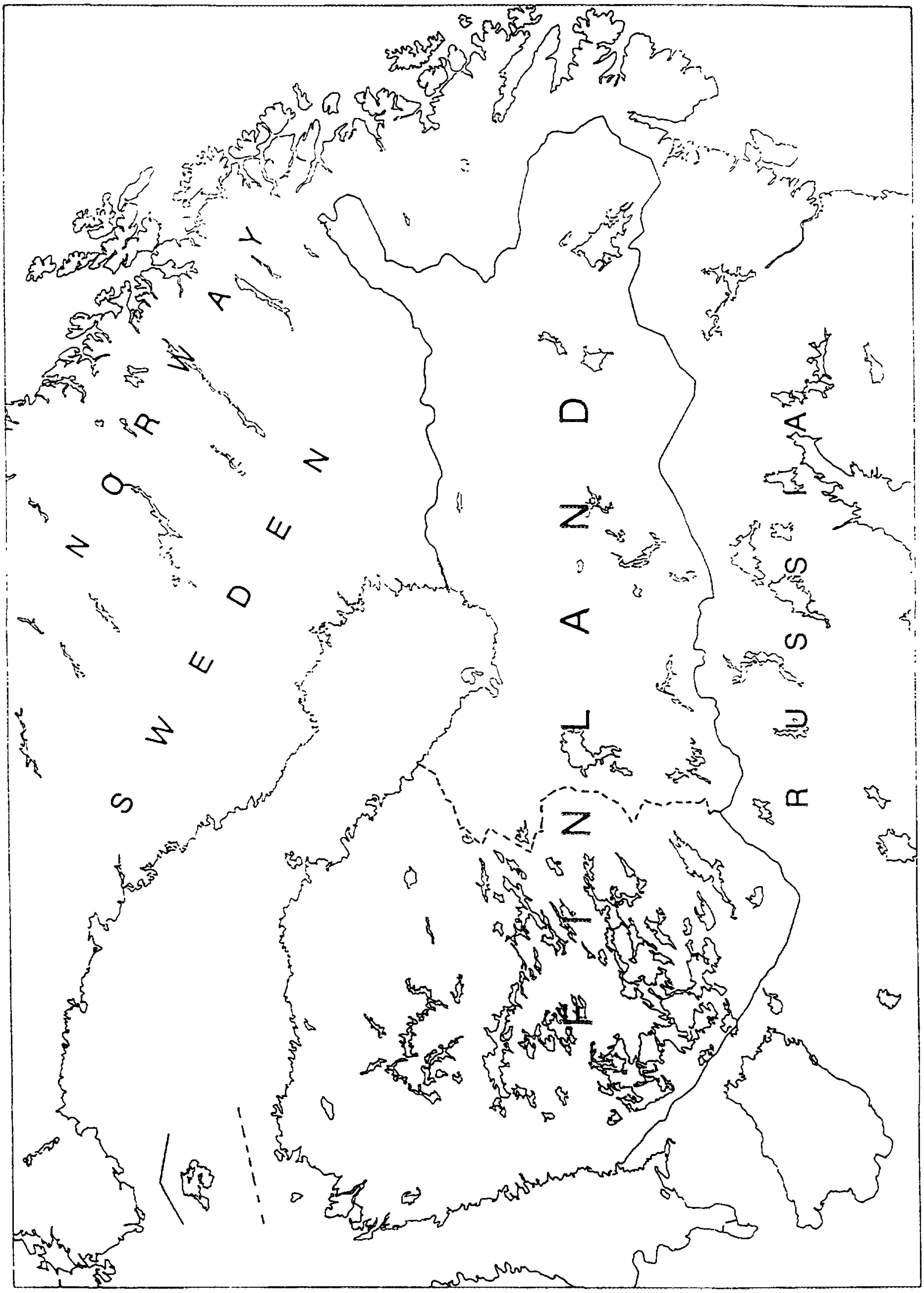


FIG. I.1. Test area S, southern Finland.

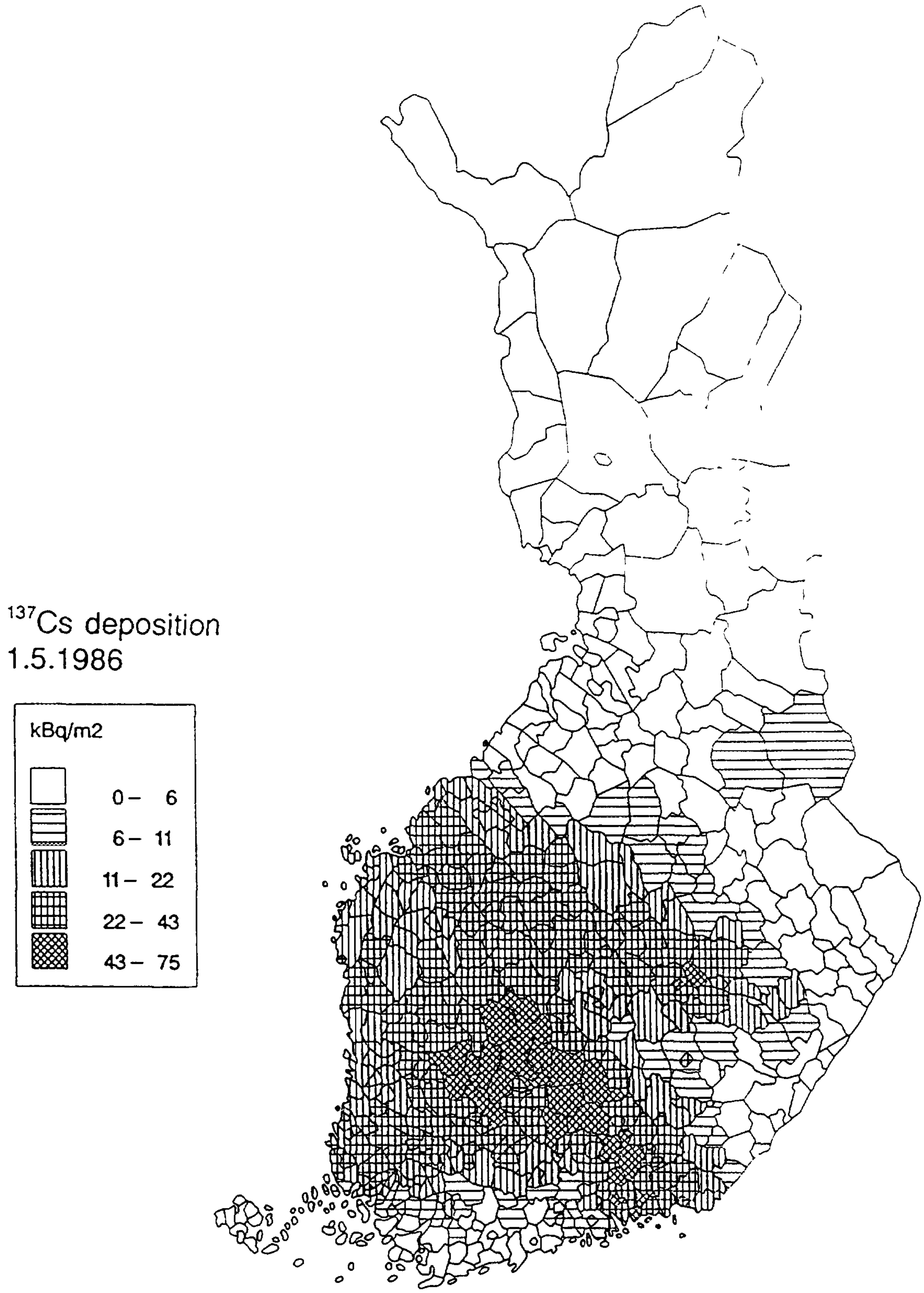


FIG. I.2. Distribution of ^{137}Cs in Finland after the Chernobyl accident. The 458 municipalities are divided into five groups according to their average deposition

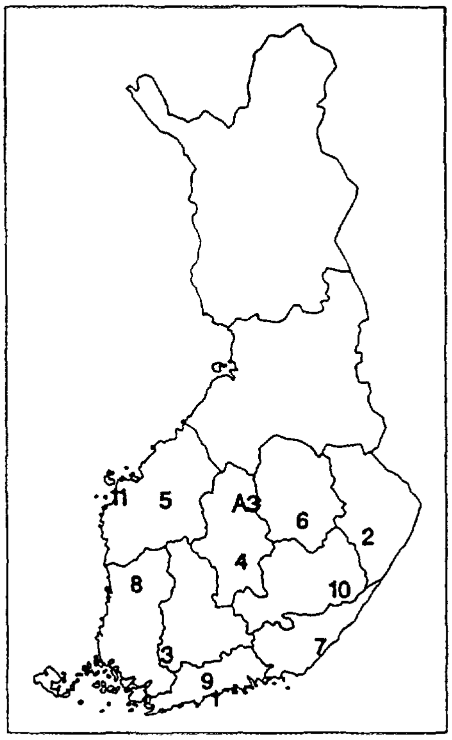


FIG. I.3. Deposition and air collection stations.

DEP1 = Helsinki
DEP2 = Joensuu
DEP3 = Jokioinen
DEP4 = Jyväskylä
DEP5 = Kauhava
DEP6 = Kuopio
DEP7 = Lappeenranta
DEP8 = Niinisalo
DEP9 = Nurmijärvi
DEP10 = Savonlinna
DEP11 = Vaasa
AIR1 = 1 = Helsinki
AIR2 = 9 = Nurmijärvi
AIR3 = A3 = Viitasaari

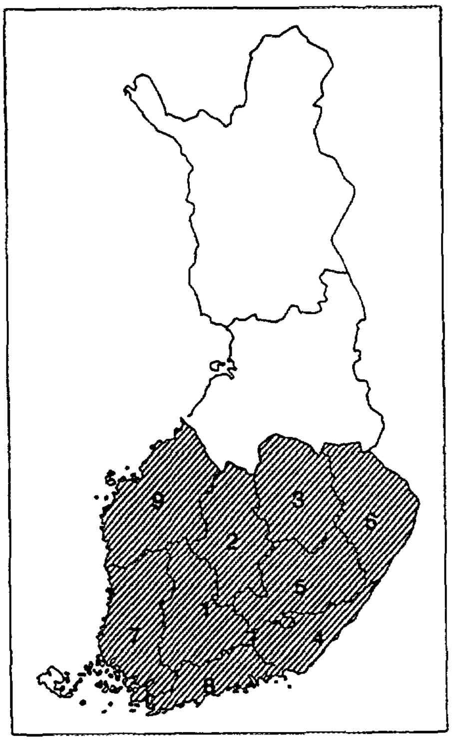


FIG. I.4. The nine provinces (population areas) of the test region.

POP1 = Häme
POP2 = Keski-Suomi
POP3 = Kuopio
POP4 = Kymi
POP5 = Mikkeli
POP6 = Pohjois-Karjala
POP7 = Turku ja Pori
POP8 = Uusimaa
POP9 = Vaasa

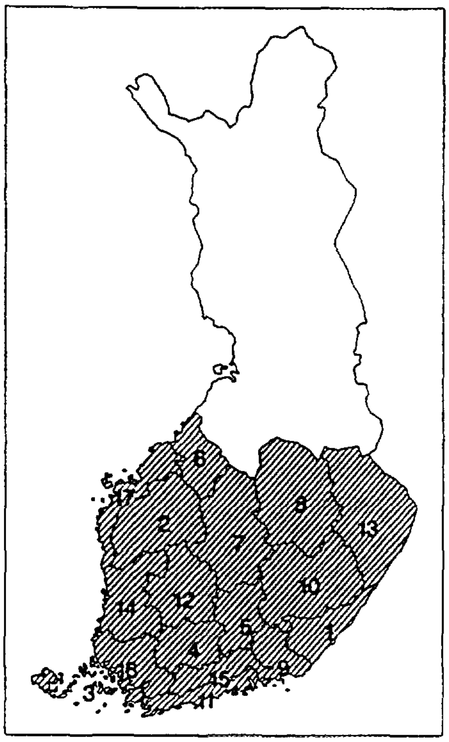


FIG. I.5. The seventeen agricultural areas of the test region.

AGR1 = Etelä-Karjala
AGR2 = Etelä-Pohjanmaa
AGR3 = Finska Hushållningssällskapet
AGR4 = Hämeen lääni
AGR5 = Itä-Häme
AGR6 = Keski-Pohjanmaa
AGR7 = Keski-Suomi
AGR8 = Kuopio
AGR9 = Kymenlaakso
AGR10 = Mikkeli
AGR11 = Nylands Svenska
AGR12 = Pirkanmaa
AGR13 = Pohjois-Karjala
AGR14 = Satakunta
AGR15 = Uusimaa
AGR16 = Varsinais-Suomi
AGR17 = Österbottens Svenska

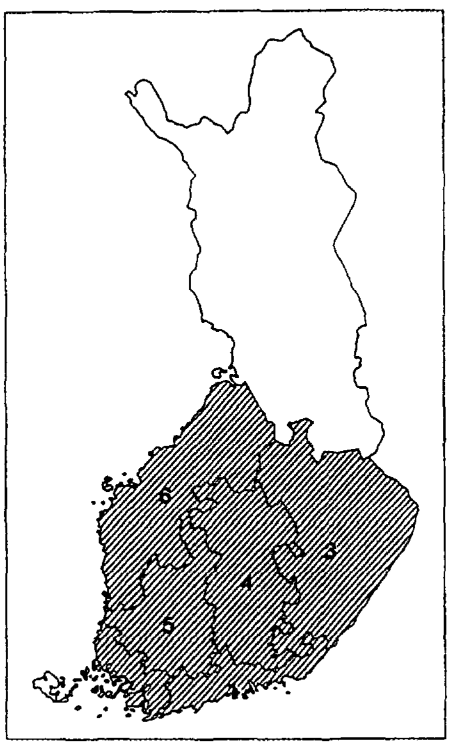


FIG. I.6. The six fish catchment areas of the test region.

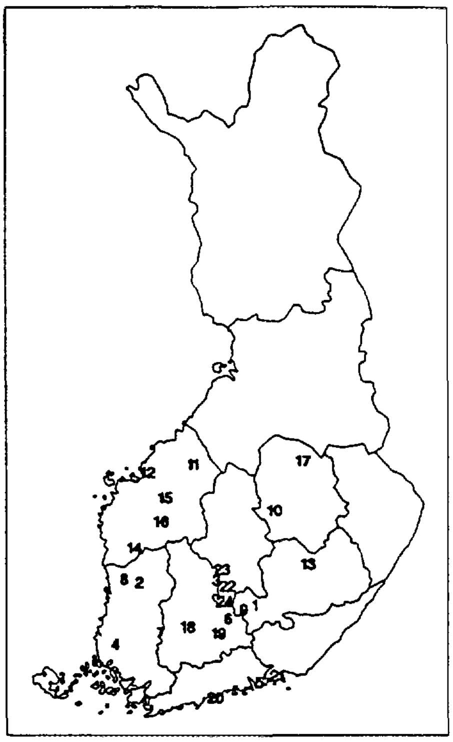


FIG. I.7. Soil sampling sites in different provinces (cf. Table I.IX).

S1 = Hartola
S2 = Kankaanpää
S3 = Kuorevesi
S4 = Laitila
S5 = Loviisa
S6 = Padasjoki
S7 = Punkalaidun
S8 = Siikainen
S9 = Sysmä
S10 = Tervo
S11 = Ullava
S12 = Uusikaarlepyy
S13 = Joroinen
S14 = Kauhajoki
S15 = Kauhava
S16 = Nurmo
S17 = Sonkajärvi
S18 = Valkeakoski
S19 = Lammi
S20 = Helsinki
S21 = Kotka
S22 = Jämsä
S23 = Jämsänkoski
S24 = Kuhmoinen

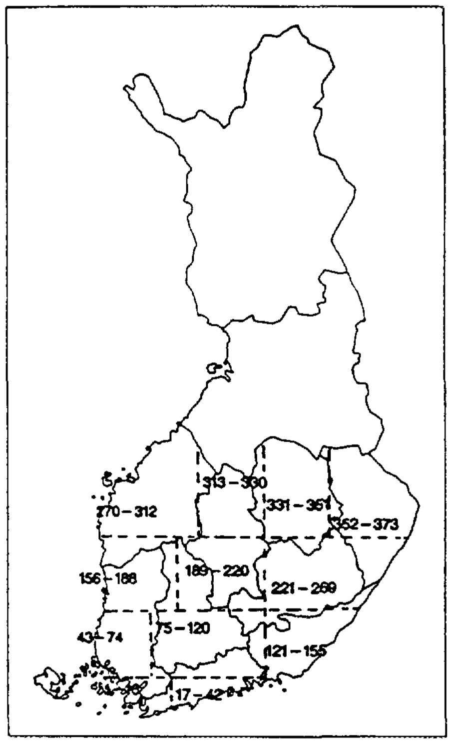


FIG. I.8. Approximate locations of the 373 rain samplers.

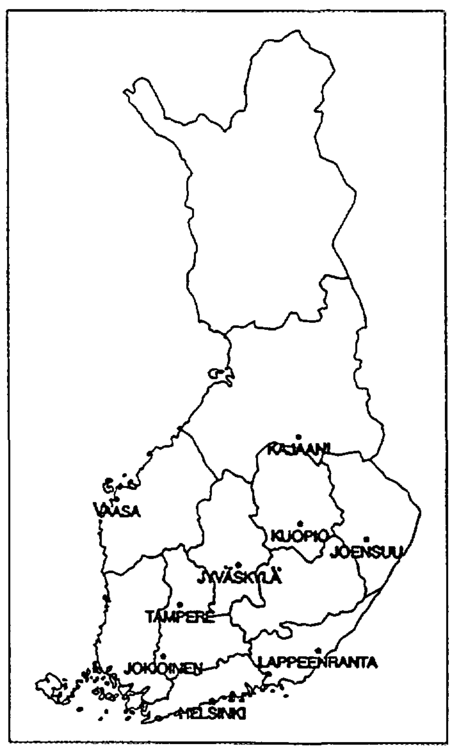


FIG. I.9. Locations of the nine sites, for which the leaf area indices and effective temperature sums are given for 1986. Cf. Figures I.10-I.14.

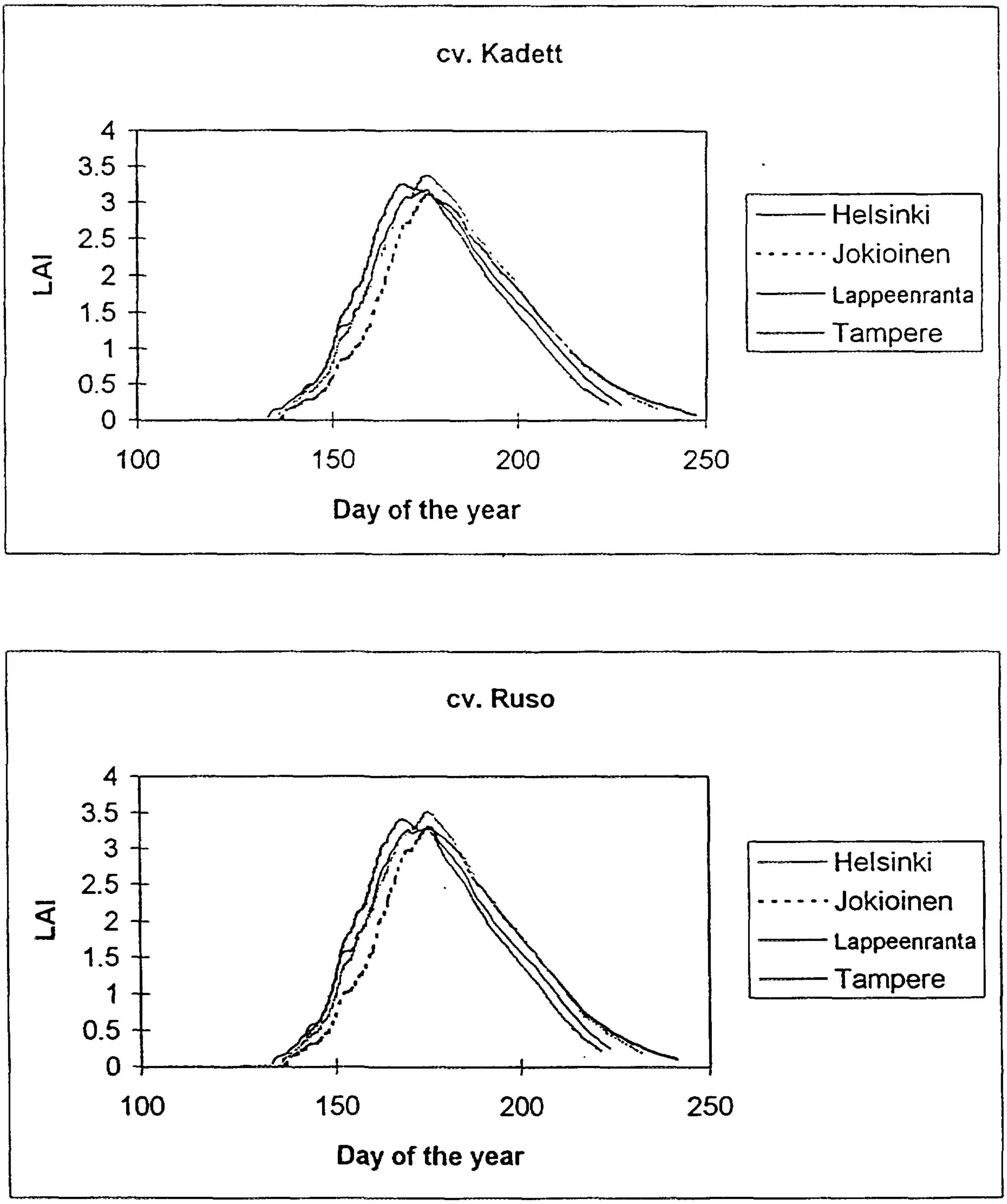


FIG. I.10. Leaf area indices for two cultivars of wheat, estimated using weather data of 1986.

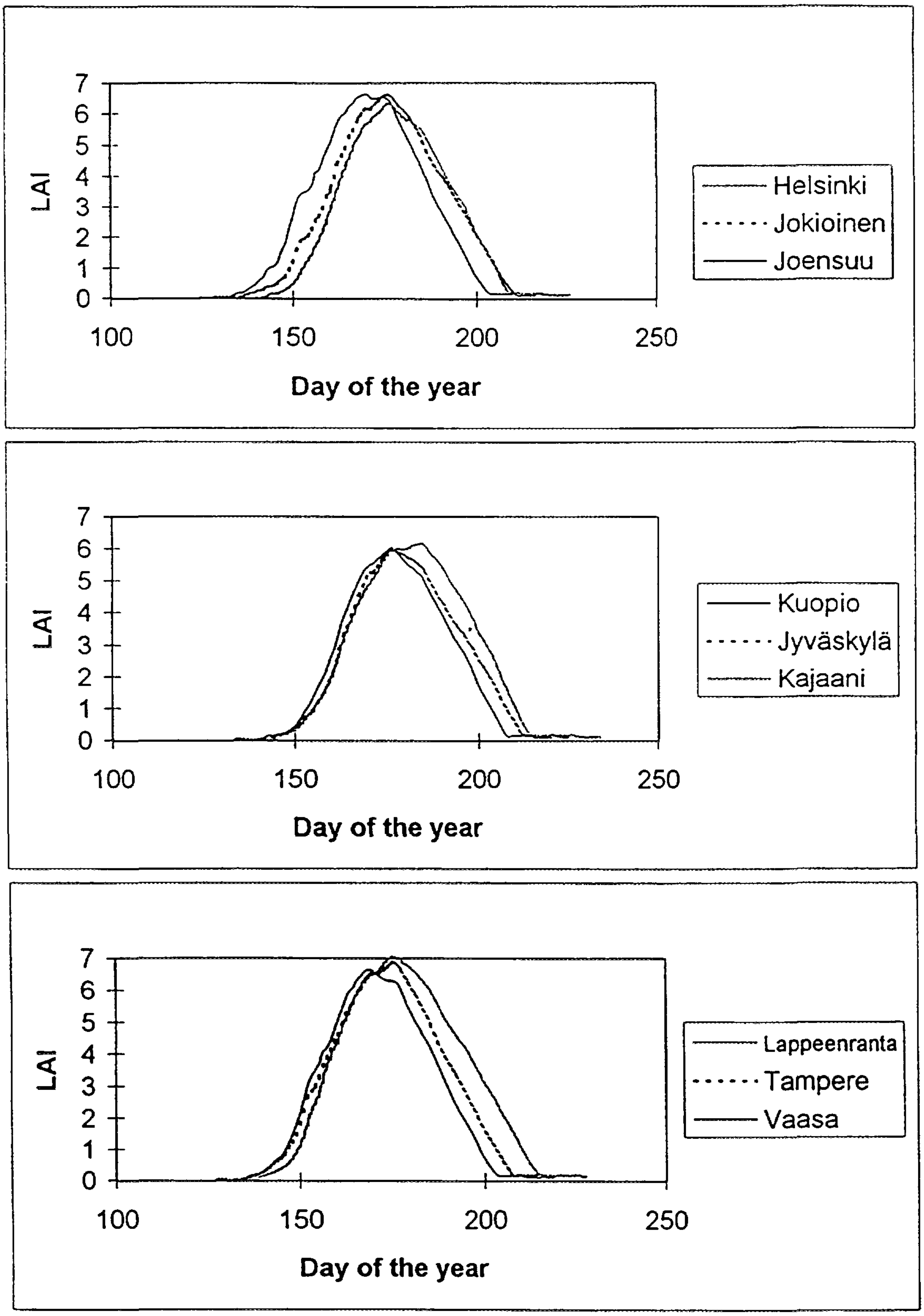


FIG. I.11. Leaf area indices for barley, estimated using weather data of 1986.

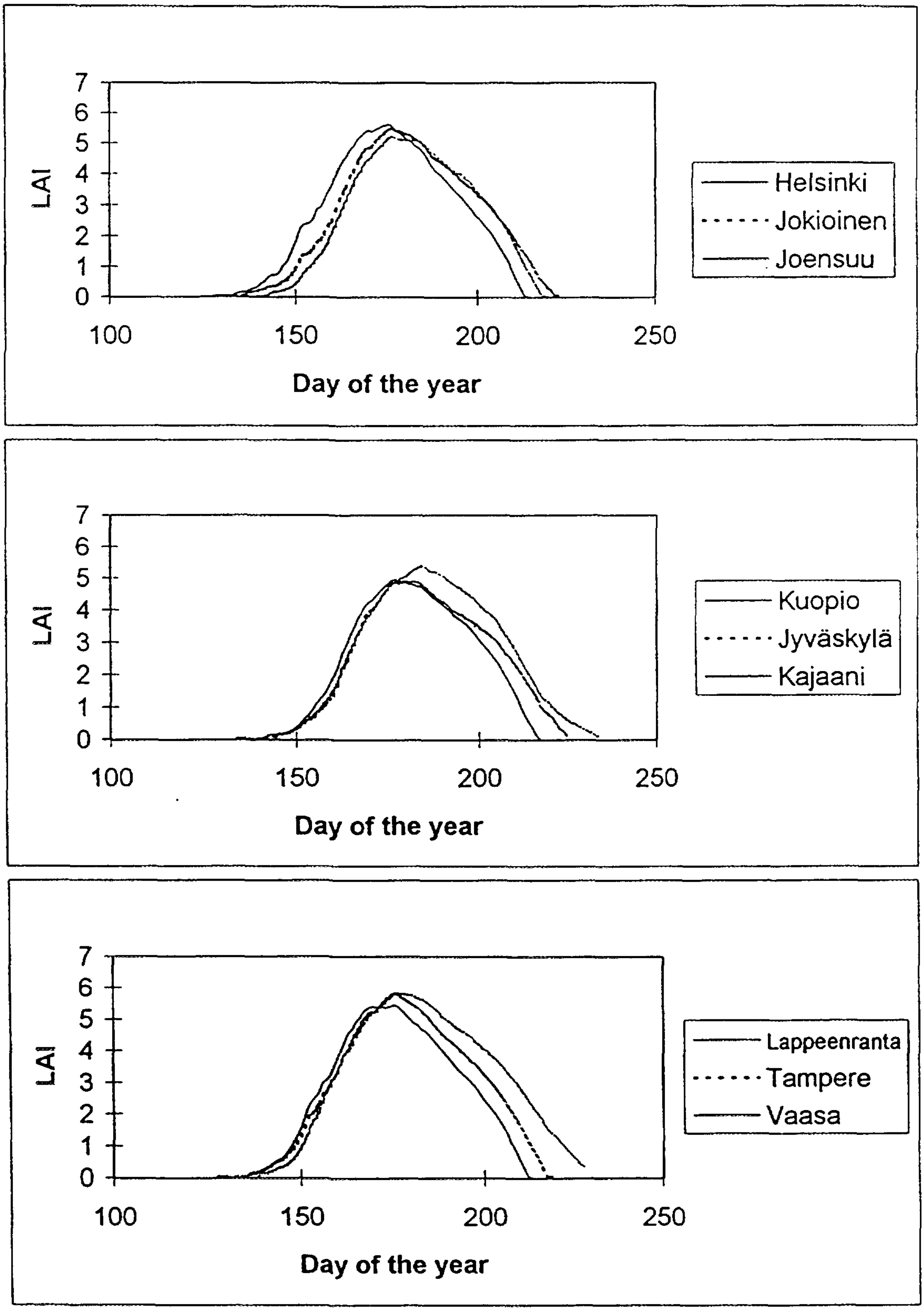


FIG. I.12. Leaf area indices for oats, estimated using weather data of 1986.

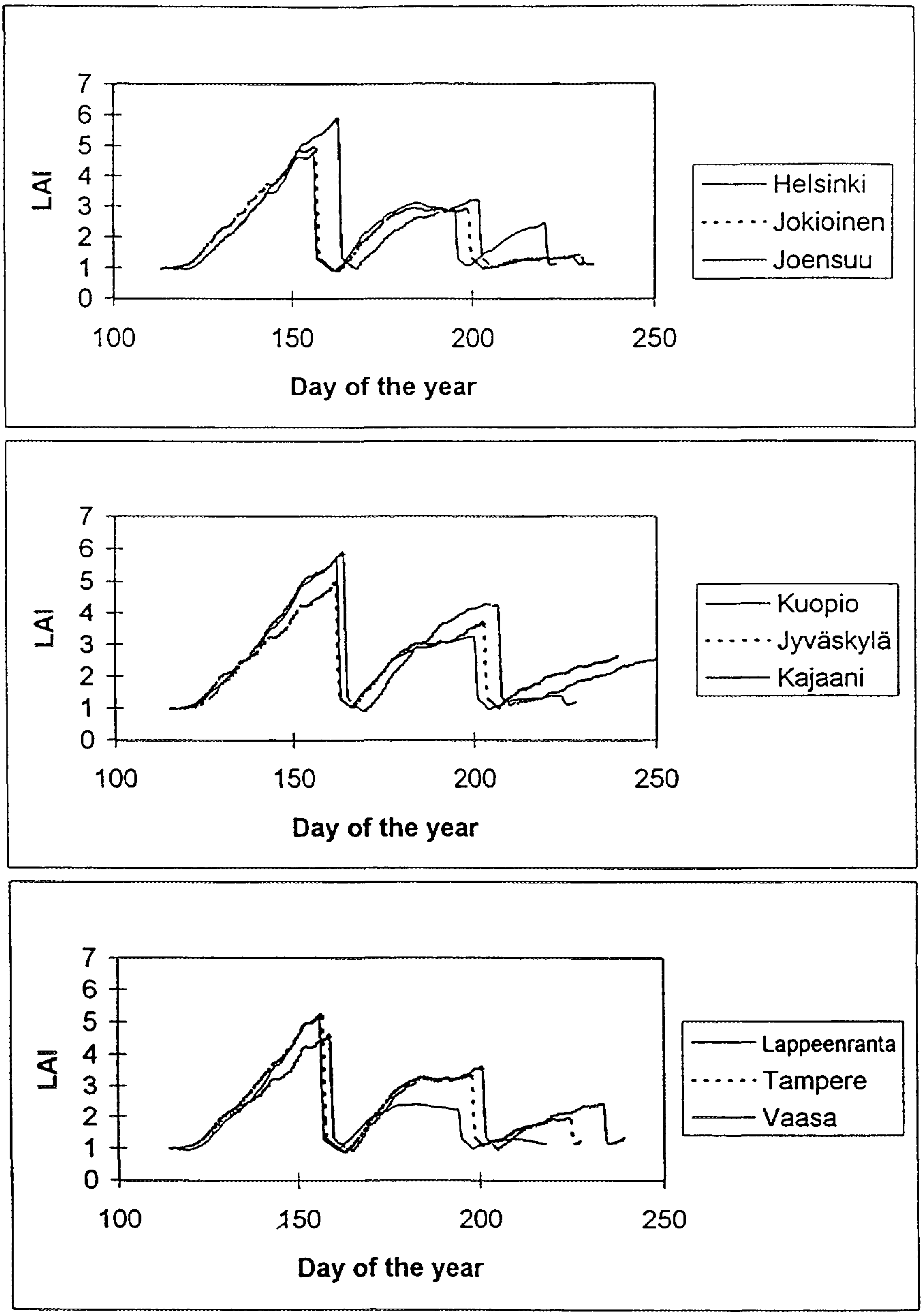


FIG. I.13. Leaf area indices for silage grass, estimated using weather data of 1986.

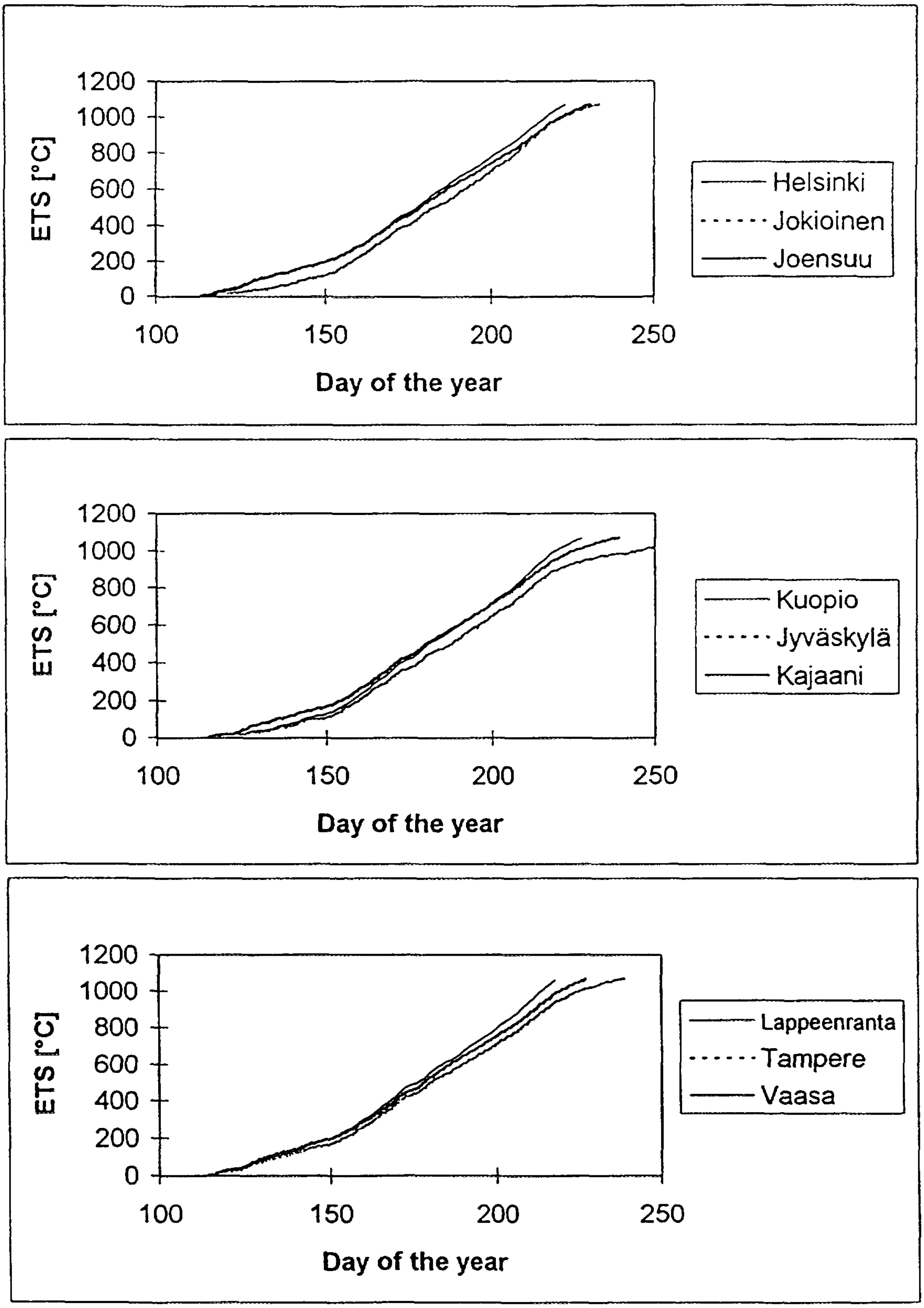


FIG. I.14. Effective temperature sum in the growth period 1986 at nine locations used for leaf area estimation in Figures I.10. - I.13.

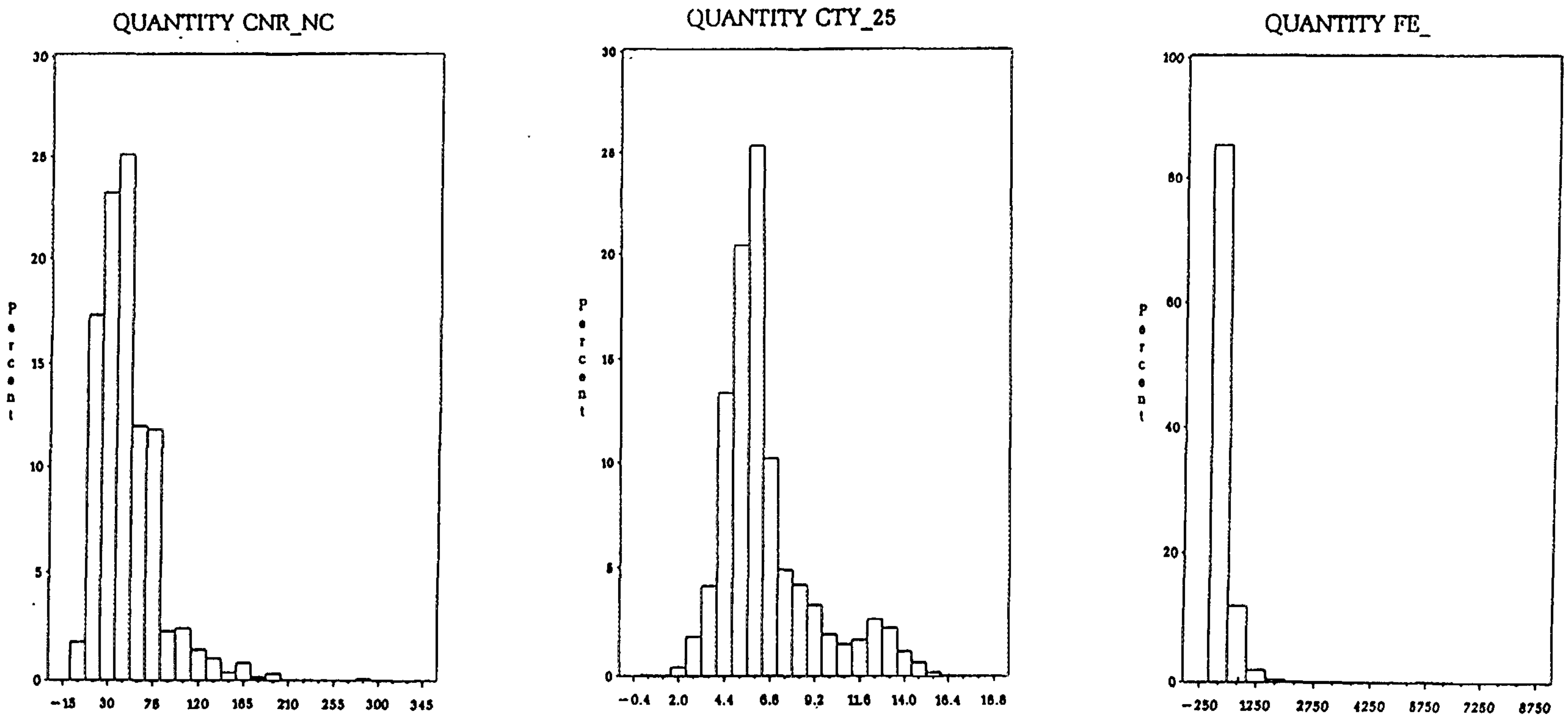


FIG. I.15. Frequency distribution of the colour number CNR_NC (mg Pt L^{-1}), specific conductivity CTY_25 (mS m^{-1}) and iron FE_ (µg L^{-1}). cf. Table I.XV.

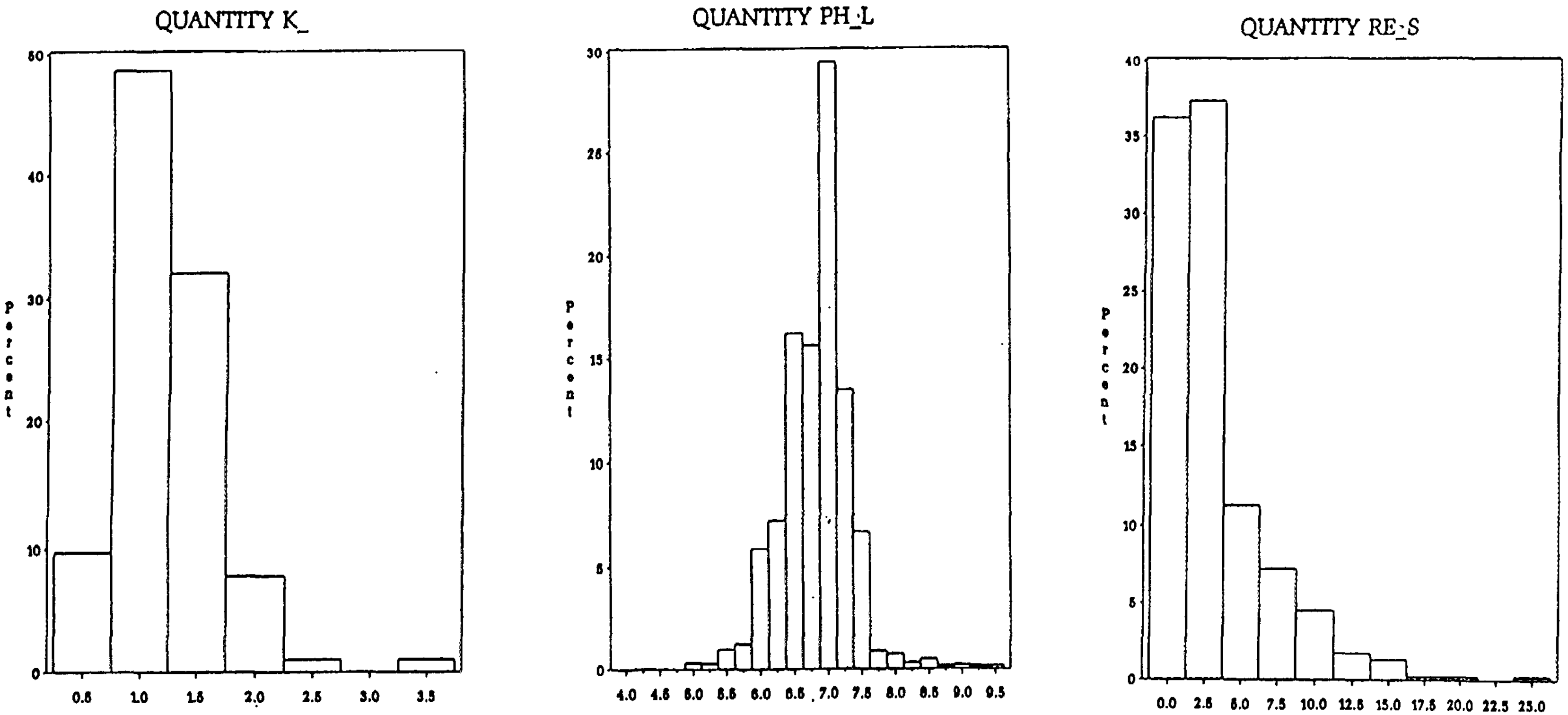


FIG. I.16. Frequency distribution of the potassium content K_ (mg L^{-1}), pH of water pH_L, and total suspended residue RE_S (mg L^{-1}). cf. Table I.XV.

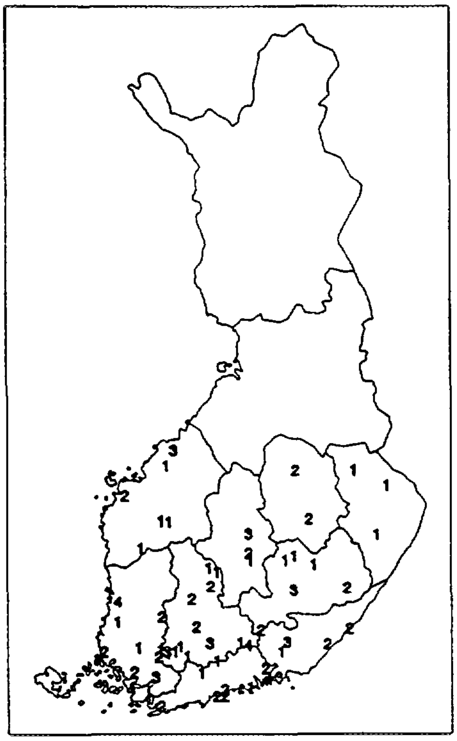


FIG. I.17. Sampling locations of pasture vegetation in 1986. The numbers refer to how many successive samples were taken in May. From two locations, altogether 31 and 22 samples were collected throughout the grazing season.

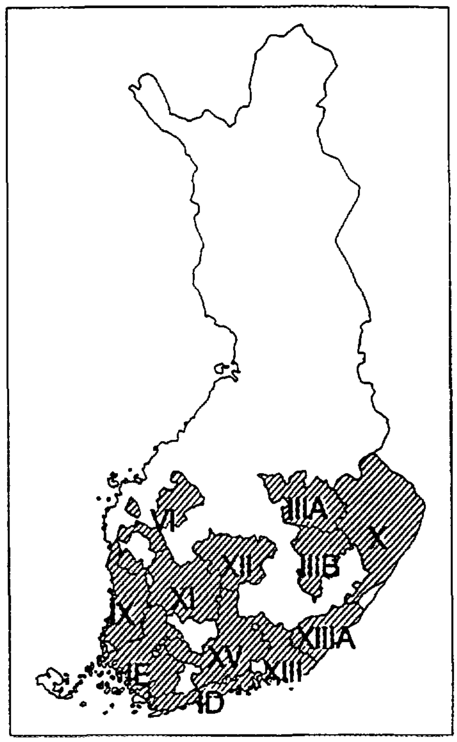


FIG. I.18. Sampling regions for milk in 1986 - 1990. Samples from area IIIA were taken only in 1986, from area XIIIA in 1988 - 1990 and from area XV only in 1987 - 1988.

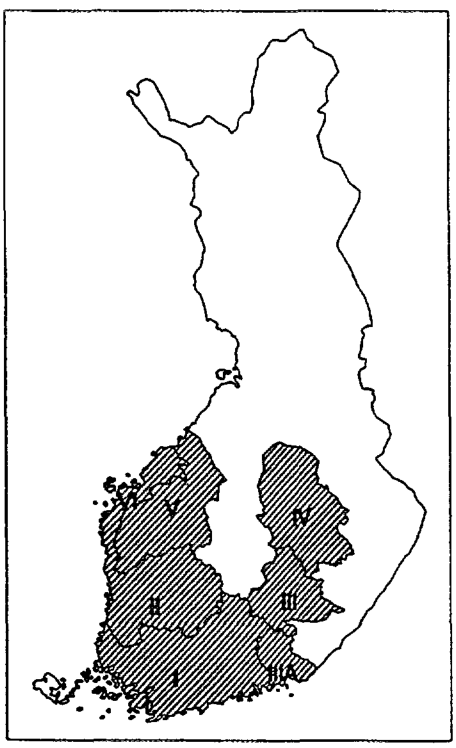


FIG. I.19. Sampling areas of beef (I - VI) and of pork (II and III).

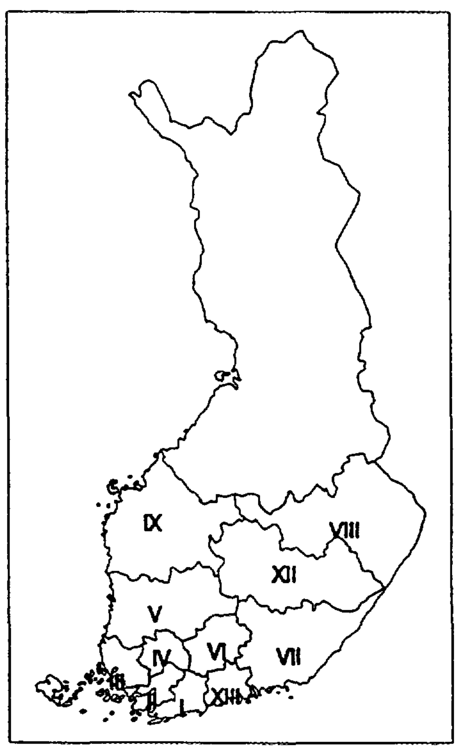


FIG. I.20. Purchase areas of the State Granary.

Number of radiocaesium determinations in 1986–1990

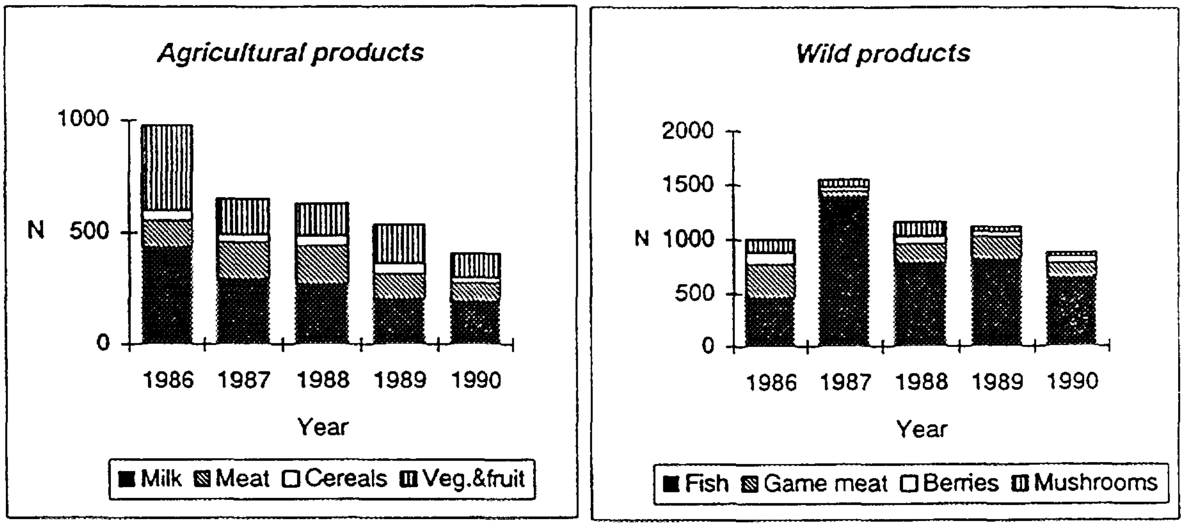
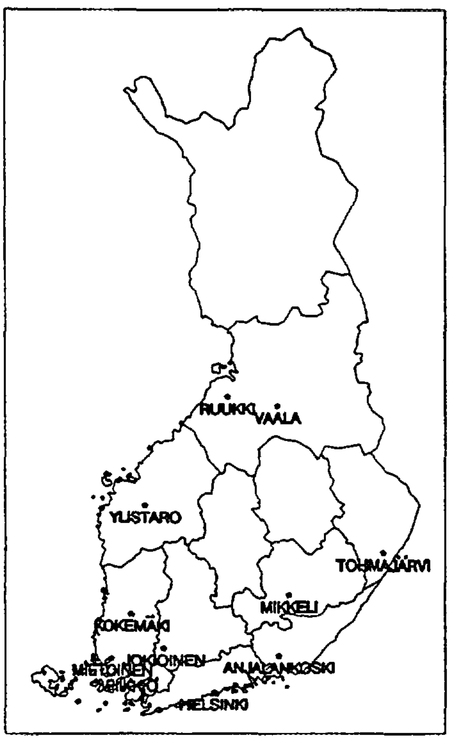


FIG. I.21. Annual numbers of measurements of radiocaesium in foodstuffs by sample type included in the test data.



Anjalankoski
Helsinki
Jokioinen
Kokemäki
Mietoinen
Mikkeli
Piikkiö
Ruukki
Tohmajärvi
Vaala
Ylistaro

FIG. I.22. Locations for which effective temperature sums are given in figure I.23.

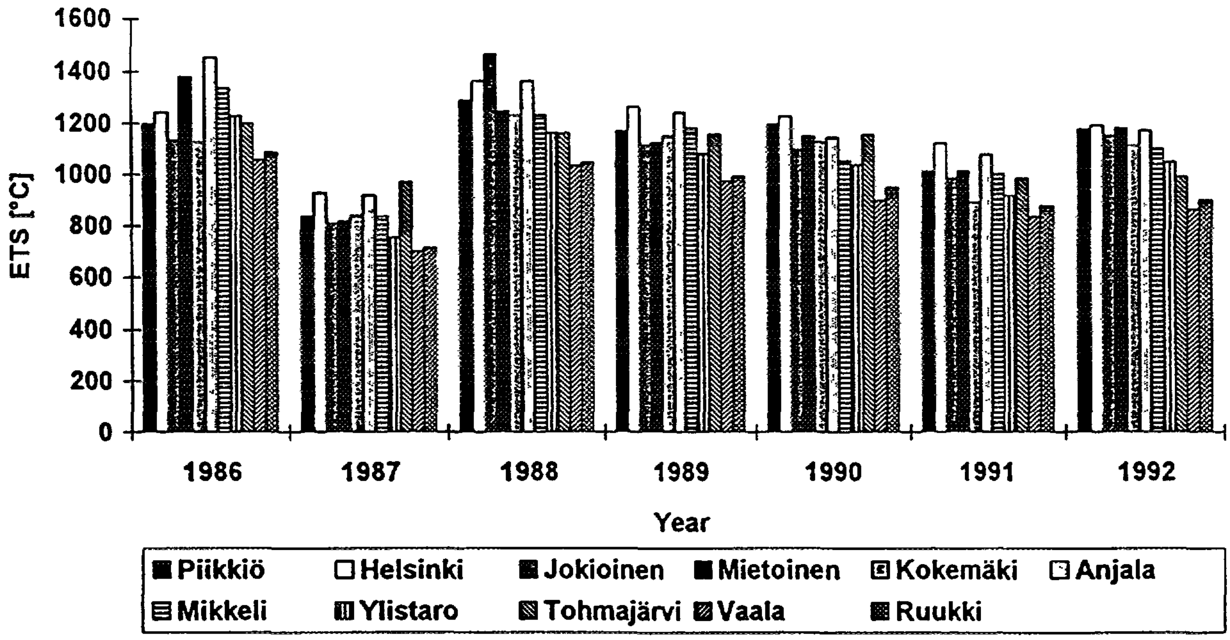


FIG. I.23. Effective temperature sums for 11 locations in different parts of the test area.

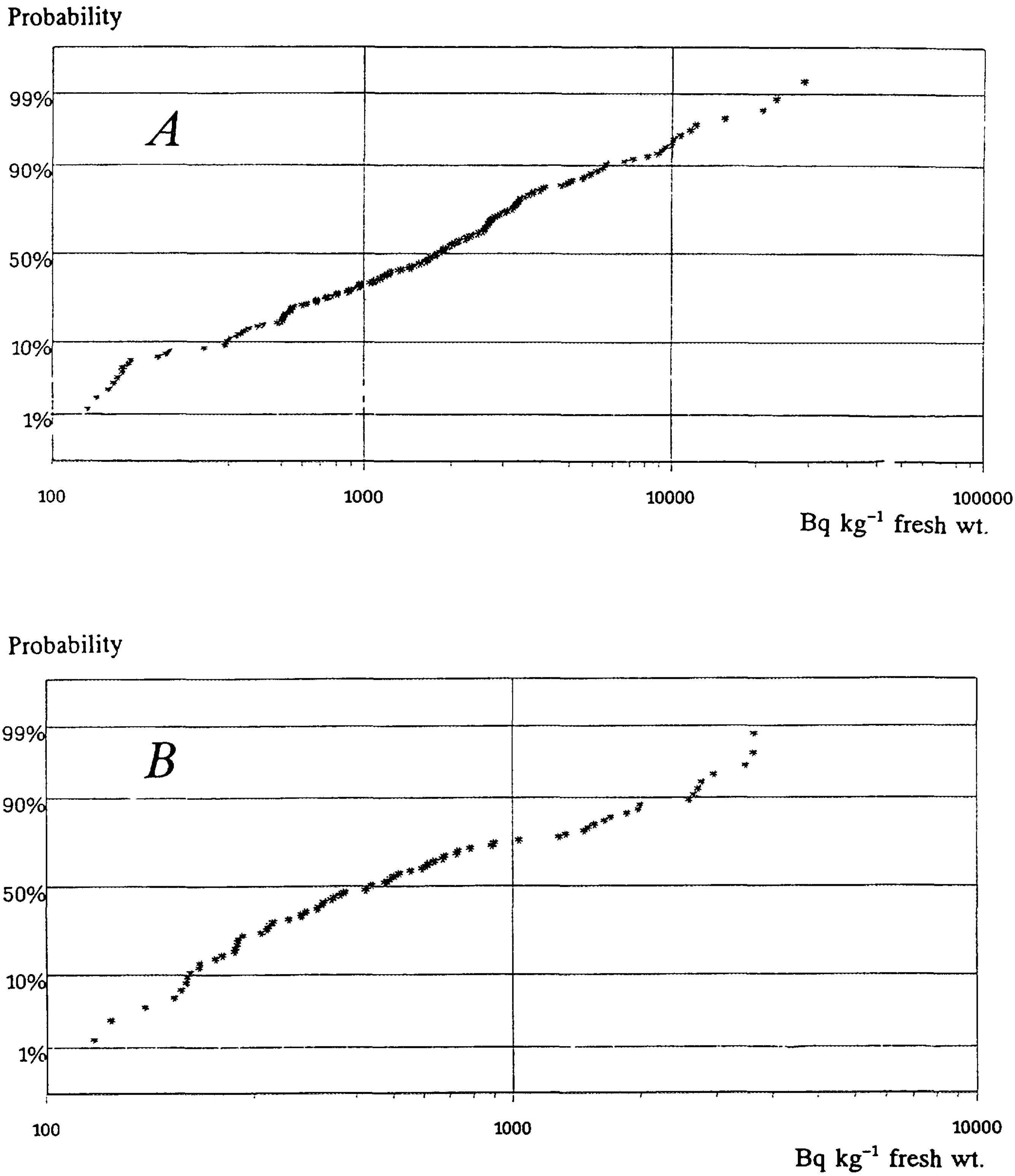


FIG. I.24. Examples on probability distributions of ^{137}Cs concentrations in fish.
A: Predators from fishing area 5 in 1987. The sample size was 165.
B: Nonpredators from fishing area 4 in 1988. The sample size was 75.

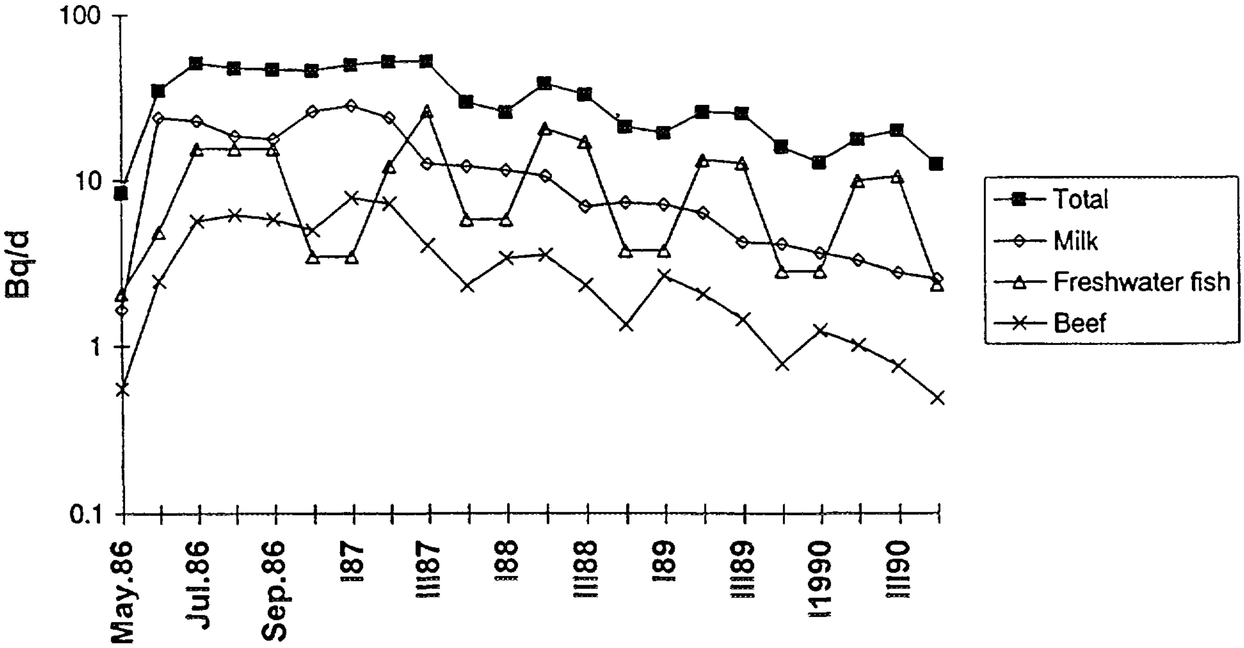


FIG. I.25. Mean dietary ^{137}*Cs received by man in the test region during the period April 27, 1986 - December 31, 1990. Three food items contributing most to the intake are also shown. Seasonal variation is caused by varying consumption of wild food products. Note the change of the time scale: after September 1986 quarters of a year are used.*

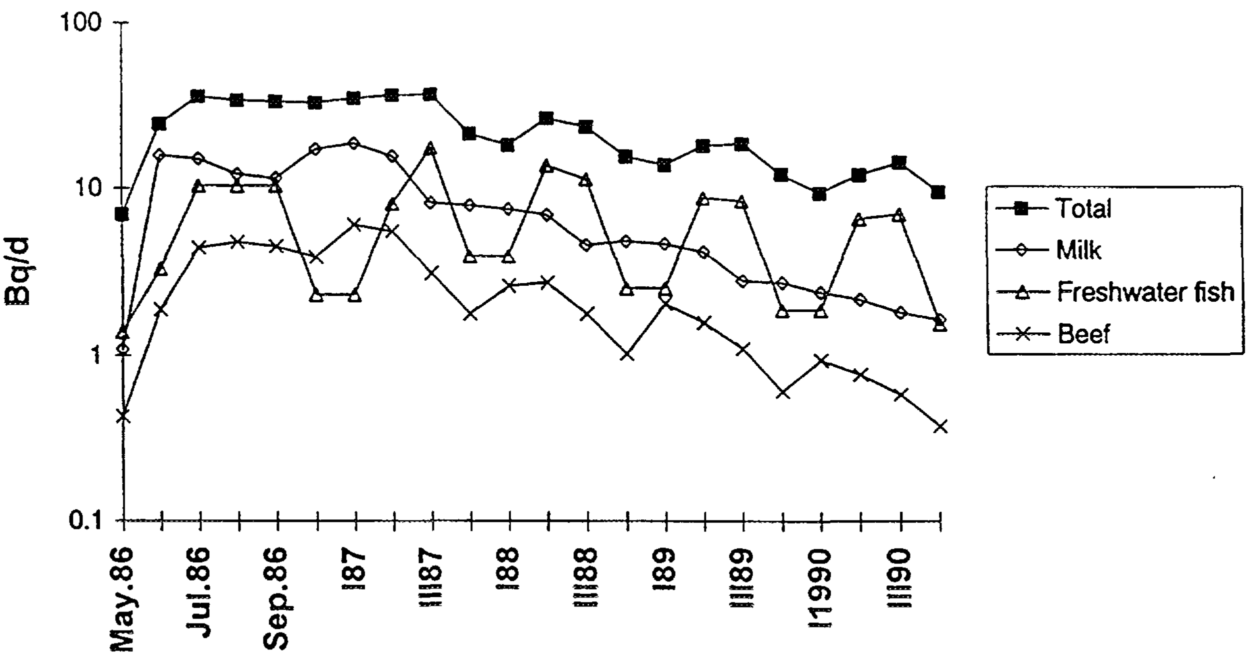


FIG. I.26. Mean dietary ^{137}*Cs received by woman in the test region during the period April 27, 1986 - December 31, 1990. Three food items contributing most to the intake are also shown. Seasonal variation is caused by varying consumption of wild food products. Note the change of the time scale: after September 1986 quarters of a year are used.*

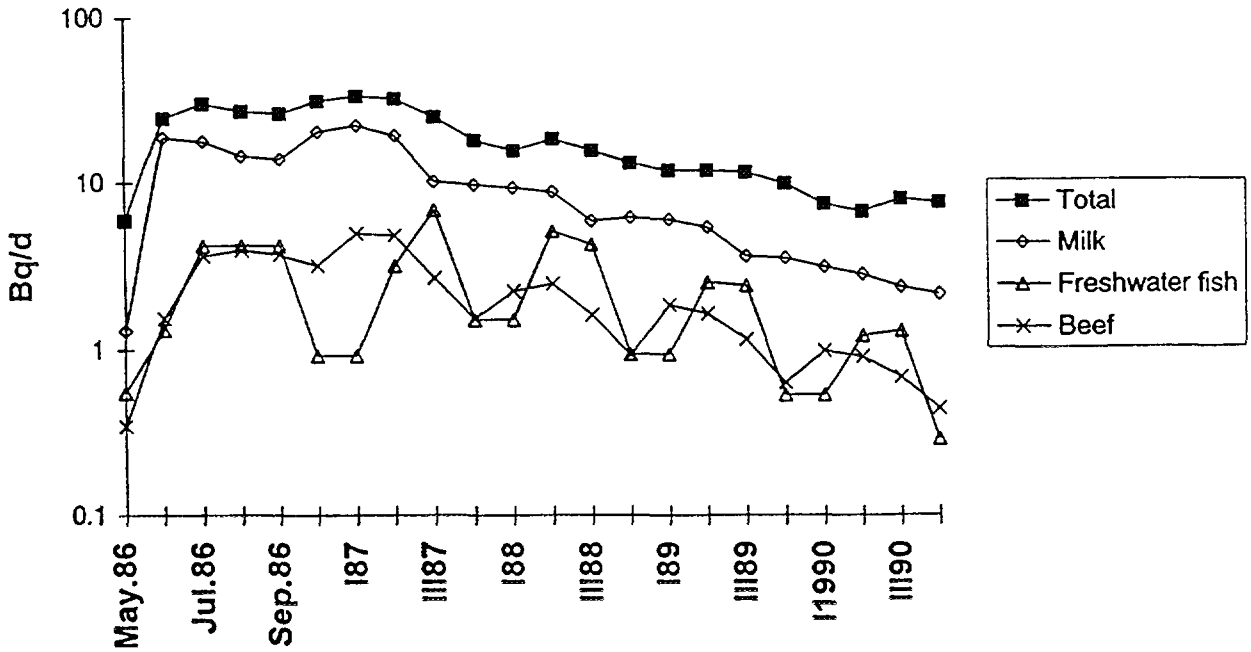


FIG. I.27. Mean dietary ^{137}Cs received by child, ten years old in 1986, in the test region during the period April 27, 1986 - December 31, 1990. Three food items contributing most to the intake are also shown. Seasonal variation is caused by varying consumption of wild food products. Note the change of the time scale: after September 1986 quarters of a year are used.

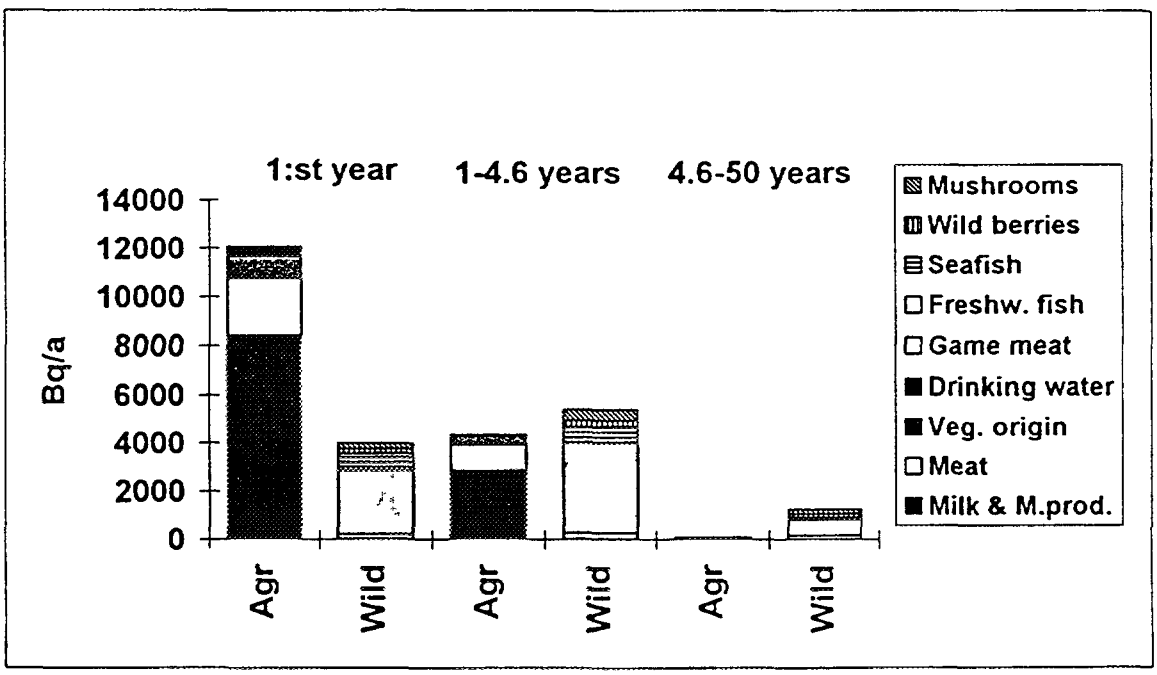


FIG. I.28. Annual dietary ^{137}Cs received by man from different types of food in three periods since May 1986. Foodstuffs of agricultural and wild origin are shown separately.

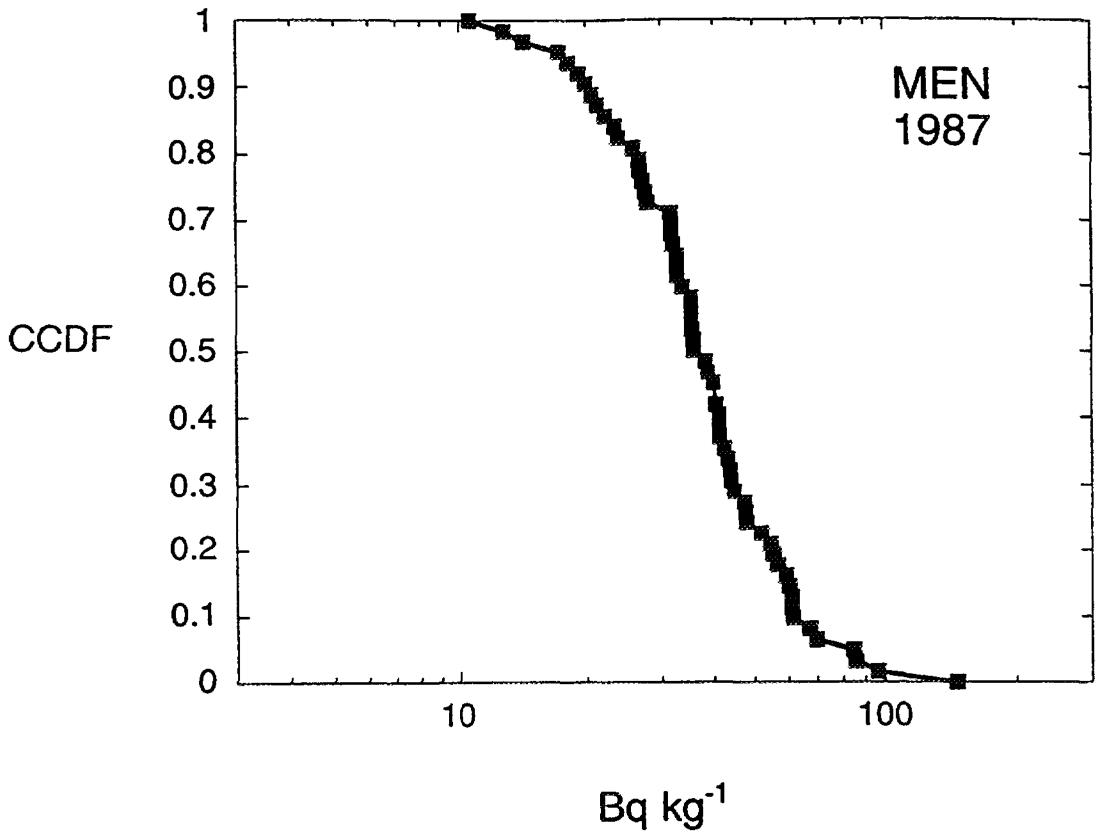


FIG. I.29. Complementary cumulative distribution of ^{137}Cs body burdens of men in 1987.

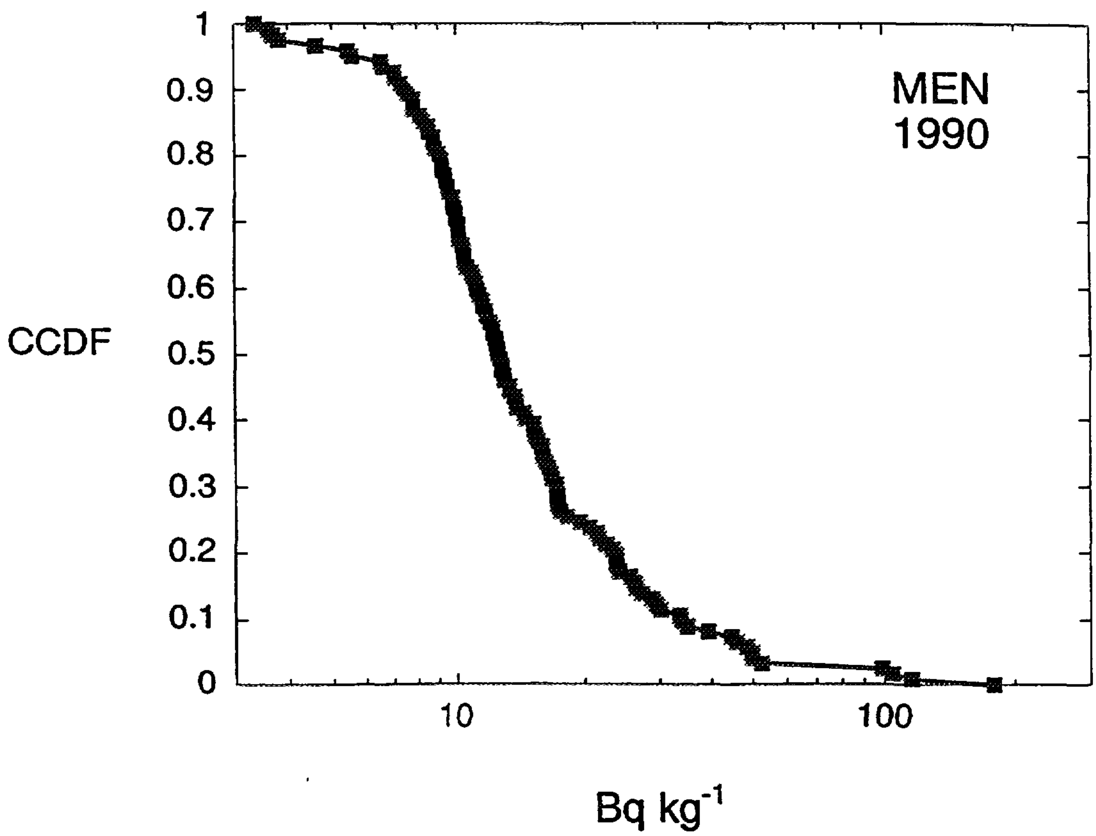


FIG. I.30. Complementary cumulative distribution of ^{137}Cs body burdens of men in 1990.

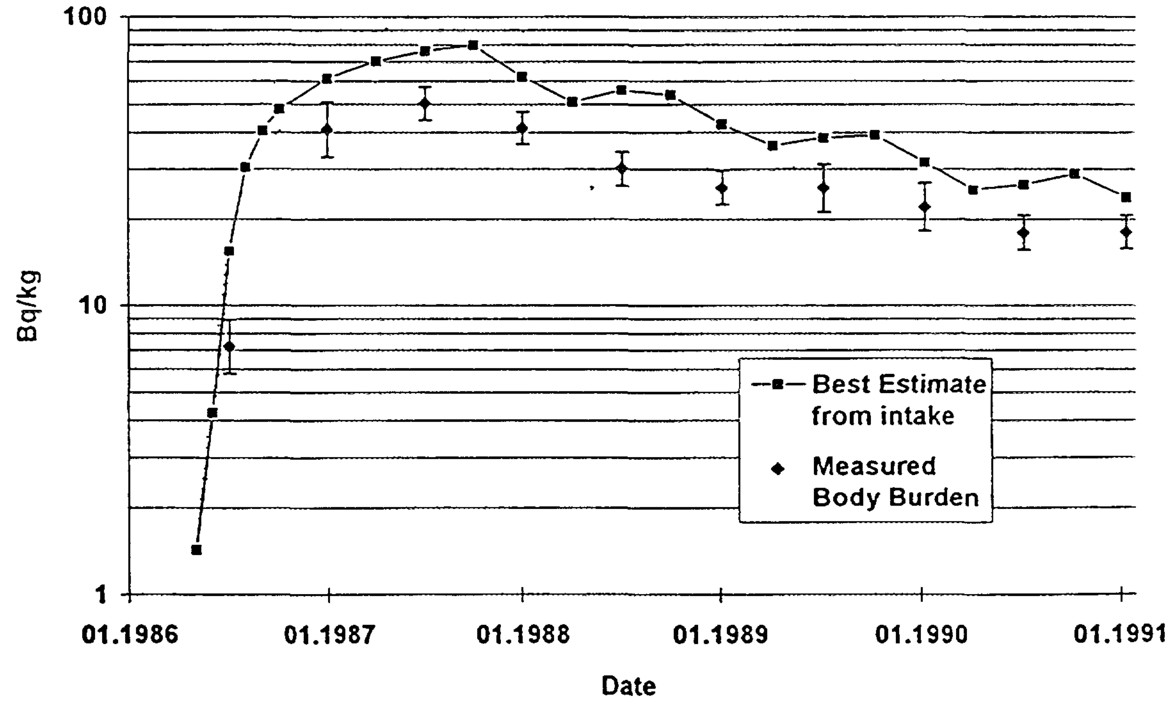


FIG. I.31. Comparison of ¹³⁷Cs body burdens of man, estimated from intake and from measured whole body concentrations.

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The authors share responsibility for the report as follows:

H. Arvela:	Sections I.3.1.3 and I.4.1.2
M. Suomela:	Sections I.3.1.4, I.3.2.6 and I.4.3.1
A. Rantavaara:	All other sections

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Appendix II

MODEL DESCRIPTIONS AND INDIVIDUAL EVALUATIONS OF MODEL PREDICTION FOR SCENARIO S

II.1. FARMLAND

1. MODEL DESCRIPTION AND EVALUATION OF MODEL PERFORMANCE

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2. MODEL DESCRIPTION

2.1. Name of model, model developer and model user

Model name: FARMLAND (Food Activity from Radionuclide Movement on Land).

It is important to stress that the FARMLAND suite of models was used in a limited selection of Scenario S calculations.

FARMLAND was used to calculate ^{137}Cs activity concentrations in:

* pasture
* milk
* beef
* leafy vegetables
* cereals

FARMLAND was not designed to calculate:

* activity concentrations in other foods such as mushrooms, moose or wildfowl.
* external dose
* ingestion dose
* inhalation dose
* whole body burden

Other methods detailed in this document were used to calculate these quantities.

Model developer: NRPB Environmental Assessments Department
Model user: Carol Attwood

2.2. Important model characteristics

2.2.1. Intended purpose of the model in radiological assessment

The FARMLAND model was originally developed for use in connection with continuous, routine releases of radionuclides, but because it has many time-dependent features it has been developed further for a single accidental release. The most recent version of FARMLAND is flexible and can be used to predict activity concentrations in food as a function of time after both accidental and routine releases of radionuclides. The effect of deposition at different times of the year can be taken into account. FARMLAND contains a suite of models which simulate radionuclide transfer through different parts of the foodchain. The models can be used in different combinations and offer the flexibility to assess a variety of radiological situations. The main foods considered are green vegetables, grain products, root vegetables, milk, meat and offal from cattle, and meat and offal from sheep. A large variety of elements can be considered although the degree of complexity with which some are modelled is greater than others; isotopes of caesium, strontium and iodine are treated in greatest detail.

FARMLAND is a generic model developed for UK agricultural practices and for use in general radiological assessments. However, selective information on agricultural practices and countermeasures have been taken into account. The model is not intended for site specific applications, however it is sufficiently flexible to be used for detailed studies if required. The purpose of NRPB's involvement in the Multiple Pathways Exercise has been to test the default, generic, FARMLAND model. There has been no attempt to fine tune the models to replicate the detail given in the Scenario S outline. This has had implications for the fit of predictions to observations.

2.2.2. Intended accuracy of model prediction

FARMLAND is primarily used to study the transfer of radionuclides to foodchains following accidental or routine releases of radioactivity to the atmosphere. The way in which the model is used and the assumptions made depend on the application. For routine releases, simplifying assumptions can be made, eg the releases are assumed to be continuous and constant throughout each year and the temporal accuracy of calculations required is not less than one year. It is therefore not necessary to model the time dependence of the transfer to the food in detail. The full complexity of FARMLAND is used for accidental release applications where predictions of the time dependence of radionuclide transfer is required as an important input to post-accident management and also, in other circumstances, to the development of emergency plans. In summary, FARMLAND comprises a suite of default, generic models which are expected to provide a *best estimate* of radionuclide activity concentration in a variety of food products. In the light of uncertainties associated with predictions, (see Section 2.2.3) FARMLAND tends to err on the side of caution by overestimating food activity concentrations.

2.2.3. Estimates of uncertainty associated with model predictions

When the Scenario S assessment was carried out, FARMLAND had no built in mechanism for the estimation of parameter uncertainty. Work is currently in progress under a CEC contract, to address the issue of quantifying uncertainties in foodchain calculations as inputs to accident consequence codes[1]. NRPB therefore accepts that some estimate of the uncertainty surrounding dose quantities is desirable and indeed necessary in radiological assessments. However, in normal circumstances, measures of uncertainty associated with intermediate quantities are not calculated by NRPB as part of a dose assessment. These might be radionuclide activity concentrations in environmental media, eg foods, water, air or sediments. However, model predictions are compared with those of similar models for given conditions (verification), and with a variety of environmental measurement data (validation) as a first step toward quantifying model performance.

Verification

Throughout the development of FARMLAND the predicted activity concentrations in foods were checked against hand calculations, and compared with the results given by relatively simple, multiplicative foodchain models. FARMLAND has also been used in four extensive model intercomparison studies at various stages of its development, e.g comparison with ECOSYS (GSF Germany, 2 studies[2,3]), comparison with dynamic foodchain models produced by Associated Nuclear Services[4] UK for MAFF, and with a foodchain model developed by the Central Electricity Generating Board. FARMLAND has also been used in the BIOMOVS intercomparison exercise. In the model comparison studies, the activity concentrations in food predicted by FARMLAND and other models were in reasonable agreement, and the same pattern of time dependence was seen. Where agricultural practices were not fixed as input these led to the largest differences between model predictions. Agreement was generally closest for strontium, caesium and iodine, elements which have been extensively studied and the largest differences were for plutonium and ruthenium for which data are poor. In the BIOMOVS model intercomparison the predictions of FARMLAND and other foodchain models have shown that FARMLAND compares favourably with other major foodchain models in Europe. The performance of FARMLAND in these exercises gives confidence in the implementation of the model as differences between models are largely due to the choice of parameter values and assumptions on agricultural practice.

Validation

FARMLAND has also been tested against different types of measured data. These were data from field studies in Cumbria[6], activity concentrations in milk from fallout due to weapons testing over the last 30 years[7], and, more recently, measurements made in various foods after the Chernobyl reactor accident[8,9] both from monitoring programmes and site-specific measurements. The comparison of FARMLAND predictions with measurement data and especially post-Chernobyl measurements has strengthened confidence in the validity of the model for use in general assessments for which it was intended. However, where discrepancies occurred these were found to be due to differences between assumptions made in the default FARMLAND model and the actual conditions encountered, and where deposition occurred in rainfall. FARMLAND does not account for wet and dry deposition explicitly.

Most models have been validated to some extent by comparing their results with experimental observations. Such comparisons provide a crude indication of model uncertainty but there is no guidance on how to determine the likely uncertainty in situations for which the model has not been validated.

Uncertainty

There are a number of stages in the development and use of a model each of which introduces uncertainty into model predictions. Different sources of uncertainty can be grouped as follows:

Measurement uncertainty: uncertainty in field or laboratory derived data. Empirical data may form the basis for the development of a new model or an input to an existing model.

Conceptual uncertainty (or conceptual model uncertainty): uncertainty in the process of model design. Uncertainties arise when we draw together essentially sketchy information about the behaviour of radionuclides in the environment from field and laboratory studies into a coherent conceptual model. A number of conceptual models might be consistent with the data available, given that the data themselves are uncertain and may be limited. The choice of the most appropriate model can introduce a major element of uncertainty.

Modelling uncertainty: uncertainty in representing the conceptual model in mathematical and then computational terms. This includes the use of simplifying assumptions, discretisation and numerical methods of solution. An example of a simplifying assumption is the representation of the continuous variation of atmospheric conditions by a finite number of discrete stability classes.

Completeness uncertainty is the uncertainty resulting from the omission of a process which is important to the situation being modelled. It can be considered as a part of conceptual modelling uncertainty.

Parameter uncertainty: uncertainty caused by not knowing the most appropriate value to choose for the various parameters in the model.

The extent to which these uncertainties can be quantified varies considerably. For example, a relatively large amount is known about the errors involved in using numerical methods to solve equations, (they are applicable generally to methods in mathematical computing), and the uncertainty from this source can be constrained. Considerable research effort is currently being devoted to methods of analysing the uncertainty in predictions, although the emphasis has been on parameter uncertainty. The likely uncertainty arising from conceptual and modelling uncertainties cannot easily be quantified, and little progress has been made in this area.

Tables I–IV place the Multiple Pathways Scenario S calculations within the uncertainty analysis context. The purpose of the tables is to indicate the sources of uncertainty associated with the calculation of activity concentrations in food using FARMLAND and the transfer factor approach, and uncertainty associated with the calculation of whole body contents and dose quantities.

The discussion has shown that uncertainties associated with model design, the use of inappropriate assumptions and to a lesser extent mathematical and measurement uncertainty cannot be quantified readily. The extent to which these uncertainties are propagated through a dose calculation is still less clear. It is important to state precisely what an uncertainty estimate is intended to quantify when presenting predictions or the results of calculations. Estimates of uncertainty are typically quoted with the implication that a comprehensive range of uncertainties are accounted for, when the reality is that only parameter uncertainty has been quantified explicitly.

The problem of quantifying model parameter uncertainty has received the greatest attention from modellers. A multiplicative approach to quantifying parameter uncertainty has been proposed in which the uncertainty in a dose prediction for example, is assumed to be the product of uncertainties incurred at each level of calculation. This approach relies on the assumption that given the expected range of a model parameter, each value has an equal chance of being selected. This is not the case and the process of assigning a distribution to all parameters presents many difficulties.

Acknowledging the problems associated with quantifying uncertainty as outlined above, for the purposes of this exercise our approach to uncertainty has been pragmatic. FARMLAND does not have the facility to quantify parameter or any other form of uncertainty. The anticipated uncertainties presented below are therefore based on experience. They attempt to quantify the range of uncertainties, ie, those associated with model development, mathematical interpretation of the conceptual model, empirical data and the use of model parameters.

(1) Estimates of daily intake, total dose, ingestion dose, whole body burden, external and inhalation doses were expected to be within a factor of 10 of the observed values.

(2) Food activity concentrations were expected to be within a factor of 20 of the observed values.

(3) All predictions were expected to be conservative, ie, food activity concentrations, body burdens and doses were generally expected to be over-predicted.

2.3. Detailed documentation of FARMLAND

Detailed documentation of the FARMLAND model including descriptions of procedures, equations and parameters are given in reference 10.

TABLE I. UNCERTAINTIES ASSOCIATED WITH THE PREDICTION OF FOOD CONCENTRATIONS USING FARMLAND

Food concentration	Source of uncertainty	
Milk	***FARMLAND* model**	
Beef		conceptual uncertainty
Green vegetables		mathematical uncertainty
Wheat		parameter uncertainty
Rye		inappropriate assumptions, eg yield
	Measurement uncertainty	
		Chernobyl deposition data for agricultural regions
	Data uncertainty	
		food production information

TABLE II. UNCERTAINTIES ASSOCIATED WITH THE CALCULATION OF WHOLE BODY CONTENTS

Source of uncertainty	
FARMLAND model used to calculate ^{137}Cs concentrations in foods and environmental materials	
	conceptual uncertainty
	mathematical uncertainty
	parameter uncertainty
	inappropriate assumptions, eg yield
Measurement uncertainty	
	Chemboyl deposition data for agricultural regions
	Surface water concentrations (fish only)
Data uncertainty	
	Food production information
Human consumption rates	
Whole body retention data	
Gastro-intestinal uptake factors	

TABLE III. UNCERTAINTIES ASSOCIATED WITH THE CALCULATION OF DOSE QUANTITIES

Dose	Source of uncertainty	
External; cloud		conceptual uncertainty
External; deposited material		mathematical uncertainty
Internal; inhalation of cloud		parameter uncertainty
Internal; inhalation of resuspended material		inappropriate assumptions
	Measurement uncertainty	
		deposition data
	Inappropriate assumptions	
		deposition velocity
		factor relating air concentration to external dose rate
	Dose per unit intake data	

TABLE IV. UNCERTAINTIES ASSOCIATED WITH THE PREDICTION OF FOOD CONCENTRATION USING THE TRANSFER FACTOR APPROACH

Food concentration	Source of uncertainty
	FARMLAND used to calculate environmental concentration et ^{137}Cs in soil or pasture
Mushrooms	conceptual uncertainty
Big game	mathematical uncertainty
Small game	parameter uncertainty
Pork	inappropriate assumptions, eg yield
Fish	**Measurement uncertainty**
	Chernobyl deposition data for agricultural regions
	Surface water concentrations (fish only)
	Data uncertainty
	Food production information
	Selection of equilibrium transfer coefficient for foodstuff

2.4. Methodology adopted for the Scenario S exercise

The purpose of this section is to outline the procedures adopted for calculating the quantities required by Scenario S. The prediction of certain quantities, eg total deposition, whole body contents, external dose, inhalation dose and total dose do not lie within the scope of FARMLAND. These calculations are described in detail. FARMLAND was used to estimate ^{137}Cs activity concentrations in various food stuffs. There was no attempt to fine tune the suite of models to replicate the detail given in the scenario outline. However, minor adjustments to agricultural practices were made and these are indicated.

2.4.1. Total ^{137}Cs Deposition and Inventory

The mean ^{137}Cs deposition over the entire study region S (Bq m^{-2}) was calculated using the following methodology:-

(1) Deposition data presented in the Scenario S description Table VII for 11 monitoring stations in 9 subregions were used. For each station, monthly or daily deposition data were summed over the entire deposition period. Where 2 monitoring stations occurred in one region, mean values for the deposition period were summed.

(2) Scenario S Figure 4 and Table XII were used to establish the areas (m^2) over which the deposition occurred.

(3) The mean weighted deposition over region S was calculated using the following formula:-

$$D_{ws} = \sum_{i=1}^{n} D_i \times \frac{A_i}{A_s} \qquad (1)$$

where

D_{ws} = mean weighted deposition for region S (Bq m^{-2})
D_i = deposition in subregion i (Bq m^{-2})
A_i = area of subregion i (m^2)
A_s = area of region S (m^2)
n = number of deposition subregions

The ^{137}Cs inventory over the entire study region S (Bq m^{-2}) was calculated using stage 1 as above and the following formula:-

$$I_s = \sum_{i=1}^{n} (D_i \times A_i) \qquad (2)$$

where

I_s = ^{137}Cs inventory for region S (Bq)
D_i = deposition in region i (Bq m^{-2})
A_i = area of region i (m^2)

2.4.2. Food items contributing to total diet

For the purposes of model prediction, the entire Chernobyl deposit was assumed to have been deposited on 27 April 1986.

2.4.2.1. Milk

The FARMLAND soil-pasture-cow module was used to provide estimates of ^{137}Cs activity concentrations in milk at the times specified, given a unit deposit of 1 MBq m^{-2}. Default grazing intensities (400 cows km^{-2}) and milk yields (10 l d^{-1} cow^{-1}) were assumed. The default model was adjusted to account for the precise timing of the deposit, the seasonal movement of cattle indoors and outdoors and the storage and winter consumption of silage. In 1986, it was assumed that the movement of cows from indoor quarters to the fields was delayed until 26 May. In subsequent years cattle were kept indoors until 10 May. In all years cattle were brought indoors for the winter season on 20 September. The approach did not account for variation in livestock diet or milk yield from region to region. Cattle were assumed to eat pasture in the summer and silage in the winter. No other animal feeds were considered. Milk was taken as having a unit density, ie, 1 kg l^{-1}.

The mean ^{137}Cs activity concentration in milk (Bq kg^{-1}) in region S was calculated for each output time as follows:

$$C_{milk} = \sum_{i=1}^{n} \frac{I_i \, D_i \, P_i}{Y \, d \, P_s} \qquad (3)$$

where

C_{milk} = ^{137}Cs activity concentration in milk (Bq kg^{-1})
I_i = Integrated ^{137}Cs inventory in milk from a unit deposit of ^{137}Cs in subregion i. (Bq d m^{-2} per MBq m^{-2}). $I_i = I_{t2} \dagger I_{t1}$ where t2 and t1 define the integration period.
D_i = deposition in subregion i (MBq m^{-2})
Y = daily milk yield (4.0 10^{-3} kg m^{-2})
d = number of days between integrated ^{137}Cs inventory predictions (d)
P_i = milk production in subregion i. (kg)
P_s = milk production in region S. (kg)
n = number of agricultural subregions

2.4.2.2. Beef

For the purposes of modelling, beef cattle were assumed to have identical physiological and metabolic characteristics as dairy cattle and to be subject to the same husbandry. Integrated ^{137}Cs inventories in cattle meat (Bq d^{-1} m^{-2}) were generated by the FARMLAND model run for milk as Section 2.4.2.1. A grazing density of 400 beef cattle per km^2 and a yield of 360 kg of meat per animal were assumed.

The mean ^{137}Cs activity concentration in beef (Bq kg^{-1}) in region S was calculated for each output time as follows:

$$C_{beef} = \sum_{i=1}^{n} \frac{I_i \, D_i \, P_i}{Y \, d \, P_s} \tag{4}$$

where

C_{beef}	=	^{137}Cs activity concentration in beef (Bq kg^{-1})
I_i	=	Integrated ^{137}Cs inventory in beef from a unit deposit of ^{137}Cs in subregion i. (Bq d m^{-2} per MBq m^{-2}). $I_i = I_{t2} - I_{t1}$ where t2 and t1 define the integration period.
Y	=	beef yield (0.144 kg m^{-2})
d	=	number of days between integrated ^{137}Cs inventory predictions (d)
P_i	=	beef production in subregion i. (kg)
P_s	=	beef production in region S. (kg)
n	=	number of agricultural subregions
D_i	=	deposition in subregion i (MBq m^{-2})

2.4.2.3. Leafy vegetables and root vegetables

The FARMLAND leafy green and root vegetable models were run for a unit deposit of 1 MBq m^{-2}. The interception factor was assumed to be 0.3 for green vegetables and 0.4 for root vegetables. The FARMLAND model assumes yields of 1 kg m^{-2} and 0.4 kg m^{-2} for a green and root vegetables respectively. For short term deposits, FARMLAND models the cropping of green and root vegetables as a continuous removal from the system. The intention here was to assess the performance of the default leafy green vegetable module. No adjustments to account for regional variation in cropping practices were made. The ^{137}Cs activity concentration in leafy green and root vegetables was calculated as follows:-

$$C_{veg} = \sum_{i=1}^{n} \frac{I_i \, D_i \, P_i}{Y \, d \, P_s} \tag{5}$$

where

C_{veg}	=	^{137}Cs activity concentration in green/root vegetables (Bq kg^{-1})
I_i	=	Integrated ^{137}Cs inventory in green/root vegetables from a unit deposit of ^{137}Cs in subregion i. (Bq d m^{-2} per MBq m^{-2}). $I_i = I_{t2} - I_{t1}$ where t2 and t1 define the integration period.
Y	=	green vegetable yield (1 kg m^{-2}) root vegetable yield (0.4 kg m^{-2})
d	=	number of days between integrated ^{137}Cs inventory predictions (d)
P_i	=	green/root vegetable production in subregion i. (kg)
P_s	=	green/root vegetable production in region S. (kg)
n	=	number of agricultural subregions
D_i	=	deposition in subregion i (MBq m^{-2})

2.4.2.4. Cereals

The default FARMLAND grain module was set up without modification to calculate integrated ^{137}Cs inventories in the edible portions of grain (wheat and rye) for the harvests of 1986 to 1990. An instantaneous unit deposit of 1 MBq m^{-2} was assumed to occur on 27 April 1986. The sowing date for grain was assumed to be 20 May. It follows that no interception of the deposit by grain occurred. In 1986, cereals were assumed to be harvested on 20 August, the second crop was sown on 20 May 1987 and harvested 20 August 1987. During the winter period the ground was assumed to be fallow.

Continuous cropping was assumed from 1988 onwards, ie, an annual average rate constant is used to simulate the removal of crops. The ^{137}Cs activity concentration in rye and wheat were calculated as follows:

$$C_{grain} = \sum_{i=1}^{n} \frac{I_i\ D_i\ P_i}{Y\ d\ P_s} \tag{6}$$

where

C_{grain} = ^{137}Cs activity concentration in wheat/rye (Bq kg^{-1})
I_i = Integrated ^{137}Cs inventory in wheat/rye from a unit deposit of ^{137}Cs in subregion i. (Bq d m^{-2} per MBq m^{-2}). $I_i = I_{t2} - I_{t1}$ where t2 and t1 define the integration period.
Y = wheat and rye yield (0.4 kg m^{-2})
d = number of days between integrated ^{137}Cs inventory predictions (d)
P_i = wheat/rye vegetable production in subregion i. (kg)
P_s = wheat/rye vegetable production in region S. (kg)
n = number of agricultural subregions
D_i = deposition in subregion i (MBq m^{-2})

2.4.2.5. Pork

At present there is no dynamic model for the transfer of radionuclides to pigs available at NRPB. An equilibrium transfer approach was therefore used for the uptake of radiocaesium in to pigs. The diet of pigs was assumed to consist of grain only. Grain consumed by pigs was assumed to be harvested in the previous year. The grain eaten in 1986 was therefore assumed to be uncontaminated. Results produced by the FARMLAND grain model, (see Section 2.4.2.4) formed the basis of the calculation of ^{137}Cs activity concentrations in pork. ^{137}Cs activity concentration in grain at the end of each harvest was scaled for the regional Chernobyl deposit and pork production, multiplied by consumption of grain by pigs and the equilibrium transfer factor. Pigs were assumed to eat 1 kg d^{-1} of contaminated grain.

2.4.2.6. Game

^{137}Cs activity concentrations in large game (moose) and small game (wildfowl) were calculated using a simple transfer factor approach since there are no models for these foods available at NRPB.

Wildfowl

Information concerning the feeding behaviour and transfer factors for geese and ducks were taken from a paper by Lowe and Horrill[11], (1986). The paper looks at the transfer of radionuclides to man from the consumption of greylag geese and widgeon which graze the saltmarshes around the Ravenglass Estuary, Cumbria, UK. The assumption is made that these data are applicable for inland feeding by wildfowl. To calculate the ^{137}Cs activity concentration in wildfowl 3 quantities need to be derived:

* Transfer factor for uptake of ^{137}Cs into edible portions of the birds (d kg^{-1})
* ^{137}Cs activity concentration in the birds' diet (Bq kg^{-1})
* Daily intake of food by the birds (kg d^{-1})

(1) Transfer factors for the uptake of radiocaesium into the edible parts of the birds were derived thus

$$T_f = \frac{C_b}{C_t} \tag{7}$$

where

T_f = transfer factor for uptake of ^{137}Cs into wildfowl (d kg^{-1})
C_b = ^{137}Cs activity concentration in breast muscle (Bq kg^{-1})
C_t = ^{137}Cs activity concentration in faeces (Bq kg^{-1}) x mass of faeces produced per day (kg $^{d-1}$) at equilibrium. This quantity (Bq d^{-1}) is assumed to be equivalent to the daily intake of ^{137}Cs activity from the birds' diet.

Therefore: Greylag goose T_f = 0.59 d kg^{-1}
Widgeon T_f = 0.57 d kg^{-1}

(2) The diet of widgeon and greylag geese was assumed to comprise 50% grain and 50% grass. The FARMLAND model was therefore use to derive mean ^{137}Cs activity concentrations in grass and grain given a unit deposit of 1 MBq m^{-2}, which was then scaled to account for the deposition in each subregion.

(3) To derive an estimate of the daily food intake of geese and ducks, all birds were assumed to be adults and therefore were not growing and gaining in weight. It was therefore assumed that the mass of faeces equalled the mass of food ingested. An estimate of the food intake per day was made given the defecation rate, dry weight of faeces and the dry weight of the food.

TABLE V. DAILY FOOD INTAKE FOR DUCKS AND GEESE

	Daily food intake (kg d^{-1})	
Bird	grass	grain
Widgeon	0.36	0
Greylag goose	0.37	0.16

The ^{137}Cs activity concentration in wildfowl in each region was calculated as follows accounting for differences in feeding habits where applicable:-

$$C_b = \frac{(I_{P2} - I_{P1})\, D_c\, I_p\, T_f}{d\, Y_p} + \frac{(I_{G2} - I_{G1}) D_c\, I_g\, T_f}{d\, Y_g} \qquad (8)$$

where

C_b = ^{137}Cs activity concentration in the breast muscle of greylag geese or widgeon (Bq kg^{-1})
P = pasture
G = grain
I_2 = integrated ^{137}Cs inventory in pasture or grain at the end of the integration period. Bq d m^{-2} per unit deposit, ~(MBq m^{-2}).
I_1 = integrated ^{137}Cs in inventory in pasture or grain at the beginning of the integration period. Bq d m^{-2} per unit deposit (MBq m^{-2})
d = number of days in the integration period (d)
Y = yield (pasture = 0.5 kg m^{-2}, grain = 0.4 kg m^{-2})
D_c = ground deposition due to Chernobyl accident (Bq m^{-2})
I = daily intake of pasture and grass (kg d^{-1}) as table above.
T_f = transfer factor for uptake of ^{137}Cs in to breast muscle (d kg^{-1})

Moose

Equilibrium transfer factors for moose (0.02 Bq kg^{-1} per Bq m^{-2} for 1986/7 and 0.03 Bq kg^{-1} per Bq m^{-2} for 1988) were obtained from the literature[12,13]. The FARMLAND soil model was used to estimate the integrated inventory of ^{137}Cs in the surface layers of soil (Bq d m^{-2}) following an instantaneous unit deposit of 1 MBq m^{-2}. For each time period required by Scenario S, integrated inventories were converted to a mean inventory in soil (Bq m^{-2}) and scaled to represent the Chernobyl deposit. The moose transfer factor was applied and the ^{137}Cs activity concentration in moose meat derived.

2.4.2.7. Mushrooms

The FARMLAND soil-pasture module was used to derive integrated inventories of ^{137}Cs in the top 1 cm of soil substrate on which edible mushrooms were assumed to grow. Output was generated for the times required by the scenario specification. A literature search was conducted to determine the range of uptake factors for ^{137}Cs in mushrooms. A variety of species, substrates and growing conditions were explored. For the purpose of the exercise, the mushroom ***Boletus edulis*** growing in beech woodland, with an uptake factor of 1.0 10^{-1} m^2 kg^{-1}[14] was assumed. The ^{137}Cs activity concentration in mushrooms during the 1986-1990 autumn harvests was calculated thus:

$$C_m = \sum_{i=1}^{n} \frac{I_2 - I_1}{d} \times D_{ci} \times C_f \qquad (9)$$

where

C_m = mean ^{137}Cs activity concentration in edible mushrooms in region S. (Bq kg^{-1})

I_2 = integrated ^{137}Cs inventory in the top 1 cm of soil at the end of the integration period. (Bq d m^{-2} per unit deposit)

I_1 = integrated ^{137}Cs inventory in the top 1 cm of soil at the beginning of the integration period. (Bq d m^{-2} per unit deposit)

d = the number of days in the integration period

D_{ci} = ground deposition in subregion i due to the Chernobyl accident (Bq m^{-2})

C_f = mushroom concentration factor (m^2 kg^{-1})

2.4.2.8. Wild berries

The activity concentration of ^{137}Cs in wild berries was not calculated.

2.4.2.9. Freshwater fish

Mean ^{137}Cs activity concentrations in surface water for each region and year (1986-1990) were extracted from Scenario S Table XIV.

(1) The ^{137}Cs activity concentration in surface water was derived for each year as follows:

1986	mean of surface water concentrations for August and October
1987 & 1988	mean of surface water concentrations for March, May, August and October
1989	Mean concentrations for May, August and October
1990	(No data: surface water concentrations were extrapolated from the trend in the previous years).

(2) Fish concentration factors for predatory, non-predatory and intermediate fish species were derived from the literature:

predatory fish	5700 m^3 t^{-1}
intermediate fish	4000 m^3 t^{-1}
non-predatory	2400 m^3 t^{-1}

(3) For each year the mean ^{137}Cs activity concentration in all fish caught in each subregion was calculated thus:

$$Cs = \sum_{i=1}^{n} \left((Cw_i \times Cf_{(P)i} \times \frac{F_{(P)i}}{F_{Ti}}) + (Cw_i \times Cf_{(NP)i} \times \frac{F_{(NP)i}}{F_{Ti}}) + (Cw_i \times Cf_{(I)i} \times \frac{F_{(I)i}}{F_{Ti}}) \right) \times \frac{F_{Ti}}{F_{Ts}} \qquad (10)$$

where

Cs = mean ^{137}Cs activity concentration in fish in subregion i (Bq kg^{-1})

Cw_i = ^{137}Cs activity concentration in surface water in region i (Bq L^{-1})

$Cf_{(P)}$ = concentration factor for predatory fish (Bq kg^{-1} per Bq L^{-1})

$Cf_{(NP)}$ = concentration factor for non-predatory fish (Bq kg^{-1} per Bq L^{-1})

$Cf_{(I)}$ = concentration factor for intermediate fish (Bq kg^{-1} per Bq L^{-1})

$F_{(P)i}$ = predatory fish catch in region i (kg)

$F_{(NP)i}$ = non-predatory fish catch in region i (kg)

$F_{(I)i}$ = intermediate fish catch in region i (kg)

F_{Ti} = total fish catch in region i (kg)
F_{TS} = total fish catch in region s (kg)

In summary, the calculation of ^{137}Cs activity concentration in fresh water fish has taken account of the relative contributions of predatory, non-predatory and intermediate fish caught in each subregion, and the size of the subregional fish catch in relation to the total catch in region S.

2.4.2.10. Animal feeds; Barley and Oats

Calculated as Section 2.4.2.4.

2.4.3. Human intake

Assumptions associated with the calculation of human intakes arising from the consumption of contaminated foods are given below:-

(1) The ^{137}Cs contribution from eggs, cheese and poultry meat to human intake were omitted because activity concentrations for these foods were not available.

(2) Food activity concentrations were calculated as described in Section 2.4.2 with the exception of the following:-

* Peas and beans were assumed to be the same as leafy green vegetables. The FARMLAND model was used to calculate ^{137}Cs activity concentrations in peas and beans as described in Section 2.4.2.3.
* Fruit was assumed to be the same as leafy green vegetables for modelling purposes. Intake rates for fruit vegetables, fruit (non-berry), garden berries and wild berries were summed and considered as a single group; fruit.

Consumption rates used to calculate ^{137}Cs human intakes are given in Table VI.

2.4.4. Whole body concentrations

Body contents were calculated for men, women and children for 9 population groups, from daily ingestion data and daily inhalation data. The latter includes contributions from inhalation activity in the plume and inhalation of resuspended activity. The contribution from ingested activity is by far the dominant factor.

For ingestion, a gastro-intestinal uptake factor (f_1) of 1.0 was used[15]. For inhalation, the lung class was assumed to be Class D[15]. In the absence of specific information, a particle size (AMAD) of 1 μm was assumed, corresponding to a lung deposition fraction of 0.63. For both intake pathways, systematic uptake could be assumed to be instantaneous. Thus, for ingestion, daily systematic uptake was taken to be equal to daily intake, while for inhalation, daily systematic uptake was assumed to be equal to (0.63 × daily intake).

Total body activity, A_i, on each day, i arising from all intakes from day 1 to day i was calculated as follows:

$$A_i = \sum_{j=1}^{i} U_j \, R_t \qquad (11)$$

where

A_i = total body activity (Bq) on day i
U_j = uptake (Bq) on day j
$R_{(t)}$ = whole body retention of Cs. Where t represents the period between the day of uptake, j and the day for which whole body activity is being assessed, i.

Activities were calculated for each day between 27 April 1986 and 1 January 1991. Retention function parameters are given below. The values for children are those for a five year old child. Retention function parameters are also available[13] for the following ages: 3 months, 1 year, 10 years and 15 years.

TABLE VI. CONSUMPTION DATA (kg d^{-1}) USED IN THE SCENARIOS CALCULATION OF HUMAN INTAKES

Food product	Men	Women	10 year olds
Milk	0.87[1]	0.57[1]	0.74[4]
Beef	0.064[1]	0.049[1]	0.056[5]
Pork	0.088[1]	0.054[1]	0.056[5]
Game	0.0042[1]	0.0034[1]	0
Fish (freshwater)	0.015[1]	0.01[1]	0.0165[6]
Rye	0.058[1]	0.042[1]	0.052[7]
Wheat	0.135[1]	0.109[1]	0.052[7]
Other cereals	0.038[1]	0.028[1]	0.052[7]
Leafy vegetables	0.035[1]	0.045[1]	0.093[8]
Peas and beans	0.01[1]	0.01[1]	0.093[8]
Root veg and potatoes	0.26[2]	0.2[2]	0.119[9]
Fruit	0.317[3]	0.375[3]	0.225[10]
Wild mushrooms	0.0036[1]	0.0036[1]	0

Notes

1 As presented in Table XXXVII.
2 Sum of consumption rates for root vegetables and potatoes.
3 Sum of consumption rates for fruit vegetables, fruit, garden berries and wild berries.
4 Mean of milk and milk product consumption rates for 9 and 12 year old children.
5 Mean of meat and meat product consumption rates for 9 and 12 year old boys and girls divided between pork and beef.
6 Mean of fish and fish product consumption rates for 9 and 12 year old boys and girls.
7 Mean of cereal products consumption rate for 9 and 12 year old boys and girls
divided between wheat, rye and other cereals.
8 Assume consumption rate for vegetables in VAMP scenario applies to peas and
beans and to leafy vegetables equally. 0.093 kg d^{-1} applies to peas and beans as well as leafy vegetables.
9 Mean of potato consumption rate for 9 and 12 year old boys and girls.
10 Mean of fruit and berry consumption rates for 9 and 12 year old boys and girls.

Whole body activities were given in Bq which were then converted to activities per mass by assuming the following body weights:

men	70 kg	(ICRP 23: reference adult male)
women	58 kg	(ICRP 23: reference adult female)
children	32 kg	(ICRP 23: data taken from Figure 7)

TABLE VII. RETENTION FUNCTION PARAMETERS FOR CAESIUM

	Fraction	Half time (d)
Men[16]	0.1	2.0
	0.9	90
Women[17,18]	0.1	2.0
	0.9	65
Children[16]	0.45	9.0
	0.55	30

2.4.5. Dose calculations

2.4.5.1. Methodology for the calculation of ingestion dose

(1) Population weighted intakes of ^{137}Cs for region S (Bq d^{-1}) were calculated for each averaging period for men, women and children.

(2) The ^{137}Cs intake during each averaging period (Bq) was calculated by multiplying by the mean daily intake by the number of days in the averaging period.

(3) Dose per unit intake (DPUI) values for ingestion were taken from NRPB-R245[21].

men	$1.3\ 10^{-8}$ Sv Bq^{-1}
women	$1.3\ 10^{-8}$ Sv Bq^{-1}
children	$1.0\ 10^{-8}$ Sv Bq^{-1}

(4) The committed effective dose to the test person integrated over 50 years (60 years for children) was derived from the DPUI and the total intake of ^{137}Cs during the food consumption period.

2.4.5.2. Methodology for the calculation of inhalation dose

Inhalation of the plume

Activity concentrations in air from the air samplers at AIR 1 and AIR 2 were not thought to be representative of the entire region, however a representative mean weighted deposition for the region had already been calculated to satisfy the requirements of the Scenario, see Section 2.4.1. Mean weighted deposition data was used to calculate an integrated mean activity concentration in air for the region during the period of plume passage as follows:-

$$A = \frac{D_{ws}}{D_{vel}} \qquad (12)$$

where

D_{ws} = weighted deposition for region S (Bq m^{-2})

A = integrated air concentration (Bq s m^{-3})

D_{vel} = total deposition velocity (assumed to be $1\ 10^{-2}$ m s^{-1})

The air concentration was then used to calculate an individual intake and subsequent dose.

$$D_e = A \times I \times DPUI \tag{13}$$

where

D_e = committed effective dose (Sv)
A = integrated air concentration (Bq s m^{-3})
I = air intake (inhalation) rate (m^3 s^{-1})
DPUI = dose per unit intake (Sv Bq^{-1})

Inhalation of resuspended materials

A time dependent resuspension factor approach was adopted to calculate doses from resuspended activity previously deposited during the plume passage. Greater detail of the model can be found in reference 19 and the equation for time dependent resuspension is given below. The equation gives an integrated resuspended air concentration which can in turn be used to calculate average air concentrations over any period of interest. For modelling purposes it was assumed that all the deposition occurred on 27 April 1986, using deposition data for the different population regions.

$$I_r = D_p \int_1^T \frac{1.2\ 10^{-6}\ \exp(-\lambda T)}{T}\ \delta T \quad (T \geq 1\ \text{day}) \tag{14}$$

where

I_r = integrated resuspended air concentration (Bq d m^{-3})
D_p = deposition in population area of interest (Bq m^{-2})
λ = decay constant for radionuclide of interest (days)
T = time period at which integrated air concentration is required (days)

The average activity concentration, was used to calculate individual intake and subsequent dose.

$$D_e = I_r \times I \times DPUI \tag{15}$$

where

D_e = committed effective dose (Sv)
I_r = average activity concentration in air (Bq d m^{-3})
I = intake rate of air (m^3 d^{-1})
DPUI = dose per unit intake via inhalation (Sv Bq^{-1})

2.4.5.3 Methodology for the calculation of external dose

Gamma irradiation from airborne activity

The dose from gamma irradiation due to activity in air was calculated using the semi-infinite cloud model as described in reference 20, see equation below. Although ^{137}Cs is not itself a gamma emitter it is assumed to be in equilibrium with ^{137m}Ba. An average air concentration derived from the weighted deposition for the entire region was used as the source term X. A conversion factor of 0.7 Sv Gy^{-1} was used to convert absorbed dose in air to effective dose. Information concerning the degree of urbanisation of region S was given in Table XXXIV of the scenario description. The data suggests that 66% of the population is urban and 34% is rural. Accounting for shielding the urban population was assumed to spend 90% of their time indoors and 10% of their time outdoors. The rural population was assumed to spend 50% of their time indoors and outdoors.

$$D = K_1\ X \sum_{j=1}^{n} I_j\ E_j\ [\ (L_i\ C_i) + (L_o\ C_o)\ ] \tag{16}$$

where

D = absorbed dose in air (Gy)
K_1 = constant (6.36 10^{-14} Gy per MeV m^{-3})
X = air concentration (Bq s m^{-3})
I_j = fraction of photons of initial energy E_j emitted per disintegration

E_j = initial energy of the photon (MeV)
n = number of photons of particular energies emitted per disintegration
L_i = indoor location factor = 0.2
L_o = outdoor location factor = 1.0
C_i = indoor occupancy (%)
C_o = outdoor occupancy (%)

Deposited gamma dose

External doses arising from a unit deposit (1 MBq m^{-2}) were obtained from a model as described in reference 19. External dose from a unit deposit was then scaled by the population weighted Chernobyl deposition as follows. In acconting for shielding, the population distribution between rural and urban environments and indoor and outdoor occupancy were considered as described in the section on cloud gamma dose.

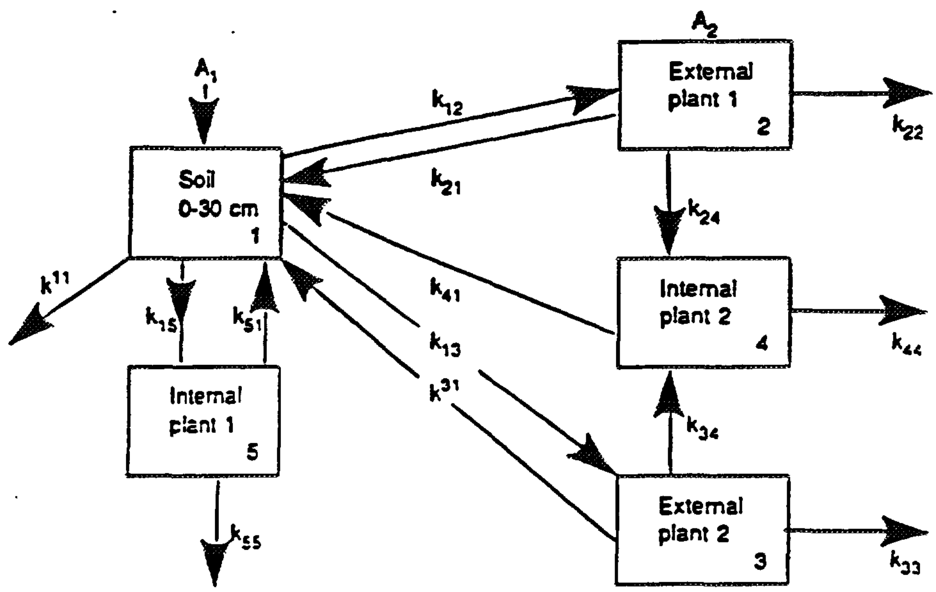
$$D_s = D \sum_{i=1}^{n} DEP \times \frac{P_i}{P_S} [(L_i C_i) + (L_o C_o)] \tag{17}$$

where

D_s = mean external gamma dose for region S (Sv)
D = external gamma dose from a unit deposit (Sv per MBq m^{-2})
DEP = ^{137}Cs deposition in each population region i (MBq m^{-2})
P_i = population of region i
P_s = population of region S
L_i = indoor location factor = 0.1
L_o = outdoor location factor = 1.0
C_i = indoor occupancy (%)
C_o = outdoor occupancy (%)

2.5. Diagrams indicating the structure of the FARMLAND model

Green vegetables

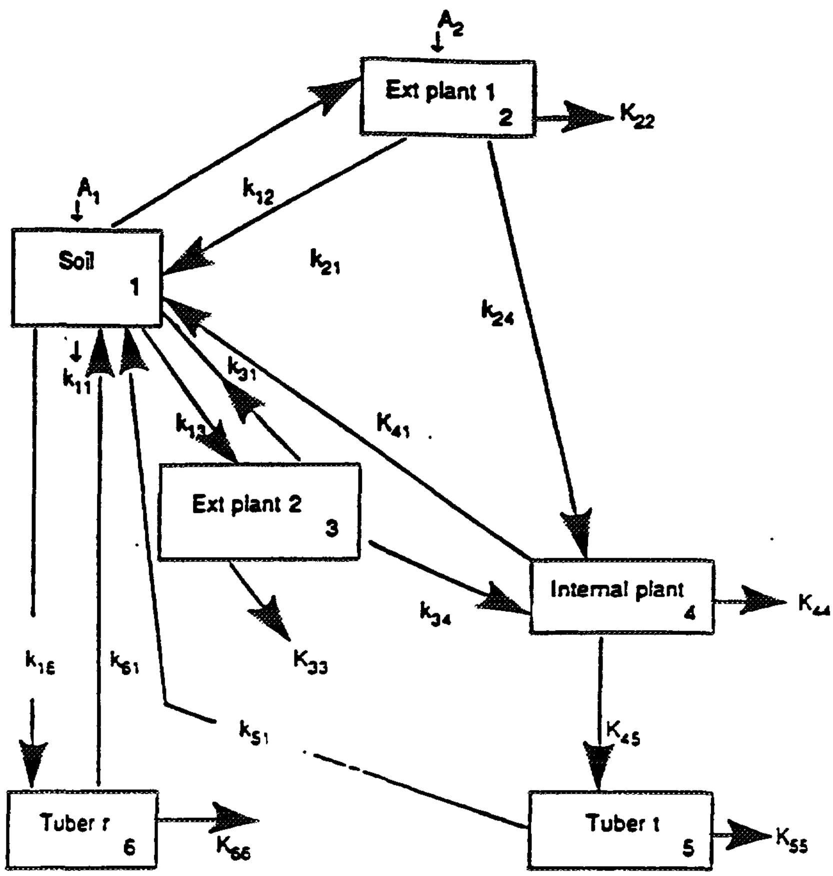


Inputs	A_1	=	(1 - p) units
	A_2	=	p units
where	p is the interception factor (see Table 3 16).		

Notes

1. External plant (1) is for direct deposition and initial resuspension.
   External plant (2) is for soil contamination.
2. Internal plant (1) is for root uptake.
   Internal plant (2) is for translocation of the surface deposit.
3. k_{12} represents initial resuspension on to external plant.
   k_{21} represents removal due to weathering processes with a 14-day half-life.
4. The translocation process is represented using the transfer coefficients k_{24}, k_{34} and k_{41}.
5. Periodic cropping of the plant throughout the year is represented by the transfer coefficients k_{22}, k_{33}, k_{44} and k_{55}. The value for these transfer coefficients is based on 2 crops per year.

Root vegetables and potatoes

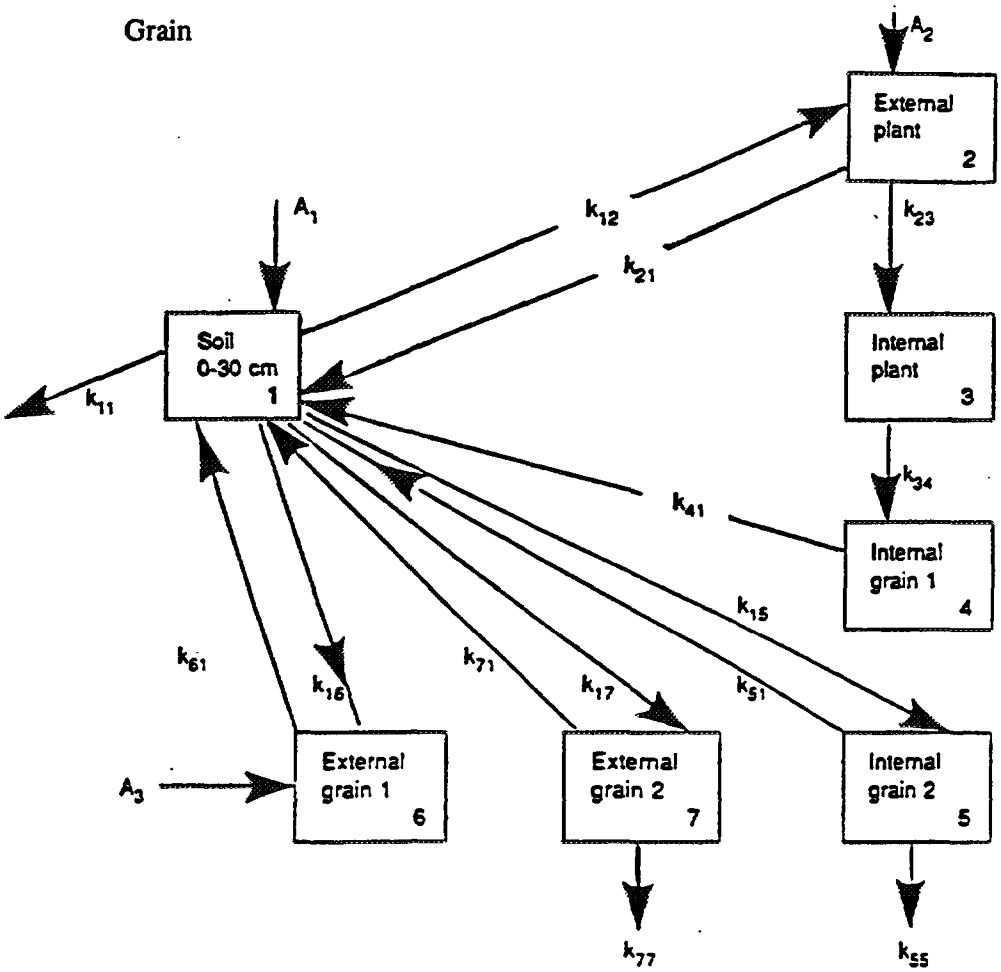


Inputs A_1 = (1 - p) units
A_2 = p units
where p is the interception factor (see Table 3.18).

Notes

1 External plant 1 is for direct deposition and initial resuspension.
External plant 2 is for soil contamination.
2 Internal plant is for translocation of the surface deposit.
3 Tuber t is for translocation of the surface deposit.
Tuber r is for root uptake.
4 k_{12} represents initial resuspension onto the plant.
k_{21} represents removal due to weathering processes with a 14 day half-life.
5 The translocation process is represented using the transfer coefficients
k_{24}, k_{34}, k_{45} and k_{51}.
6 Cropping of the plant throughout the year is represented by the transfer coefficients
k_{22}, k_{33}, k_{44}, k_{55} and k_{66} based on one crop per year.

Grain



Inputs $A_1 = 1 - (P_1 + P_2)$ units

$A_2 = P_1$ units

$A_3 = P_2$ units

where P_1 and P_2 are interception factors for the external plant and external grain respectively (see Table 3.18).

Notes:

1 External plant is for initial resuspension and direct deposition on to the whole cereal plant.

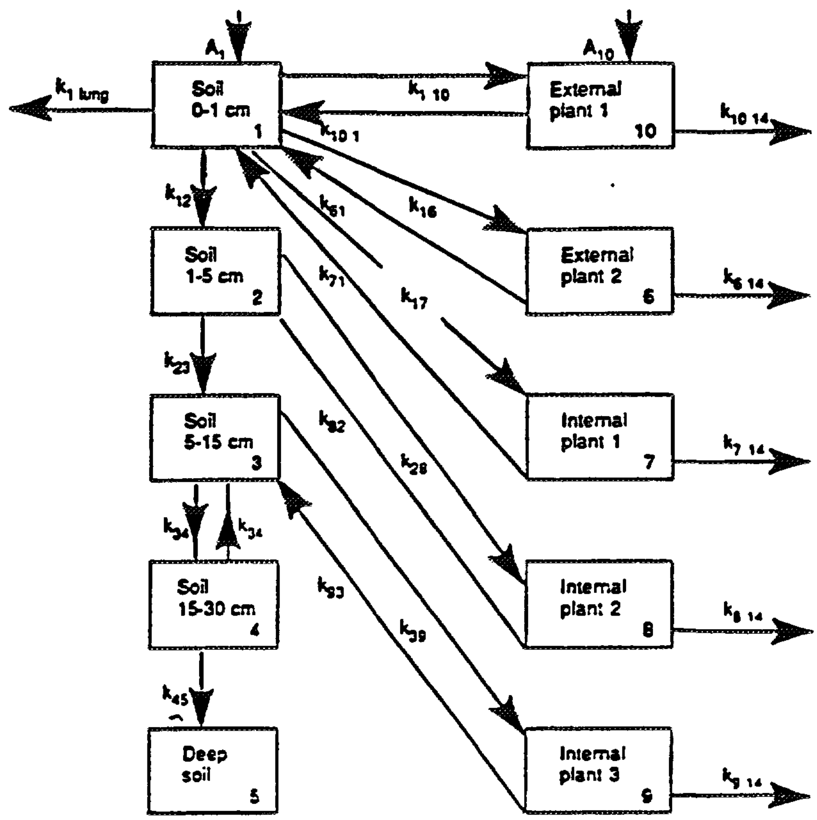
2 Internal grain (2) is for root uptake.
External grain (1) is for initial resuspension and direct deposition on to the grain seed.
External grain (2) is for soil contamination of grain.

3 k_{12} represents initial resuspension on to the whole cereal plant in the period immediately after the input.
k_{21} represents removal due to weathering processes from the whole cereal plant.

4 k_{16} represents initial resuspension on to grain seed in the period immediately after the input.
k_{61} represents removal due to weathering processes from grain.

5 The translocation process is represented by transfer coefficients k_{23}, k_{34} and k_{41}.

Undisturbed pasture



Inputs A_1 = (1 - p) units

A_{10} = p units

where p is the interruption factor (see Table 3.18)

Notes

1 This is the basic model for undisturbed pasture. There is an additional part of the model for caesium which is described later.

2 External plant (1) is for direct deposition and initial resuspension.
External plant (2) is for surface soil contamination of the plant, represents all soil consumed by an animal on the pasture.

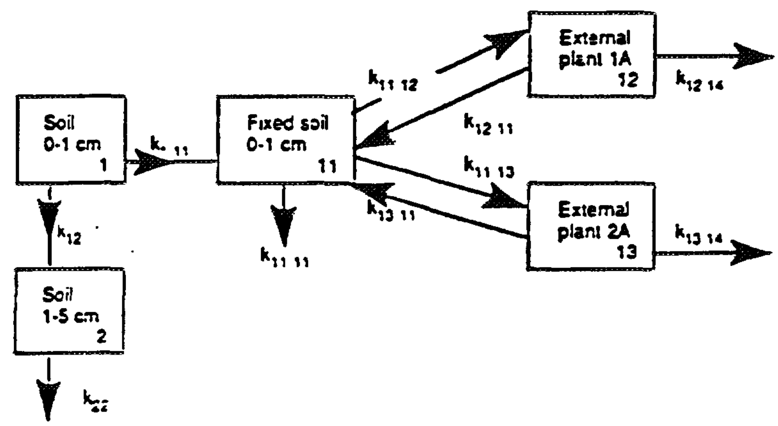
3 The internal plant compartments represent root uptake from the different layers of soil.

4 $k_{1\ 10}$ represents resuspension on to the plant surface, and $k_{10\ 1}$, the losses due to weathering processes.

5 $k_{6\ 14}$, $k_{7\ 14}$, $k_{8\ 14}$, $k_{9\ 14}$ and $k_{10\ 14}$ represent losses from the pasture due to its consumption by animals.

6 $k_{1\ lung}$ represents inhalation by the animal of resuspended material from the soil.

Cow model for isotopes of caesium



Notes

1 External plant 1A is used for fixed activity resuspended on to plant surfaces
External plant 2A is used for surface contamination by soil containing fixed activity, and includes any fixed activity consumed by animals.
2 $k_{1\ 11}$ represents the process of fixation.
3 k_{22} represents the loss of activity due to the fixation process in the 1-5 cm layer of soil
4 $k_{11\ 12}$ is a loss term representing migration from the surface soil layer of fixed activity

3. COMPARISON OF OBSERVED DATA AND MODEL PREDICTIONS

3.1. Total deposition and inventory of Chernobyl ^{137}Cs

Observed total deposition (Bq m^{-2}):-		Predicted total deposition (Bq m^{-2}):-	
mean	19900	mean	9003
lower 95%	9950		
upper 95%	29850		

Observed total inventory (Bq)		Predicted total inventory (Bq)	
mean	3.5 10^{15}	mean	1.5916 10^{15}
lower 95%	1.8 10^{15}		
upper 95%	5.3 10^{15}		

The total deposition and inventory in region S were calculated by manipulation of the data given in Table VII of the scenario description, (see Section 2.4.1). These data were chosen because they were considered to represent the type of raw data which would normally be available. Both quantities were underestimated by a factor of ≈2 and fail to lie within the observed uncertainty bounds. Three possible reasons for this are explored:-

(1) Two subregions were represented by a pair of deposition collectors. Samplers 11 and 5 represented region 1, and samplers 9 and 1 represented region 8. Within each region there was

an order of magnitude difference between the deposition collected by the samplers and it was not clear from the Scenario description why this should be the case. As a result, the mean deposition and total ^{137}Cs inventory for the region was calculated using the mean sample deposition for these regions. The estimates have been reworked using the highest deposition value in regions 1 and 8. The results were as follows:-

Predicted total deposition	10669 Bq m^{-2}
Predicted total inventory	1.876 10^{15} Bq

The improvement in predictions is insufficient to support this explanation.

(2) The calculations assumed that deposition occurred uniformly throughout each subregion. This is unlikely to have been the case, particularly if it rained shortly after the accident. Some areas could have experienced more or less deposition than was indicated by the sampler. Indeed, the area over which deposition occurred could have been less than the total area of each subregion. Since spatial distribution of deposition in each region is unavailable, it is difficult to assess how far this explains the difference between the observed and predicted ^{137}Cs deposition and inventory.

(3) A third estimate using ^{137}Cs deposition calculated for agricultural areas (Scenario S, Table V), estimated ^{137}Cs deposition over the entire region S at 19500 Bq m^{-2}. This compares well with the observed value 19900 Bq m^{-2} and falls well within the confidence limits. Proceeding similarly for the total inventory, a value of 3.05 10^{15} Bq is obtained. These data were not used in the initial calculations because they are 'derived' quantities which have already been subject to some form of manipulation. It was felt that it was inappropriate to use these data. A description of how the ^{137}Cs deposition values for each agricultural area (Scenario S, Table V) were derived and how these relate to Scenario S, Table VII, Radiocaesium in wet and dry deposition would be useful.

The dominant source of error in the prediction of the ^{137}Cs deposition and ^{137}Cs inventory for region S, stems from the choice of data used (Tables V and VII Scenario S), and the various ways in which the data can be manipulated. This applies to both observed and predicted quantities.

In subsequent calculations of ^{137}Cs activity in food products a deposition of 19500 Bq m^{-2} was assumed. This was based on the data for agricultural areas given in Table V.

3.2. ^{137}Cs activity concentration in food items contributing to the total diet

3.2.2.1. Milk and beef

Figures 1 and 2 compare observed and predicted ^{137}Cs activity concentrations in milk and beef respectively. The overestimation of activity concentrations can be largely accounted for by differences in diet, particularly for beef cattle. From the feed utilisation data presented for Scenario S, Table XXVI, it can be estimated that beef cattle in the main beef producing areas of region S consume an average of about 8 kg d^{-1} dry weight of natural and processed feedstuffs. The assumption has been made that the dry weight content of silage and pasture is 20%. Grain accounts for approximately 40% of this daily intake. In the FARMLAND predictions it has been assumed that both dairy and beef cattle consumed 14 kg d^{-1} dry weight comprising silage, pasture and hay.

In 1986 and 1987 the contamination of silage, pasture and hay is several orders of magnitude higher than that predicted and observed concentrations in grain. By assuming an intake of 14 kg d^{-1} for beef cattle and assuming all the diet is silage, pasture and hay the concentrations in beef have been overestimated by up to a factor of 4. This largely explains the differences seen between the predicted and observed values.

For dairy cows the effect of diet will be less over the summer of 1986 where cows are eating primarily pasture. The use of other feedstuffs during the winter months with lower contamination levels will also lead to an overestimation in milk concentrations.

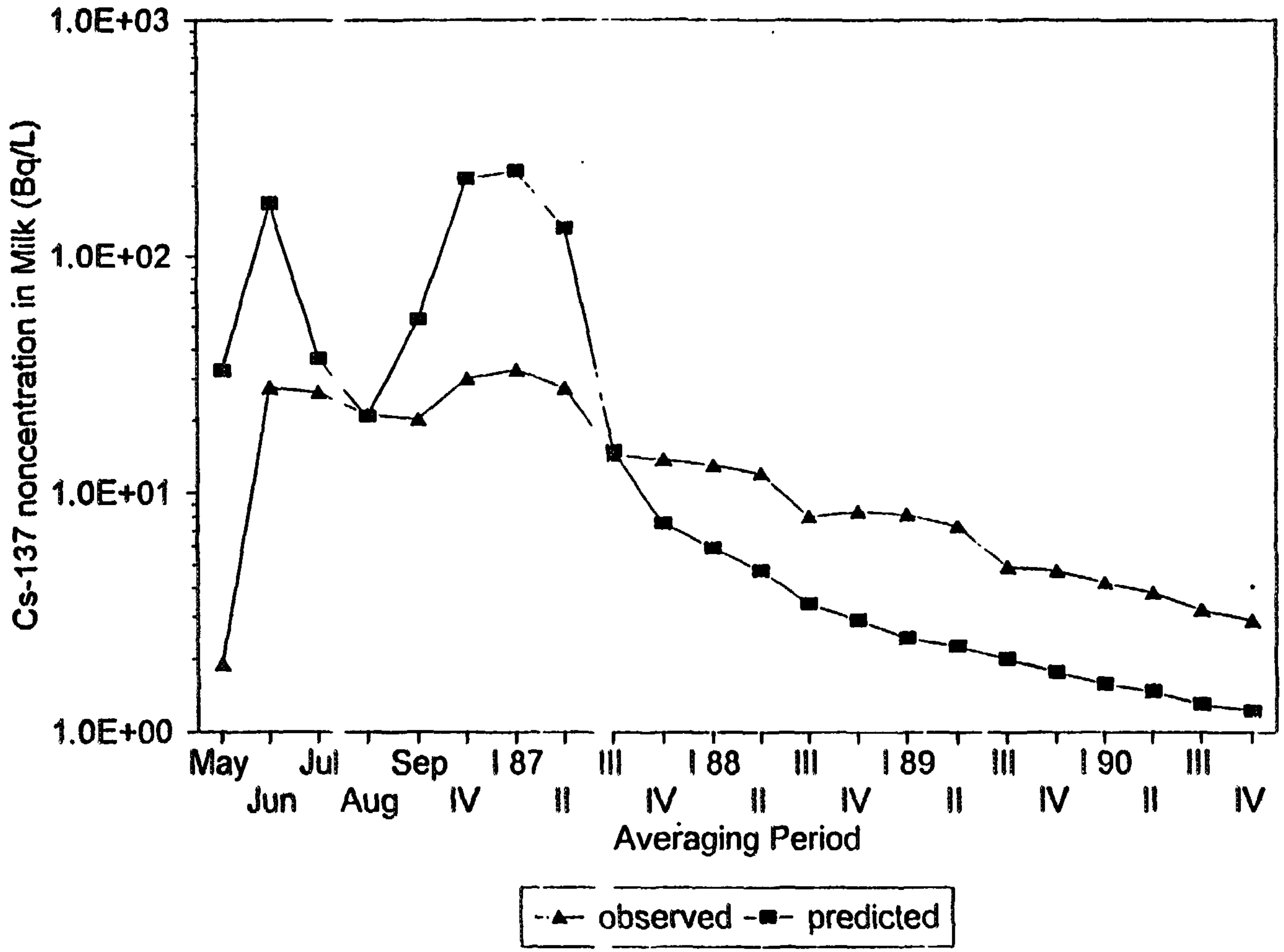


FIG 1. Comparison of observed and predicted ^{137}Cs activity concentrations in milk. Revised predictions April 1994

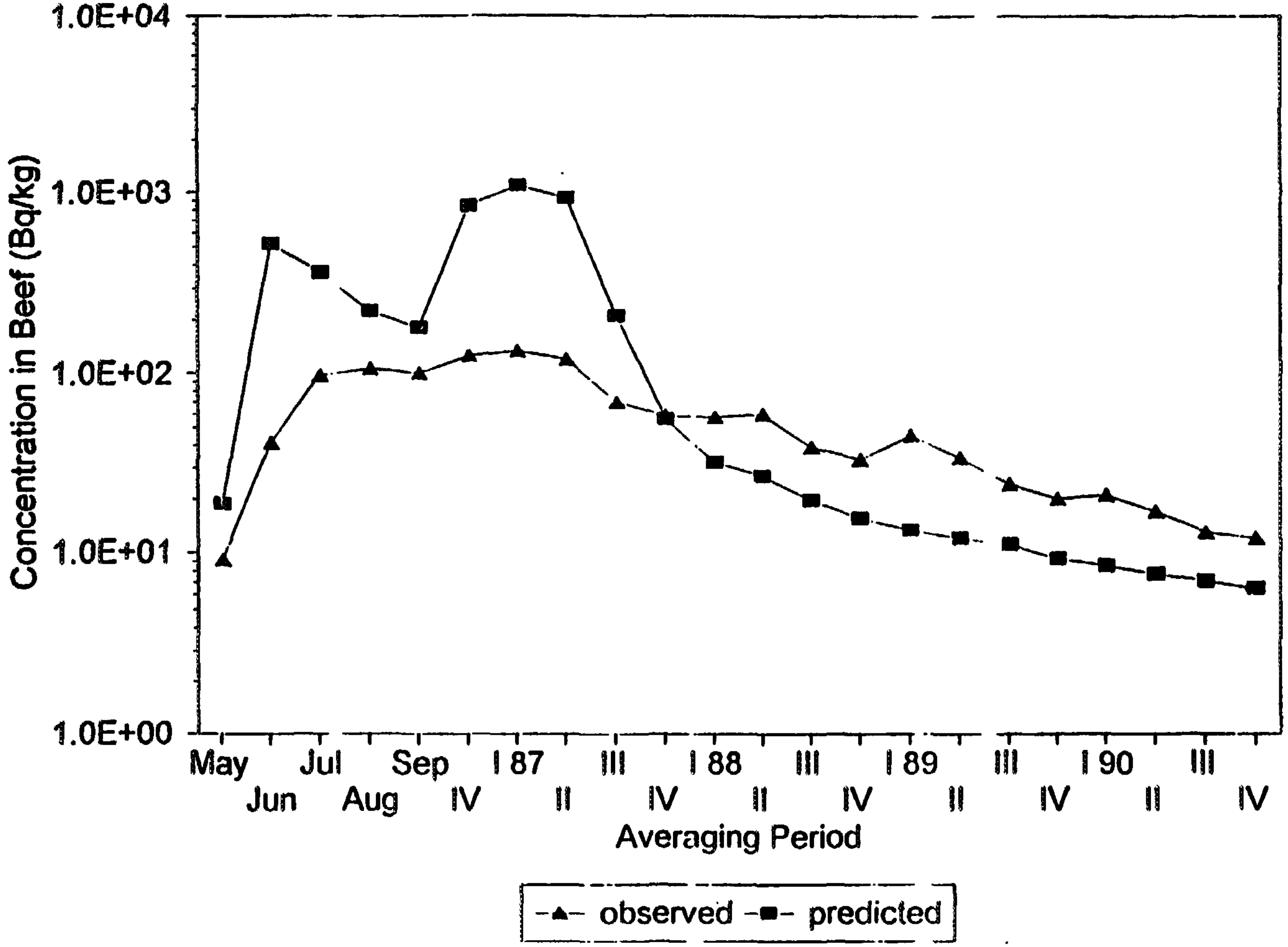


FIG 2. Comparison of observed and predicted ^{137}Cs activity concentrations in beef. Revised predictions April 1994

Another factor affecting the overestimation of milk concentrations during the winter of 1986 is the concentrations in hay and silage predicted by FARMLAND. These concentrations are likely to have been overestimated due to the cropping period assumed in FARMLAND. The majority of the winter diet is silage which is harvested over the period 1 June to autumn in region S. The default assumptions in FARMLAND are three cuts over the period 1 May to 15 September. The yields assumed in the model are similar to those given for region S. However, using an extended cropping period will lead to some overestimation in concentrations. This will also contribute to the overestimation in beef but to a much lesser extent because of the lower contribution of silage and hay to the diet.

From 1988 onwards milk and beef concentrations are underestimated by FARMLAND by up to a factor of 2. An explanation for this could be the overestimation of caesium fixation in soil in FARMLAND.

3.2.2.2. Leafy vegetables

NRPB predicted ^{137}Cs activity concentrations in leafy green vegetables for the months of May to September 1986. Only one observed value was given for 1986, therefore the results are not directly comparable. (See also Figure 4.) Comparison of the predicted activity concentration for May (590 Bq kg^{-1}) with the observed value (3.3 Bq kg^{-1}) shows that FARMLAND has grossly overestimated leafy green vegetable activity concentrations in the immediate aftermath of an accident in this case. However, this comparison is not entirely valid, because the predicted value is dominated by ^{137}Cs intercepted by foliage. Given that the observed leafy vegetable activity concentration is the average for the 1986 harvest, it is more reasonable to compare this with the lower end of the range of predictions for 1986. For September, FARMLAND predicted an activity concentration of 4.5 Bq kg^{-1} which compares more favourably with the observation of 3.3 Bq kg^{-1}, and in fact falls within the upper and lower confidence limits, 1.4 - 8.9 Bq kg^{-1}. Scenario S also states that between 7-15 May

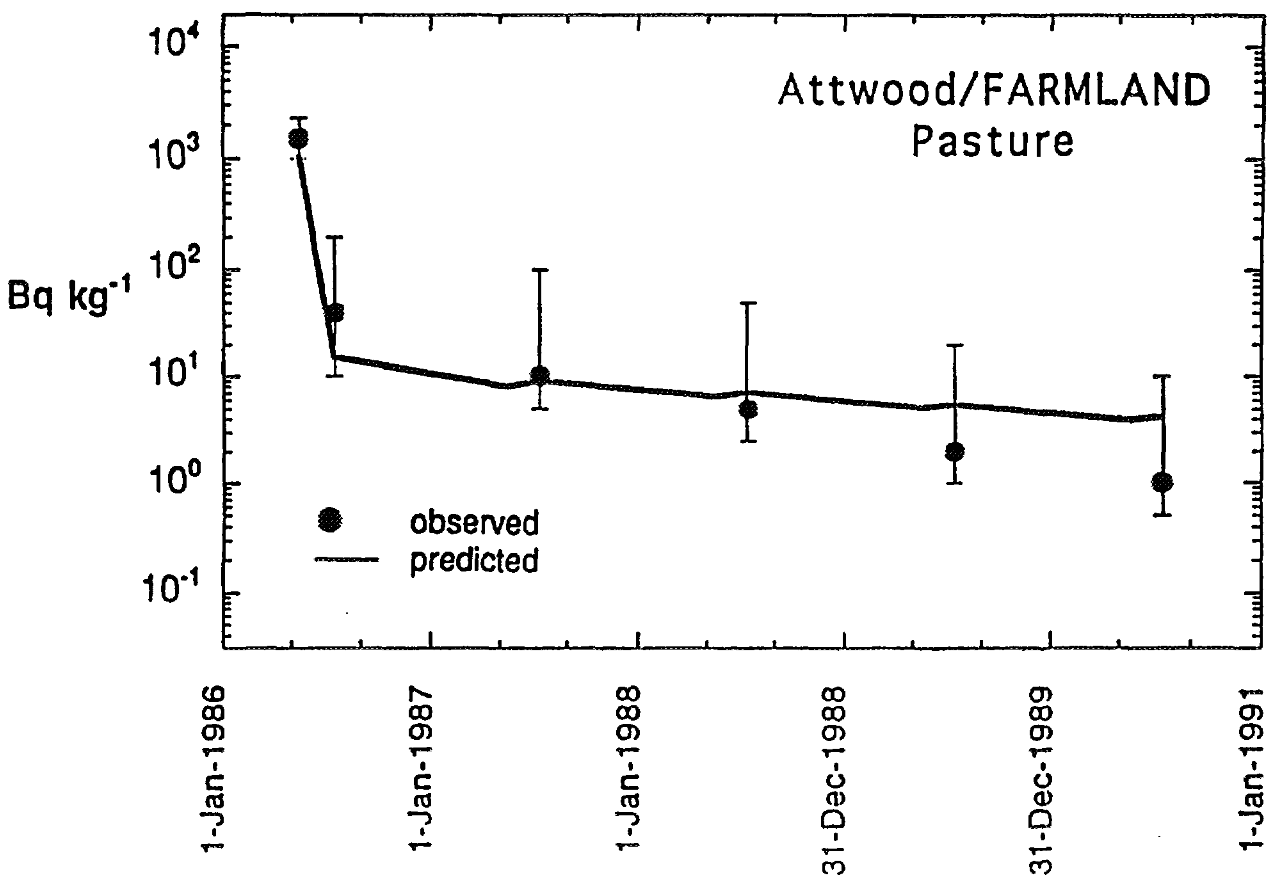


FIG 3. Comparison of observed and predicted ^{137}Cs activity concentrations in pasture

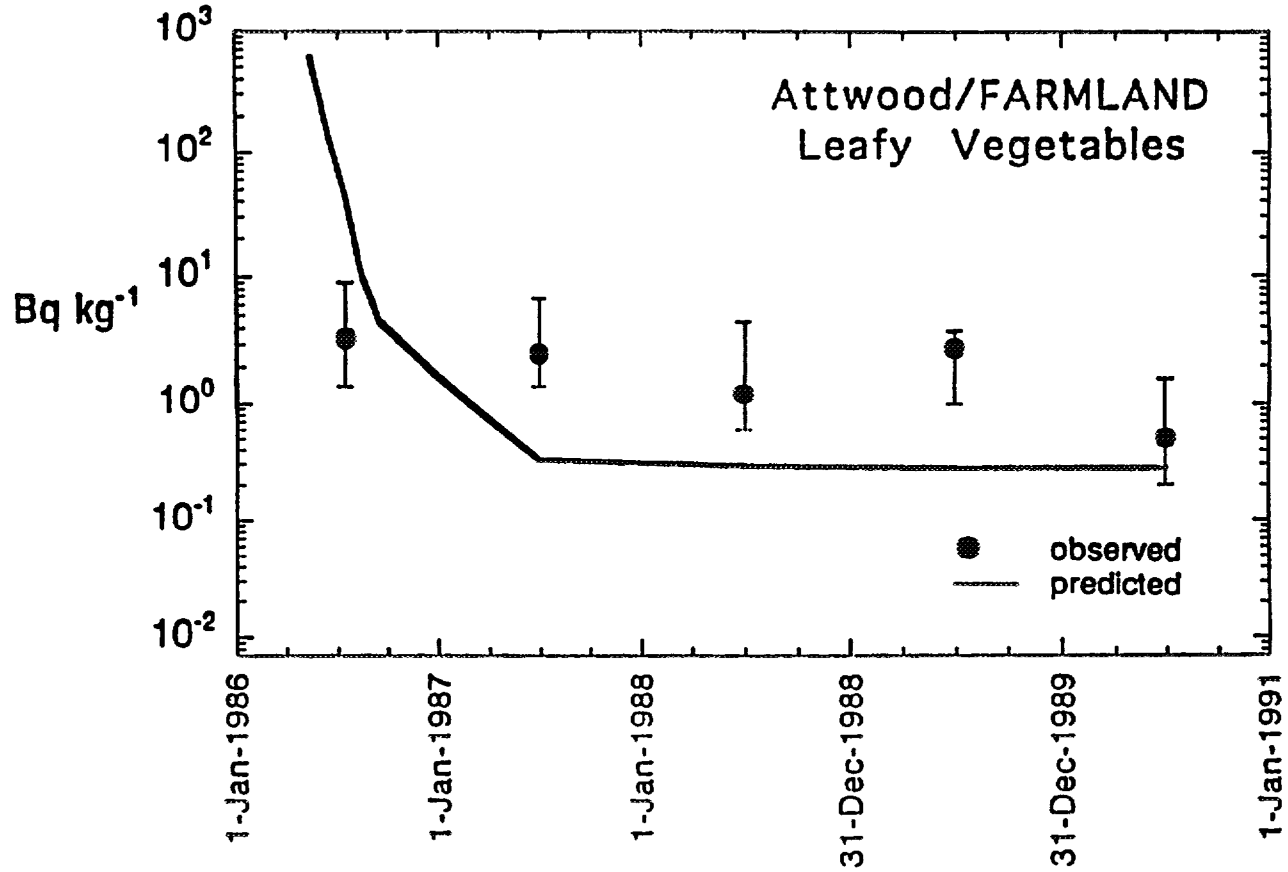


FIG 4. Comparison of observed and predicted ^{137}Cs activity concentrations in leafy vegetables

1986 there was a recommendation to postpone the open field sowing of lettuce, spinach and other fast-growing vegetables. Although it is not clear to what extent this recommendation was implemented across all regions, the fact that FARMLAND did not account for any delay in sowing also contributes to the discrepancy between observed and predicted leafy vegetable activity concentrations in 1986. Differences in assumed and actual lettuce production methods may be a further factor, although this cannot be considered a *major* cause of misprediction. In this implementation, FARMLAND treats lettuce as a field vegetable not grown under glass. The Scenario S description stated that lettuce grown in greenhouses accounts for 7% of leafy vegetable consumption. This could lead to the overestimation of activity concentrations through interception and resuspension processes, which in reality did not occur.

For the years 1987 to 1990, FARMLAND underestimated the ^{137}Cs activity concentration in leafy vegetables by a factor of between 4 and 10 which is within the uncertainty limits specified in Section 2.2.3. All estimates of activity concentration in food were expected to be conservative, but this underestimation merits further exploration. The long term underestimation of activity concentrations in leafy green vegetables is probably due to the use of inappropriate root uptake factors for Scandinavian growing conditions. The root uptake factors used were derived for more usual UK and European Union soil conditions which are dominated by clays. Root uptake factors are generally higher for non-clay soils e.g organic peats and sandy soils such as those encountered in Scenario S. In a study by Nisbet and Shaw[22] (1994), concentration ratios for ^{137}Cs were greatest for crops grown in peat by up to an order of magnitude.

3.2.2.3. Cereals

Figures 5 and 6 compare observed and predicted ^{137}Cs activity concentrations in wheat and rye. Observed activity concentrations show a peak in 1986 of 4.9 Bq kg^{-1} and 28 Bq kg^{-1} for wheat and

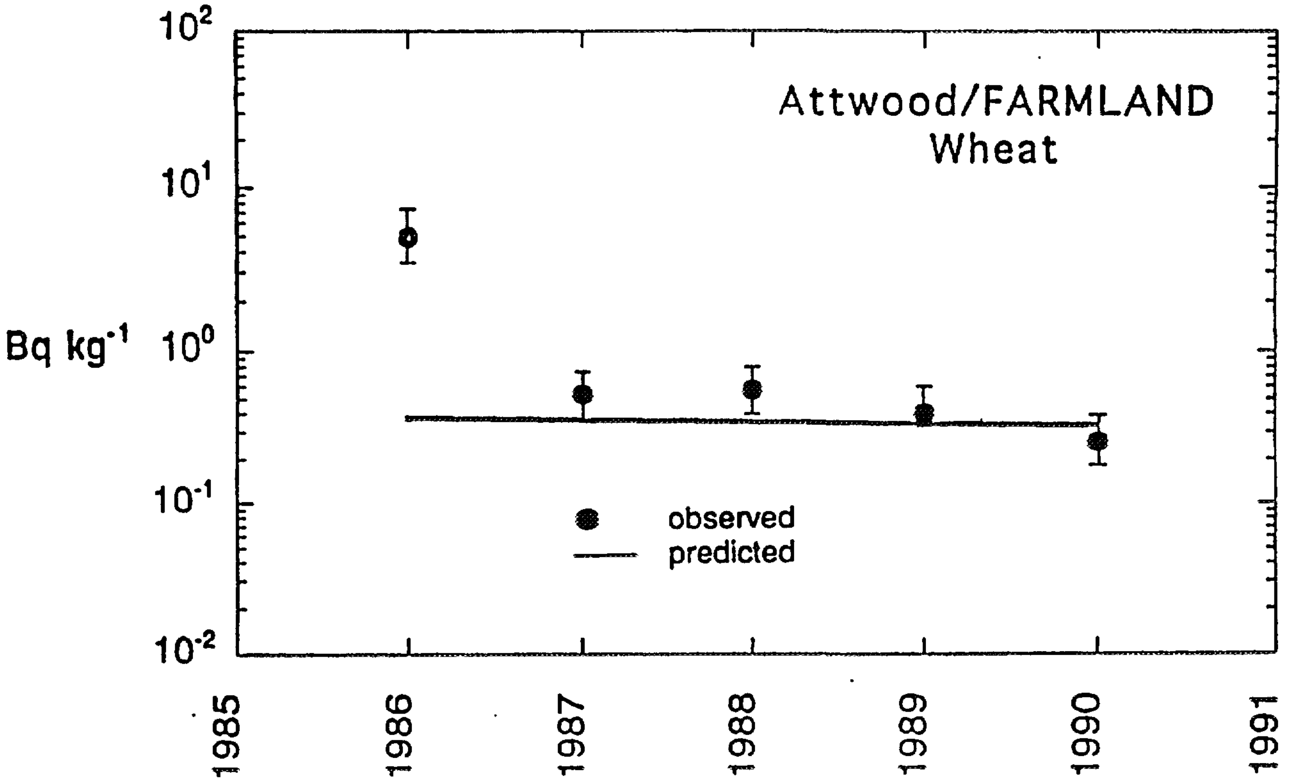


FIG 5. Comparison of observed and predicted ^{137}Cs activity concentrations in wheat

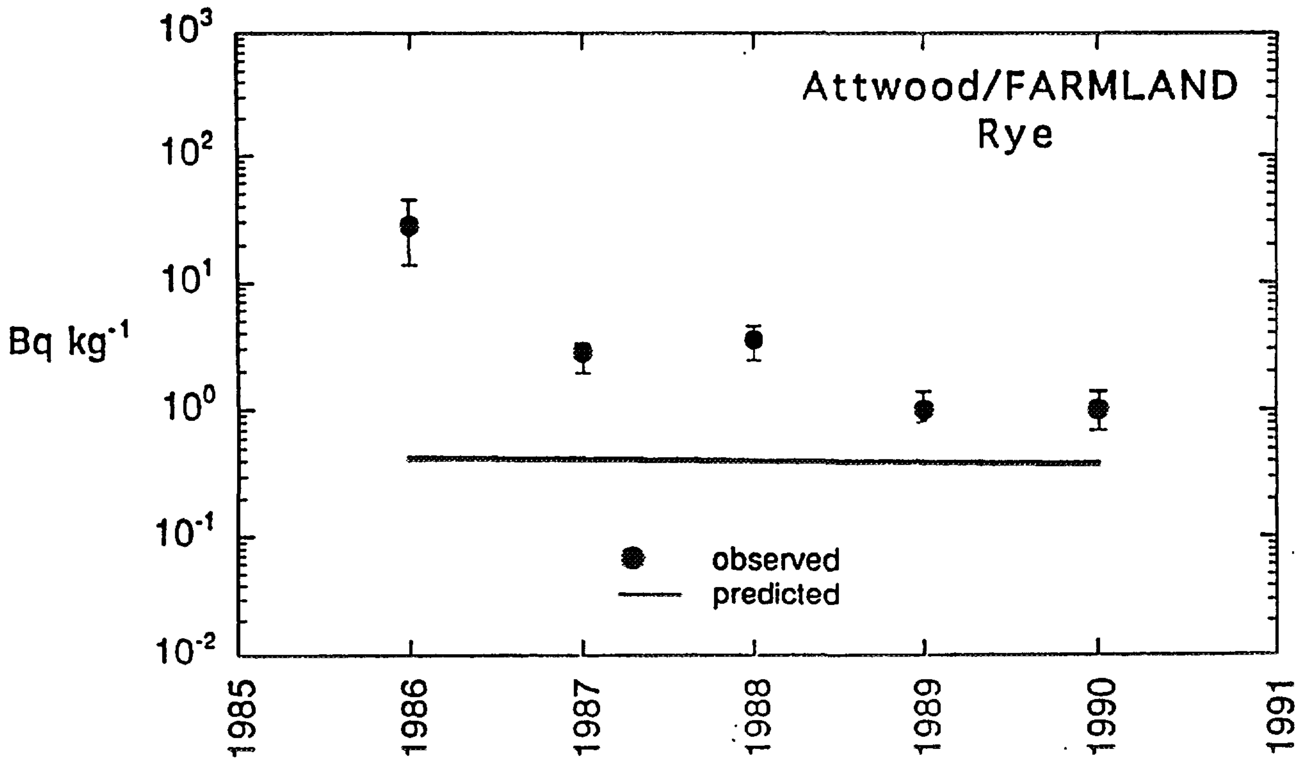


FIG 6. Comparison of observed and predicted ^{137}Cs activity concentrations in rye

rye respectively, decreasing to 0.26 and 1.0 Bq kg^{-1} in 1990. A small secondary ^{137}Cs peak in 1988 is also apparent for both crops. FARMLAND generally underestimated ^{137}Cs activity concentrations in cereals with the greatest discrepancy occurring in 1986, (factor of 13 underestimation). Between 1987 and 1989 FARMLAND underestimated activity concentrations in cereals by factors of between 1.1 and 1.6. The model overestimated by a factor of 1.2 in 1990. FARMLAND predictions decline slightly through time but fail to replicate the secondary peak in 1988.

FARMLAND was implemented assuming that the cereals were not sown until 20 May, ie, after the time of deposition. As a result, there was no contribution from external contamination and translocation. The observations imply that there was external contamination in 1986 as the activity concentrations are an order of magnitude higher in 1986 than in subsequent years. The assumption adopted in FARMLAND to delay sowing until 20 May was based on information presented in Scenario S, Table XIX. The table indicates that in 13 subregions a maximum of 50% of crops were sown by the end of May 1986, and in some regions much less than this.

On examination of the scenario details, no spring varieties (wheat, oats and barley), were sown prior to the accident. However, approximately 10% of production in region S is from winter grown varieties which would have been sown before the accident. From a FARMLAND run for winter sown cereals an activity concentration in harvest of about 240 Bq kg^{-1} would be seen assuming the default harvest of 5 August. The FARMLAND run submitted to VAMP estimated activity concentrations in spring varieties at approximately 0.4 Bq kg^{-1}. If the assumption is made that 10% of production is winter varieties this gives an average activity concentration in cereals for 1986 of 24 Bq kg^{-1}. This is consistent with the observation for rye (28 Bq kg^{-1}) and an overestimate for wheat (4.9 Bq kg^{-1}).

3.2.2.4. Pork

The scenatio description states that domestically grown cereals constitute 60% of pig diet. It is acceptable to assume that these cereals were contaminated with ^{137}Cs at the time of the accident because they were grown within region S. An estimate of activity concentrations in pork was made assuming the following:

* Pig food intake is 3 kg d^{-1} of which 60% is contaminated, ie, 1.8 kg d^{-1}.
* Wheat activity concentration of 0.2 Bq kg^{-1}.
* Pig diet has 2 components; 30% wheat, 70% barley.
* 10% of the wheat consumed by pigs is grown during the winter.

This led to the following results:-

Year	Observed (mean) (Bq kg^{-1})	Predicted (Bq kg^{-1})
1986	5	0
1987	12	5
1988	6	0.3
1989	6	0.3

These predictions give reasonable agreement for 1987 but underestimate activity concentrations by an order of magnitude in later years. The assumption that pig diet is composed of cereals harvested in the previous year meant that activity concentrations in the year of the deposition was completely mispredicted. Even if we assume that all food consumed by pigs is contaminated, ie, 3 kg d^{-1}, the activity concentration in pork is still only 1-2 Bq kg^{-1}. This is lower than the observations by a factor of 2-3. It is important to note the uncertainty surrounding the assumptions about pig diet and the lack of time dependency in the models used.

3.2.2.5. Game

Small Game: duck and geese

Figure 7 compares observed and predicted ^{137}Cs activity concentrations in duck and geese. At worst, ^{137}Cs activity concentrations were underestimated by 2 orders of magnitude. The reasons for this were as follows:

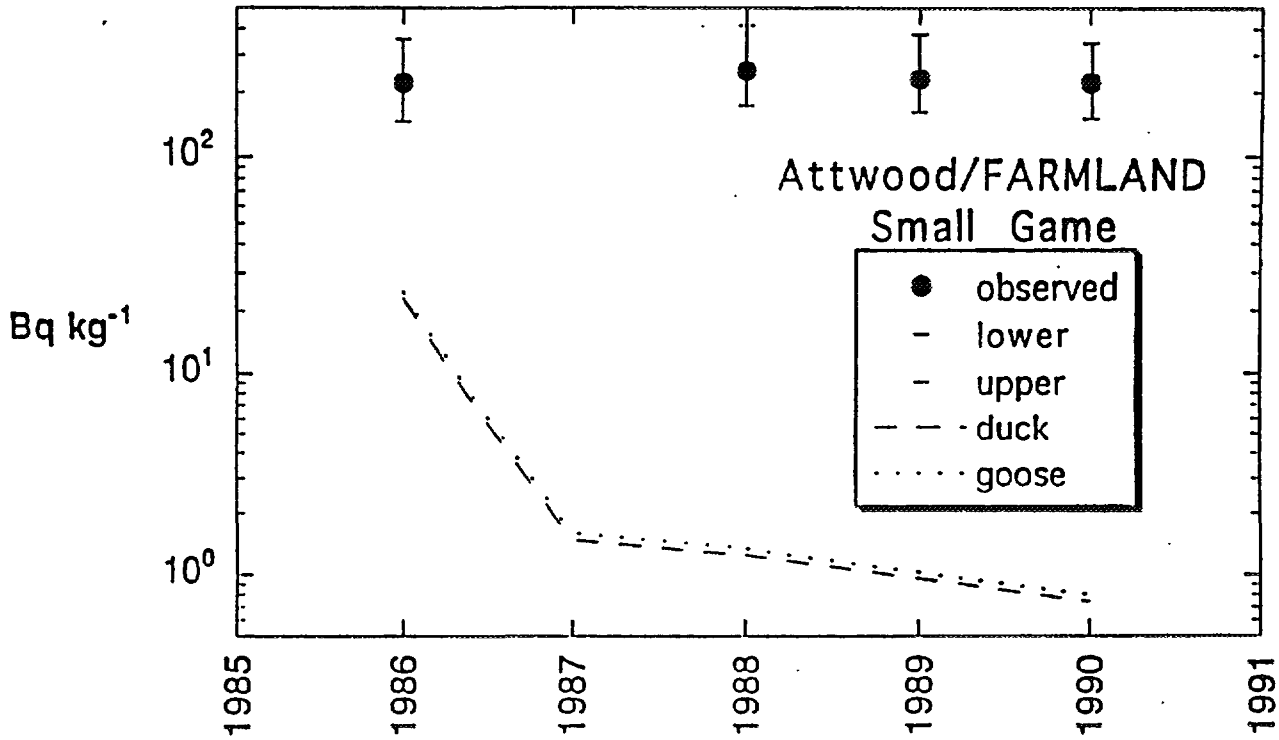


FIG 7. Comparison of observed and predicted ^{137}Cs activity concentrations in duck and geese

(1) The most important species contributing to the *small game bag* in scenario S are hare, waterfowl and terrestrial birds. NRPB considered activity concentrations in waterfowl alone. These results were compared with activity concentrations averaged over all species in the scenario S small game bag.

(2) The intake of ^{137}Cs by geese and ducks was dominated by the assumed pasture diet. Although geese were assumed to eat grain, the impact of this foodstuff on ^{137}Cs intake was negligible. This might have more to do with the underestimation of grain activity concentrations as discussed in Section 3.2.2.3 than any process operating in nature. Further, the transfer factors for waterfowl were derived from UK data relating to saltmarsh grazing and may therefore not be totally applicable to inland grazing. No account was taken of any other contaminated feed other than pasture and grain.

(3) Daily intakes by the waterfowl were based on defecation rate data for birds on Cumbrian saltmarshes and are therefore subject to uncertainty.

(4) The calculation ignores direct ingestion of soil particles by birds.

(5) The equilibrium transfer factor for uptake of ^{137}Cs into edible portions of the birds (d kg^{-1}) takes no account of time dependency in the calculations.

Big Game: Moose

An appropriate transfer coefficient for 1986[12,13], 0.02 Bq kg^{-1} per Bq m^{-2} was applied to the NRPB estimate of total deposit, 19500 Bq m^{-2} to predict the concentration in moose meat. This gave a ^{137}Cs activity concentration of 390 Bq kg^{-1} in moose meat for 1986 overestimating observed values by a factor of 1.6.

3.2.2.6. Mushrooms

Figure 8 shows the relationship between observed and predicted ^{137}Cs activity concentrations in wild edible mushrooms for the harvests of 1986 to 1990. At worst, the transfer factor approach described in Section 2.4.2.7 overestimates mushroom activity concentrations by a factor of 7 in 1986, and at best underestimates by a factor of 1.5 in 1989 and 1990. Figure 9 presents results for the same period for a variety of mushrooms grown on different substrates and serves to illustrate the dependence of mushroom activity concentration on the transfer factor adopted. Observed ^{137}Cs activity concentrations in mushrooms reached a peak in 1989, whereas predicted activity concentrations showed a gradual decline. The latter trend was a function of the FARMLAND estimate of ^{137}Cs activity in the top 1 cm of the soil. The predictions might be improved by accounting for the precise timing of the mushroom season. In the absence of other information, the harvest was assumed to occur in September, as in the UK. The fit of observations and predictions could also be tightened by considering regional variation in the substrate on which mushrooms grow and applying an appropriate transfer factor. However, these adjustments are unlikely to influence the ingestion dose estimate because the contribution of mushrooms to the overall diet is insignificant.

3.2.2.7. Freshwater fish

Figure 10 reveals a close agreement between observed and predicted mean ^{137}Cs activity concentrations in freshwater fish for region S. For 1986, the method outlined in Section 2.4.2.9 overestimated ^{137}Cs activity concentrations in the edible parts of freshwater fish by a factor of 2.5, and for the following years, underestimated by a factor of approximately 2. These uncertainties lie well within the expectations set in Section 2.2.3. This is a pleasing result given the wide range of freshwater fish concentration factors presented in the literature. What seems like an overestimation of ^{137}Cs activity concentrations in fish in 1986 may well be a function of the timing of fish

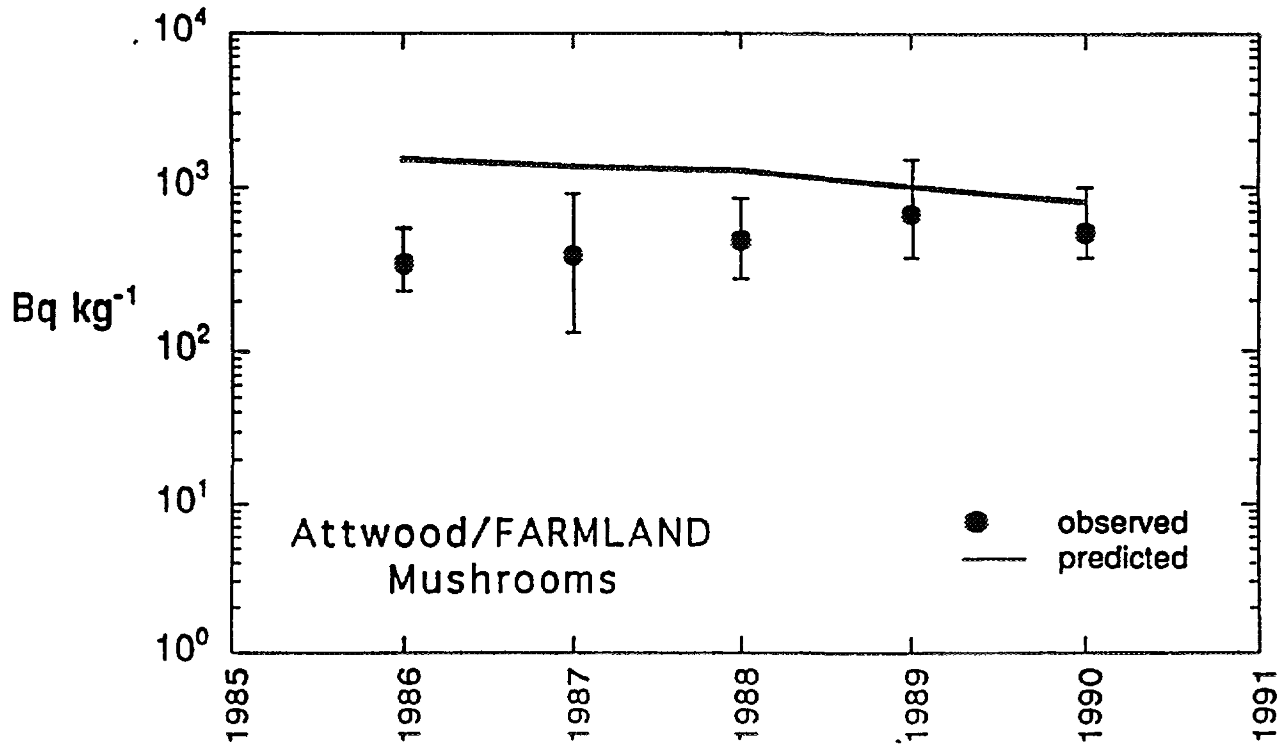


FIG 8. Comparison of observed and predicted ^{137}Cs activity concentrations in mushrooms

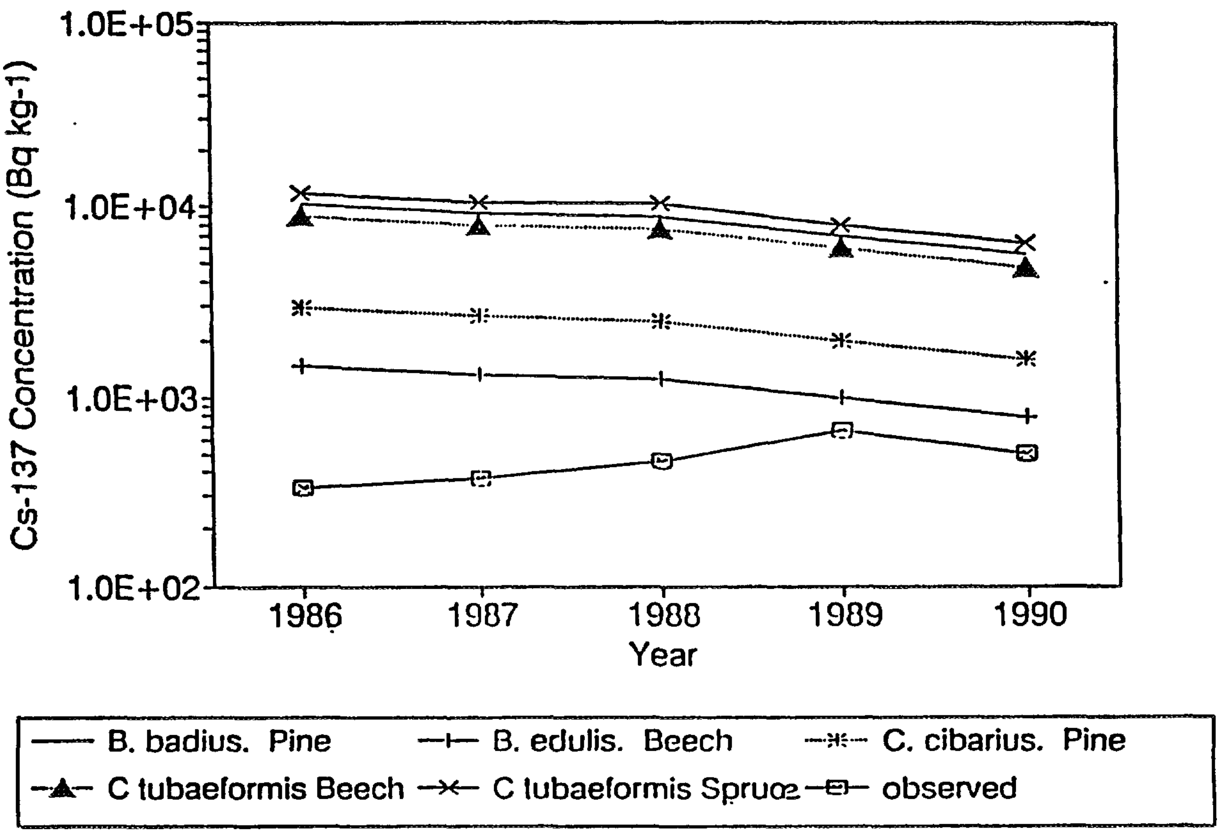


FIG 9. Concentration in mushrooms. Uptake factors from RISO report

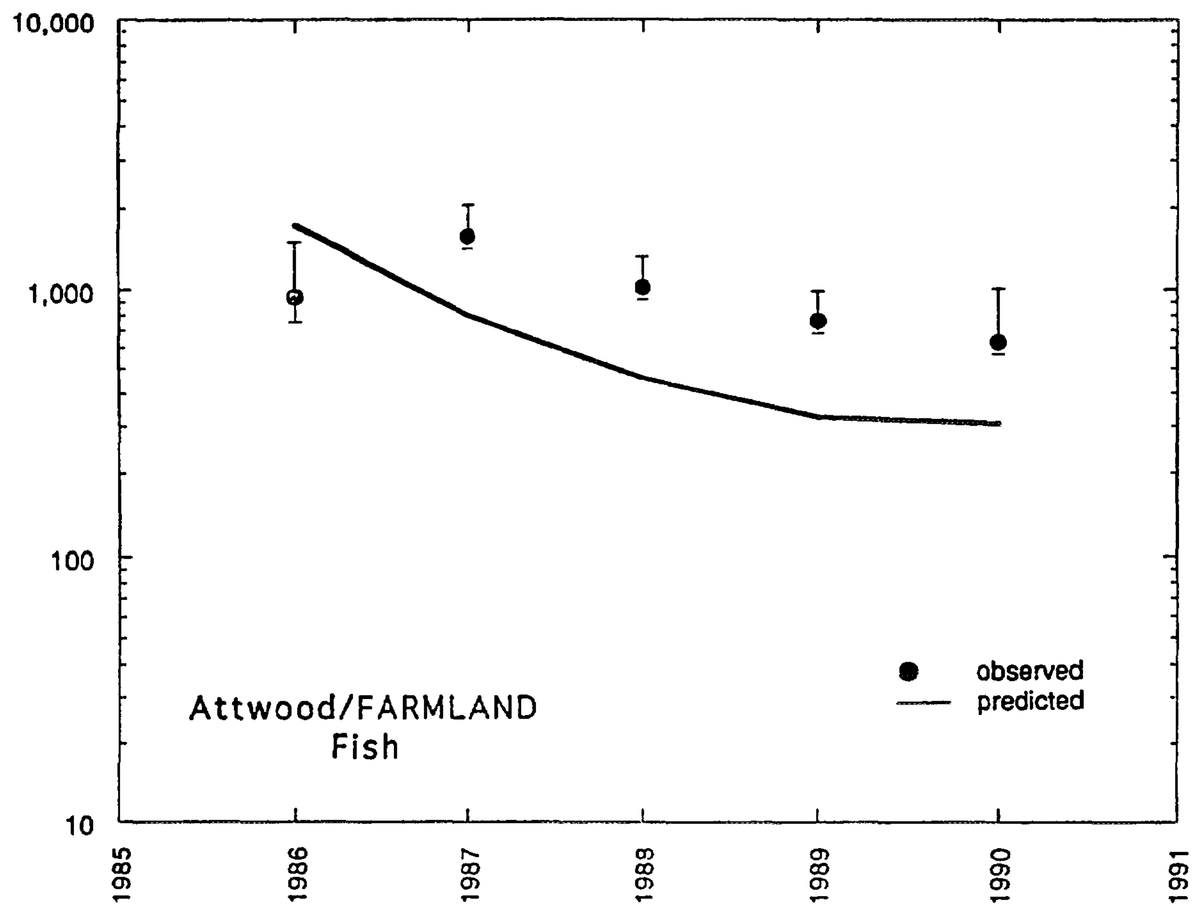


FIG 10. Comparison of observed and predicted ^{137}Cs activity concentrations in freshwater fish

measurements. Ten percent of the surface area of region S is covered by water and received direct deposition from the plume. Two phases of surface water contamination can be envisaged after an accident. The first involves a rapid increase in surface water concentrations as a result of direct deposition on to lakes and rivers. The second is a period of more gradual increase in ^{137}Cs water concentrations due to transfer of radionuclides through the catchment hydrological system. Therefore, measurements of ^{137}Cs in fish during the first phase cannot account for the full impact of deposition on lakes and rivers. The predicted fish activity concentrations for 1986 used an average of surface water concentrations for the 2 months supplied in the Scenario description, August and October. Their data account for a proportion of the second phase of radionuclide influx to lakes. It is unlikely that fish were sampled in all areas at a time directly comparable with the averaging applied to surface water concentrations. For 1986 in particular, it is dangerous therefore, to over emphasise the discrepancy between observed and predicted fish activity concentrations.

3.2.2.10. Animal feeds: barley and oats

Figures 11 and 12 compare observed and predicted ^{137}Cs activity concentrations in barley and oats. The calculation of ^{137}Cs activity concentrations in barley and oats was as for wheat and rye. For an analysis of observed to predicted activity concentrations see Section 3.2.2.3.

3.3 Human intake and mean whole body contents (man)

Predicted daily ^{137}Cs intakes for males were estimated and presented to VAMP in June 1993. The predicted daily intakes were derived using estimates of ^{137}Cs food activity concentrations, which

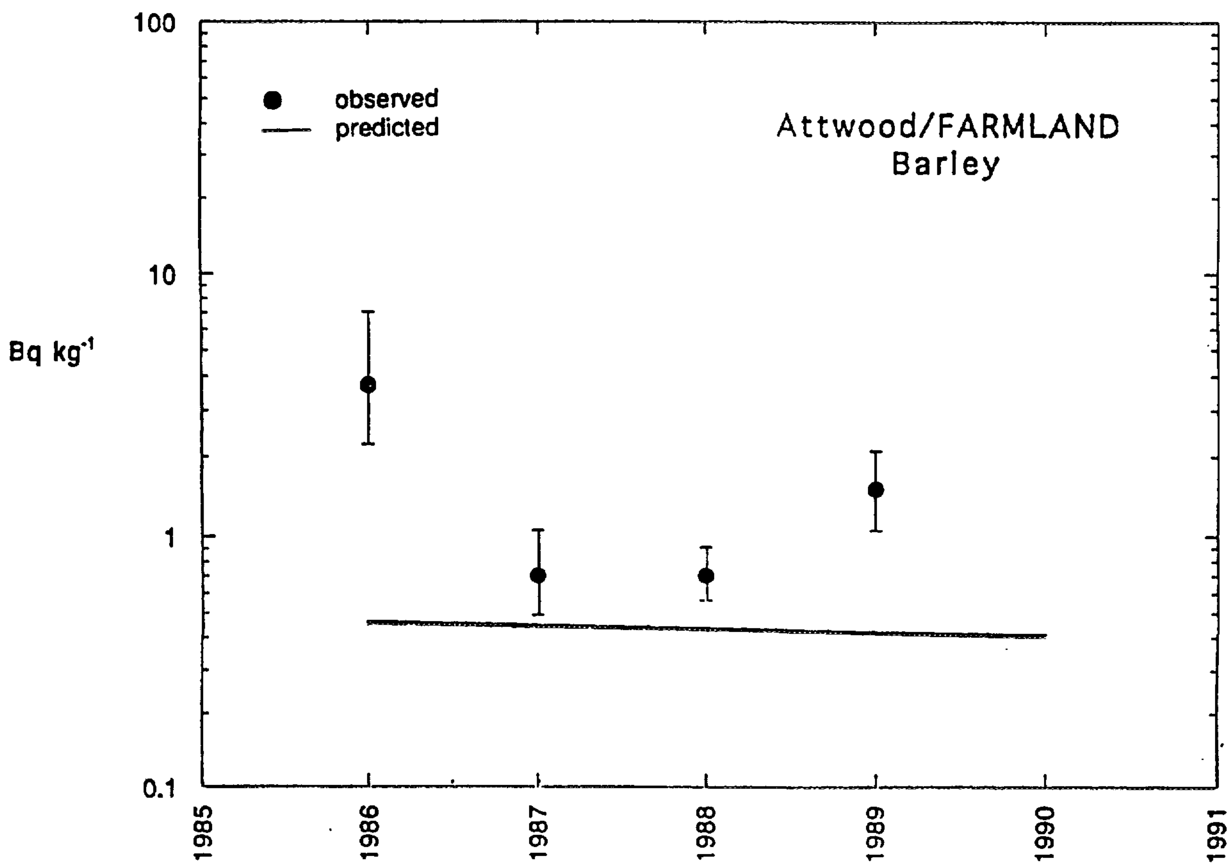


FIG 11. Comparison of observed and predicted ^{137}Cs activity concentrations in barley

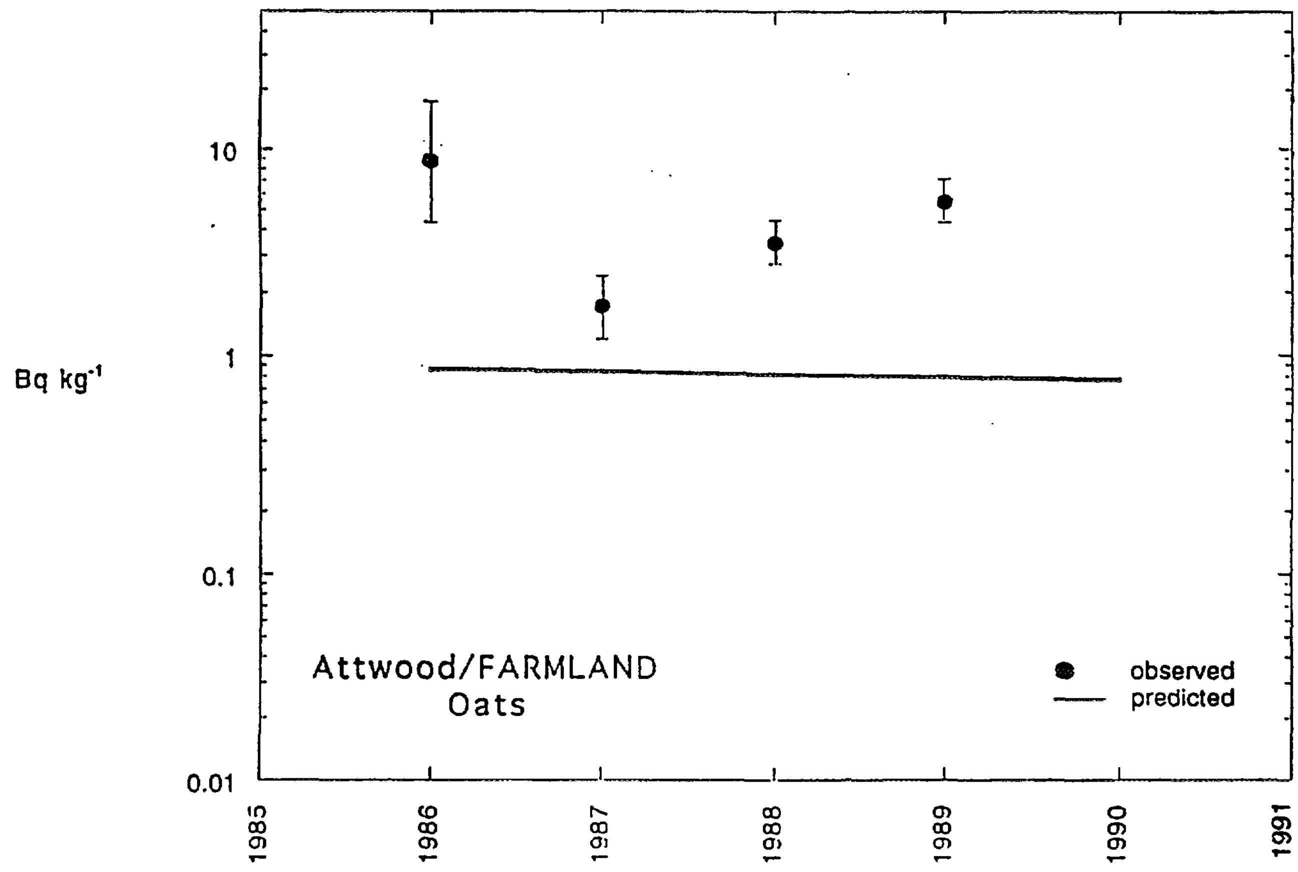


FIG 12. Comparison of observed and predicted ^{137}Cs activity concentrations in oats

for some foods, (milk, beef, pork and moose), were in poor agreement with the observed values provided by VAMP. Subsequent analysis of the methods used to derive food activity concentrations revealed the following errors:

(1) *Milk and Beef*
The first estimates of ^{137}Cs activity in milk and beef underestimated observed concentrations in the months to the end of 1986. Careful examination of the FARMLAND input files set up for this scenario, revealed that the parameter representing transfer from the gut to blood was entered incorrectly for all times considered. A value of 1.48 10^{-1} was used instead of the correct value, 1.48 10^{1}. This explains the underestimation of ^{137}Cs activity concentrations in milk and beef in the months immediately after the accident. In the years following the accident, observed milk activity concentrations were in close agreement with observations. Use of the incorrect transfer factor for gut to blood had shifted the entire curve of predictions bringing it in line with observations. The FARMLAND model was run a second time with the transfer factor corrected and these results are presented here (Section 3.2).

(2) *Pork*
In the original results there was poor correspondence of the observed and predicted ^{137}Cs activity concentrations in pork. This was because the activity concentration in pig feed (cereals), used in the calculation of pork activity concentrations was an order of magnitude too low; 0.02 Bq kg^{-1} was used rather than the correct value of 0.2 Bq kg^{-1} estimated by FARMLAND. In addition improvements were made in the way the diet of pigs was modelled. This is explained in Section 3.2.2.4.

(3) *Moose*
The original predicted ^{137}Cs activity concentrations in moose were underestimated by at least 2 orders of magnitude. A close look at the spreadsheet deriving activity concentrations in moose meat revealed that an integrated inventory of ^{137}Cs in pasture had been used instead of the integrated inventory in the top layers of the soil. Corrected concentrations were estimated as discussed in Section 3.2.2.5.

Human intakes have not been recalculated following the corrections to the activity concentrations in milk, beef, pork and moose. Therefore, no results are presented here. However, a number of general observations can be made based on the earlier analysis.

* Milk and beef dominate the ^{137}Cs intakes. This is a function of their importance in male diet.
* Food ingestion made the largest contribution to human intakes. The influence of inhalation was negligible.
* Uncertainties may accumulate over each level of calculation. Uncertainties in initial calculations can therefore effect end points such as human intakes, whole body burdens and dose.

3.4. Dose calculations

Section 2.4.5 outlined the way dose from internal and external pathways were calculated. The purpose of this section is to compare VAMP estimated and NRPB predicted results. Analysis is necessarily restricted because information on how the VAMP dose estimates were achieved has not been provided. Before the VAMP estimates were released, NRPB set out uncertainty expectations for the calculation of doses as follows:-

* Predictions of total, external, inhalation and ingestion doses were expected to be within a factor of 10 of the VAMP observed (estimated) values.

* All predictions were expected to be conservative.

With the exception of doses arising from the inhalation of resuspended material, NRPB tended to overestimate doses. All NRPB predicted doses were within a factor of 10 of the VAMP estimated values, although they exceeded the confidence limits suggested by VAMP. A comparison of observed and predicted dose quantities are given in Tables XIII-X. Ingestion and total doses were presented to VAMP in June 1993; however, as discussed in Section 3.3, a number of errors were found in the input to these calculations. It has not been possible to recalculate these doses and so they are not presented here.

TABLE VIII. DOSE ARISING FROM INHALATION OF THE CLOUD

VAMP estimated inhalation dose (nSv)	NRPB predicted inhalation dose (nSv)
220	2070

NRPB over predicted the inhalation dose from the cloud by a factor of 10. The reason for this is as follows. Activity concentrations in air from the air samplers AIR 1 and AIR 2 were not thought to be representative of the entire region. NRPB chose to calculate integrated air concentrations during plume passage using the mean weighted deposition for the region and a deposition velocity of $1\ 10^{-2}$ m s^{-1}. This calculation, described in Section 3.1, resulted in an adult dose of 2070 nSv. A second estimate of inhalation dose from the cloud was derived using the ^{137}Cs activity concentrations in ground level air at station AIR1, see Table I of the Scenario S description. An integrated air concentration for the period 28 April to 2 June was calculated, $1.476\ 10^5$ Bq s m^{-3}. This value was used in the calculation of inhalation dose presented in Section 2.4.5.2. A dose to adults of 338 nSv was derived and this compares well with the estimate of 220 nSv provided by VAMP.

Table IX compares observed and predicted doses from the inhalation of resuspended materials. NRPB's results are in good agreement with those provided by VAMP.

TABLE IX. DOSE ARISING FROM INHALATION OF RESUSPENDED MATERIALS

	Dose (n Sv)	
Dose integration period	VAMP Estimated	NRPB Predicted
27 Apr 86 to 30 Apr 87	15	13
27 Apr 86 to 31 Dec 90	15	15
27 Apr 86 to lifetime	20	19

Deposited gamma doses predicted by NRPB are within a factor of 1.2 of values estimated by VAMP when shielding is taken in to consideration, see Table X.

TABLE X. Deposited gamma dose

	Deposited gamma dose (mSv)	
Dose integration period	VAMP Estimated	NRPB Predicted
27 Apr 86 to 30 Apr 87	0.060	0.069
27 Apr 86 to 31 Dec 90	0.190	0.227
27 Apr 86 to lifetime	0.670	0.767

A cloud gamma dose of 6.02 10^{-6} mSv was calculated by NRPB accounting for shielding. Estimates of cloud gamma dose were not supplied by VAMP.

4. EXPLANATION OF MAJOR SOURCES OF MISPREDICTION

The purpose of this section is to explore the major sources of misprediction identified in NRPB's involvement in the Multiple Pathways Exercise Scenario S.

(1) FARMLAND

The problem of representing agricultural practices described in Scenario S with the most appropriate model assumptions was probably the single most important source of misprediction. As stated in Section 2.2.1, the intention was not to fine tune models to every last detail presented in the scenario, rather, to use the exercise as a test of the default FARMLAND model. However, adjustments to sowing, harvesting and animal husbandry are easily incorporated into FARMLAND. Other factors are less easy to change due to interaction with other model parameters, eg yield which affects foliar retention and interception, and transfer parameters such a root uptake. Predictions might have been improved by changing root uptake parameters for the more organic soils encountered in Scandinavia. Countermeasures were described in some detail in the description. Where these involved a delay in the movement of animals or sowing of crops, these were accounted for as far as possible. Otherwise the FARMLAND default model was used without alteration.

(2) Equilibrium transfer factors
The transfer factor approach was used because for certain foods suitable dynamic models were not available. The approach is subject to flaws such as the lack of time dependency, and lack of appropriate data for the environment of interest. Misprediction was largely due to the uncertainty range surrounding the equilibrium transfer factors used. Figure 9, illustrating the variation in predicted ^{137}Cs activity concentrations in mushrooms according to the equilibrium transfer factor exemplifies this point. Equilibrium transfer factors provide a simple model for radionuclide transfer into environmental media and so do not describe the time dependence of activity concentration. Results obtained from this approach are highly dependent on the quality of data to which transfer factors are applied, eg pasture and soil ^{137}Cs activity concentrations. Equilibrium transfer factors are relatively easy to use, (in comparison to setting up dynamic models). In the absence of alternative techniques to calculate radionuclide uptake into food products, eg deterministic formulae or dynamic models, transfer factors derived for specific conditions are more likely to be applied to situations for which they are inappropriate.

(3) User error
An important source of misprediction arose from the need to adjust FARMLAND for the specific application. Errors which may occur during this process are less likely to be discovered by an inexperienced user. This was certainly the case for milk and beef FARMLAND input files, for which the ^{137}Cs transfer parameter for gut to blood was set two orders of magnitude too low. This exemplifies the need for rigorous quality assurance of newly created files, although the experienced user has a greater chance of detecting errors.

The Multiple Pathways Exercise, Scenario S has shown that retrospective analysis can only be as good as the data provided. It is fundamental that in model validation exercises such as this, only *like* quantities should be compared. It is clear that sampling and averaging employed in the derivation of observations may go some way to explain apparent mispredictions. A document describing sampling, measurement, regional averaging, weighting, extent to which countermeasures were implemented and any problems encountered in deriving observations would have improved the participants' analysis of results.

5. SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

NRPB considers validation to be an important part of its work in developing models for use in radiological assessments. Involvement in Multiple Pathways Scenario S under VAMP was seen as a good opportunity to validate the default FARMLAND food chain model against a comprehensive data set, to compare its performance with similar models and to learn from the experience of others working in the field. It is important to stress that the FARMLAND suite of models was only used for a limited subset of the calculations required by Scenario S. Namely, to calculate ^{137}Cs activity concentrations in pasture, milk, beef, leafy vegetables and cereals. Considerable effort was allocated to the first set of predictions, ie, food concentrations, body burdens and doses. Effort required for exercises such as Scenario S should not be underestimated. NRPB acknowledges the benefits of a second attempt at the simulations with the intention of improving predictions. Owing to many other commitments, effort has not been available for this last stage of the work. However, analyses presented in Section 3 will provide a good starting point should we wish to follow this up in future. The most important lessons learned from involvement in this exercise are summarised below.

(1) For the prediction of the mean ^{137}Cs deposition and inventory for region S the dominant source of error stems from the choice of data used and the various ways in which data can be manipulated.

(2) FARMLAND has been described as a generic model for UK and EU practices but with sufficient flexibility to allow its use in site specific studies. The model is expected to perform well over a range of sites but not necessarily at one specific site if all agricultural practices are not taken into account. This study has shown that if it is to perform well in such applications, it is essential that site specific information be considered, eg timing of deposit in relation to sowing, cropping practices, greenhouse or field production, crop yields which may differ from the UK default, animal diet and husbandry. Some of these factors are interrelated and are therefore difficult to adjust for site specific applications, eg yield is linked to interception and retention of radionuclides on the foliage. A change in the yield requires similar adjustments to interception and retention. During the first year of simulation, the most important area of uncertainty is agricultural practice. In the second and subsequent years uncertainty in model predictions are more likely to be a function of the transfer factors used in FARMLAND.

(3) In most cases, anticipated uncertainty criteria were satisfied at the intermediate stages of dose calculation, ie, activity concentrations in food. The model performed reasonably well in its default form, detecting the trend, if not the precise magnitude of food activity concentrations. Errors in the prediction of activity concentrations in food were passed on to dose calculations, eg beef and milk. However, the uncertainty criteria for dose calculations, i.e that dose estimates should be within a factor of 10 of observed values and tend toward the conservative, are likely to have been met.

(4) The transfer factor approach can provide a reasonable estimate of food activity concentrations for which dynamic foodchain models are unavailable as results for fish and mushrooms in this exercise testify. Results are dependent on the magnitude of the transfer factor and the validity of data describing radionuclide activity concentrations in appropriate substrate. The following recommendations can be made about this approach:

* Search the literature for the most appropriate transfer factor for the conditions under consideration.
* Use measurement data for activity concentrations in the substrate, eg surface water, soil etc, wherever these are available.
* Transfer factors provide an implicitly simple approach to the derivation of activity concentrations in foods. Over complicated methods to derive quantities required for the transfer factor approach are incompatible with this simplicity. For example, Section 2.4.2.6 describes the effort required to derive the ^{137}Cs activity concentration in wildfowl diet and the daily intake of food. Data manipulation and calculations such as these are prone to error and reduce the effectiveness of the transfer factors.

(5) Analysis of observed and predicted results in exercises of this kind could be much improved if a detailed description of how observations and estimates of dose were obtained.

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II.2. ECOPATH

1. ECOPATH: MODEL DESCRIPTION AND EVALUATION OF MODEL PERFORMANCE

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2 Model description

2.1 ECOPATH

Developed and used at Studsvik Eco & Safety AB by Ulla Bergström and Sture Nordlinder. The model is based upon compartment theory and the differential equations are solved by the BIOPATH code (Bergström et al, 1981).

2.2 Model characteristics

2.2.1 Purpose

The model is based upon compartment theory and it is run in combination with a statistical error propagation method (PRISM, Gardner et al. 1983). It is intended to be generic for application on other sites with simple changing of parameter values. It was constructed especially for this scenario. However, it is based upon an earlier designed model for calculating relations between released amount of radioactivity and doses to critical groups (used for Swedish regulations concerning annual reports of released radioactivity from routine operation of Swedish nuclear power plants (Bergström och Nordlinder, 1991)). The model handles exposure from deposition on terrestrial areas as well as deposition on lakes, starting with deposition values.

2.2.2 Accuracy

The model is intended to be best estimate, however somewhat conservatively biased, not to underestimate the exposure. The codes used have been verified in an international model comparison study (PSAG, 1993).

2.2.3 Uncertainties

The uncertainties in the model results, due to the uncertainty in model parameter values, are determined by Latin Hyper cube sampling from prescribed distributions of the model parameters. Correlation and regression methods are used for identifying the parameters giving dominant contribution to the uncertainties in model results. In this study, Chebychevs theorem vas used for obtaining the confidence limits about the mean values. These mean values are the arithmetic means from the generated distributions. The distribution of model parameters used represents the total expected distribution for the conditions representative for this region. Therefore, we consider the total distributions as output to be representative for the total distributions and not only for the mean values. It could be worth pointing out that we should have used our wider ranges in a real assessment as was done in Bergström et al, 1991.

2.3 Detailed description of the model

The model is described in Bergström et al, 1994. The computer codes used are described in Bergström et al, 1981 and Gardner et al, 1983.

2.4 Model structure

Schematic descriptions of the parts of the model which are dynamic are in Appendix A. The model is run on a monthly basis. All the seminatural foodstuffs are only calculated by transfer factors. No other loss than radioactive decay was assumed for the forest ecosystem. The agricultural part of the model is shown in Figure 1, Appendix B. The arrows represent the flows of activity considered such as weathering from the surfaces of vegetation, migration in soil and build-up in the muscle of cattle. The deposition occurs to the vegetation as well as to the soil. The meet pathway is the only one considered dynamically while the others are obtained from the content of Cs-137 in the soil and vegetation using concentration and distribution factors.

The aquatic part of the model is shown in Figure 2, Appendix B. The processes of importance for the redistribution of activity in the system are considered such as turnover of water, transfer to and from the sediments and leakage from the drainage area to the water body. The lake was chosen to be an "average" lake according to the scenario description. The uptake to fish is also considered dynamically by using rate constants based upon a "typical" bioaccumulation factor in combination with a biological turnover time of Cs-137 in the fish.

2.5 Descriptions of procedures, equations and parameters used in different components of the model

The equations used for obtaining the rate constants describing the flow of activity between the compartments of importance for the redistribution of activity in the system are given below.

For the agricultural exposure pathways migration of Cs-137 in soil was considered. The rate constant was described with the following expression

$$K_m = \frac{u_v}{d \cdot Ret} \text{ (month}^{-1}\text{)}$$

where

u_v	= water velocity (m/month)
d	= depth of upper soil-layer (m)
Ret	= retention

$$Ret = 1 + K_d \cdot \rho \cdot \left(\frac{1-Por}{Por}\right)$$

where

K_d	= distribution coefficient (m^3/kg)
ρ	= density (kg/m^3)
por	= porosity

Data are given in Table 1, Appendix A.

For the aquatic part the following relations are used for obtaining the rate constants describing the exchange of Cs-137 between water and sediments. Transfer from water to sediments ($K_{w,s}$).

$$K_{ws} = \frac{K_d * S}{h * (1 + K_d * SS)}$$

where

K_d	= distribution factor (concentration on solid/concentration in solution) m^3/kg
SS	= suspended matter (kg/m^3)
S	= mass sedimentation rate (kg/m^2 and month)
h	= average water depth (m)

Data are given in Table 2, Appendix A.

Transfer from sediments to water ($K_{s,w}$)

$$K_{s,w} = \frac{RES}{S}$$

where

RES	= fraction resuspended, 0.5 best estimate varying triangularly from 0.1 to 1.
S	= mass sedimentation rate.

Transport from the upper located sediments to deeper ($K_{s,\,ds}$) is obtained from the following

$$K_{s,ds} = S \cdot (1 - RES)$$

abbreviations see above

The residence time of water in the lake was as best estimate 2 years varying from 1.5 to 3 years. This "average" lake was considered to be quite big.

Leakage from the drainage area was assumed to correspond to about 0.1 % annually, varying with a factor of 10 up and down.

2.5.1 Total deposition

The total deposition was calculated from the deposition data given in the scenario description. As a result of this we obtained a weighted average deposition of 20 kBq/m^2, varying from 18 to 22 kBq/m^2. The weighting considered the actual deposition and fraction of the production in the area.

2.5.2 Food items contributing to total diet

2.5.2.1 Milk

The paths of intake of activity to cattle are by grazing and consumption of soil when grazing. Grazing occurs during the summer period and food is harvested during the same period. One simplification in the model is that the intakes of other components than grass are neglected. Pasturage is initially contaminated by retention of the deposited material onto the vegetation surface , from which it is object for weathering processes. Thereafter it is only contaminated by root-uptake. It was assumed that cows were taken out for grazing in the middle of May. Harvest of grass for winter feed was taken at the end of June. Transfer to milk from the intake of Cs-137 was modelled by a simple distribution coefficient, that is steady state was immediately assumed. Parameters and values used are given in Table 3, Appendix A.

2.5.2.2 Meat

The paths of intake to beef cattle was only assumed to be by their consumption of food as they are mostly kept inside according to the scenario description. It is calculated in similarity to the dairy animals, however taking account of their different consumption values. Because of the longer build up of Cs-137 in muscle compared to milk, beef muscle was considered as one compartment. A biological turnover time of 100 days as best estimate varying between 90 to 120 days was used. For obtaining the rate constant the distribution factor to meat was also used which a best estimate of 3.E-2 log normal distributed with a gsd of 2.1 (Bergström and Nordlinder, 1990).

2.5.2.3 Cereals

No distinction was used in the model for the different species. Swedish observations were used for a regression analysis which gave the following expression

$$C_c = Dep \cdot A \cdot e^{-B \cdot Nrm}$$

where

C_c	= concentration in cereals (Bq/kg)
Dep	= initial deposition (kBq/m^2)
A	= 4.E-4, varying from 3.E-4 to 1.E-2
B	= 0.05, varying from 3.E.-3 to 8.E-2
Nrm	= number of months after deposition

This expression is only valid for the Chernobyl fallout.

2.2.5.4 Leafy vegetables

Vegetables were mostly grown in greenhouse and only 10 % of the contamination outside was assumed. In similarity to pasturage retention on the surfaces as well as root uptake was considered. A rootuptake factor of 4.E-2 lognormal distributed was used

2.5.2.5 Pig

Major path of intake of activity to pork was considered to be by their consumption of cereals. Transfer to the muscle was simply obtained by a distribution factor (best estimate 0.3 day/kg varying from widely from 0.01 up to 2) and the concentration in cereals was obtained as given above.

2.5.2.6 Fish

Concentration of Cs-137 in fish was obtained from the following expressions describing a simplified model for the uptake in fish. Judgement was used when selecting values for the bioaccumulation factor as the values are so strongly correlated to the eutrophic level of lakes (K dependent). However information was given in the scenario description about the fraction of lake types and yield values. In addition to the value of bioaccumulation factors the biological turnover time ($T_{1/2\ b}$) is crucios when prognosing the levels in fish. $T_{1/2\ b}$ is among other things dependent upon water temperature and size of the fishes. However, the former varies over the year. An average value encompassing this variability and that most fishes for consumption are quite large was used , see below.

$$K_{w,f} = \frac{B_f \cdot \ln 2}{T_{1/2b}} \cdot \frac{M_f}{M_w}$$

where

B_f	=	bioaccumulation factor, best estimat 3 000 varying from 1 000 to 10 000
$T_{1/2b}$	=	biological half-time in fish, best estimate 15 months varying from 10 up to 20 months.
M_f	=	mass of fishes (not of importance in this model)
M_w	=	mass of water

The elimination of Cs-137 in fish was obtained from the biological halftime half-time

$$K_{f,w} = \frac{\ln 2}{T_{1/2b}}$$

2.5.2.7 Seminatural products

All these foodstuffs were simply calculated by aggregated transfer factors relating the activity in the foodstuff of interest directly to the deposition values. No loss except for radiological decay was taken into account for the natural ecosystem. Data used are given in Table 4, Appendix A.

2.5.3 Human intake

All the different foodstuffs contribute to the body burden to man according to their levels of Cs-137 and amount of consumption for respective food-stuff. These latter were used as given in the scenario description. As the model is based upon compartment theory the intake rates are calculated from rate constants which are added in the model for obtaining the contributions from all the foodstuffs.

2.5.4 Whole body concentrations

2.5.4.1 Mean whole body concentrations

Man, female, male and children are considered as compartments in this model implying that the body burdens are obtained from the concentrations in each food stuff as shown below. No loss by food processing was considered.

$$K_{f,m} = U * \frac{M_f}{TM_f}$$

where

$K_{f,m}$	= transfer rate for foodstuff f
U	= uptake through gastrointestinal, best estimate 0.9 varying from 0.8 to 1.0
M_f	= monthly consumption of foodstuff f
TM_f	= total amount of food stuff f, produced per km^2

The loss from man is simply considered to be the metabolism in man described by ln 2 divided by a biological half-time, values with best estimate, see Table 5, Appendix A. Best estimate values are taken from ICRP (ICRP 56, 1989). The different components of the excretion is not considered since the major path is lost by the longer component.

These amounts of radioactivity is divided by the weights, for male, female and child, respectively.

2.5.5 Dose calculations

Internal exposure due to consumption of foodstuffs and external exposure from ground was taken into account. Inhalation was not considered as the contribution from resupension would be negligible for Cs-137 and the model starts with deposition and not from the levls of Cs-137 in air.

2.5.5.1 External

The external calculations were based upon the average activity deposited and exposure time from hours spent outside respectively inside. The following data were used.

External dose conversion factor (Sv per $m^2$and hour)	1.3E-12 (Svensson, 1979)
Hours out door (hours per month)	200, varying triangularly from 100 to 300
Shielding factor for inside	0.1, varying from 0.01 to 0.5

2.5.5.2 Ingestion

The doses are calculated based upon the intakes rates of Cs-137..

3 Comparison of observed data and model predictions

One general comment on the comparison of observed and predicted levels is that all our results are calculated at the end of each quarter, instead as an average over the period. This is especially notable for milk during the first part of 1987.

3.1 Total deposition

The calculated average deposition of 20 kBq/m^2 coincides well with the observed given.

3.2 Food items contributing to total diet

3.2.1 Milk

Since pasturage was the main path of intake of activity it is convenient to start the comparison with the pasturage. Thereby we immediately discovered that our results were given in dry weight while they should have been given in fresh weight. This reduces the discrepancies, see Figure 3, Appendix B, where the observations are given with their estimates of uncertainty:

However, it is clearly seen that the dynamics are in bad agreement. The model does not consider any fixation of Cs-137 with time, which is necessary for not overestimating the levels in pasturage.

Results for milk are presented in Figure 4, Appendix B. In contrast to pasturage which is overestimated, the levels in milk are underestimated. This figure differs somewhat against the results presented earlier because of differences in calculated time points. Our results reflect the levels after each quarter etc and not as it should be the average value during the quarter. Therefore, the dynamics show a better agreement in this picture because of the delay in time however, it is unsure about the reasons as the uncertainties about pasturage are rather large. However in similarity to pasturage the dynamics are in bad agreement, after the first years.

3.2.2 Meat

In similarity to milk the model underestimates the levels in meat. However when using 95 % of the distributions as uncertainties estimate these ranges will cover the observations, see Figure 5, Appendix B. On the other hand, it does not seem realistic to obtain an average value of 1 Bq/kg for an average deposition of 20 kBq/m^2.·The agreement increases with time also in similarity to milk

3.2.3 Cereals

The model overestimates the levels in cereals, P/O ratios shown in Table 6, Appendix A. The observed values are averages of wheat and rye observed, because we lump them together. If only comparing by rye the agreement improves. The expression used or simply the values of coefficients need to be changed in order to simulate the level satisfactorily.

3.2.4 Vegetables

Most calculated values are within the ranges of the observed. However as for the other types of vegetation the dynamics are in bad agreement to the observed.

3.2.5 Pork

There is a quite good agreement between observed and calculated values, however with a tendency for underestimation, most P/O values are within a factor of two. However, as the only pathway to pork considered is by their consumption of cereals, which is overestimated, the agreement is unfortunately due to compensating factors.

3.2.5 Seminatural products

With the exception of mushrooms the agreement is good, mostly within a factor of two when comparing the best estimates to the mean values observed. However, improvement for mushrooms could simply be achieved by lowering the value of the transfer factor.

3.2.6 Fish

The model results are in good agreement to the observations, highest discrepancy is about 25 %.

3.3 Human intake, man

Initially, the model overestimates the intake rates while from the last quarter 1986 to the end of 1989 there is an underestimation of the values. At the end of the period there is a good agreement to the observed values. However, all best-estimate predictions are within a factor of two.

3.4 Whole-body concentrations

All model results are within a factor of two. Initially it is an overestimation followed by an underestimation. At later periods the results show a good agreement.

3.5 Doses

Initial results for doses integrated for different time points are given in Table 7, Appendix A.

Dominating exposure pathways are given below. From these initial results we were confused about the big importance from the mushrooms, which also later showed up to be due to a too high level of Cs-137 because of a too high value for uptake. In addition, we expected contribution from the meat pathway. The contribution from the external exposure increases with time. However the resulting doses show good agreement to the ones estimated from STUK which are 2.9E-4, 9.2E-4 and 2.3E-3 Sv, respectively. There are, of course, differences, however, for the contributions from the different exposure pathways.

Dominating exposure pathways at different times of integration

1987	1990	Lifetime
milk	freshwater fish	mushrooms
freshwater fish	milk	milk
cereals	mushrooms	freshwater fish

3.6 Uncertainties

The major reasons to the uncertinties in the results are identified from the regression methods in the PRISM-program. The parameters contributing mostly to the uncertainties as a function of time are handled below for some of the calculated responses.

Results for milk are presented in Figure 6, Appendix B, observe the timescale. Initially the initial retention and wheathering from the surfaces of vegetation are the processes dominating the uncertainty. This is also reflected for the levels during the first winter season as most of the hay is harvested during June, July. Therafter the analysis show that the uncertainty is still dominated by the root-uptake factor and the distribution factor to milk the following years up to the calculation period, that is 1990.

The results for meat, Figure 7, Appendix B, are in accordance with the one for milk in agreement with the the structure of the model. The faster smoothing out of the retention parameter for meat, compared to milk is due to the much longer biological half-time in meat compared to milk.

The parameters dominating the uncertainty for fish are presented graphically in Figure 8, Appendix B. Initially, the bioaccumulation factor to fish gives the major contribution while later on the turnover of Cs-137 in the aquatic ecosystem is dominant. This is in agreement with the results from VAMPs aquatic group (VAMP 95, Nordlinder et al, 1993).

For all the foodstuffs from the natural ecosystem the uncertainties are totally dominated by the aggregated transfer factor as our estimate of uncertainty in the deposition was only about 10 %.

4 Explanation of major sources of mispredictions

One major reason for mispredictions is due to that fixation of Cs-137 with time in soil was not considered except for cereals. Therefore the dynamics concerning milk and meat show a bad agreement. All the observations confirm this concerning the decline in the concentrations of Cs-137 in the foodstuffs. On the other hand the observed pasture data show a range of uncertainty. Our values for pasturage corrected for fresh weight are still higher then the observed while our values for milk and meat are lower than the observed. On the other hand, our model simplifies the paths of intake of activity to the cows by only considering grass as the intake by foodstuff. It is also obvoius from the results that mispredictions occurred for cereals due to the fact that the expression used overestimated the levels considerably. Mushrooms were overestimated due to the use of a too high aggregated transfer factor. The mispredictions of milk and meat during the first year after deposition explain the slight underestimation of daily intake rates of Cs-137. Interesting is that the model gives too low values for the daily intake while the bodyburdens are overestimated. For that we have not found any satisfactory explanation. Of course, lowering the biological half-time reduces the body burdens considerably, but we have not found any information for supporting this.

4.1 Recommendations for changes to the model

Emphasis was put to how milk, meat and cereals were modelled becaues of their big importance for the first year after deposition. Therafter the exposure from consumption of fish and seminatural products increases in importance and these latter are according to the structure of the model only dependent upon the values of the aggregated transfer factors. Improvements concerning the time fixation of Cs-137 in soil was therefor one main area as well as a better description of the uptake of Cs-137 to cereals.

4.2 Examples of how changes improved calculatios

Revised model calculataions were carried considering a fixation of Cs-137 in soil in time. In addition the model for cereals was improved and especially reduced values for the uptake in mushrooms were used. These calculations show a better agreement concerning the dynamics, on the other hand, initial values are slightly higher than the observed. However, this is satisfactory for our model because the intention is to have a model conservatively biased. On the other hand, the observations show the great importance of the initial retention on the surfaces causing the increased concentrations during the first year. This is in agreement with the results from the uncertainty analyses, see above.

Results for milk are shown in Figure 9, Appendix B, where there is a timedependence in the root uptake due to the fixation of Cs-137 with time in the soil. As can be seen the dynamics are in much better agreement while the peak values are somewhat overestimated.

In similarity to milk, results for meat, Figure 10, Appendix B, were considerably improved when considering the time dependency by plant uptake in combination with decreasing the best estimate for the distribution factor with a factor of two.

Results for mushrooms were simply improved by changing value of the aggregated transfer factor, Figure 11, Appendix B. The method used does not apply for any change of the levels in time as only physical decay is considered. On the other hand, the ecological half-time of Cs-137 in seminatural ecosystem seems to coincide with the physical one.

As a result of these improvements of the parameter values as well as the dynamics of the model the revised calcuations show as expected a close agreement with the observed values for the body burden of of Cs-137 in man, see Figure 12, Appendix B.

These recalculations lead also till important changes of the contributions from respective pathway, see Figure 13, Appendix B. The figure shows integrated doses for two timeperiods considered.

4.3 Uncertainties

The incommon dominating sources to the uncertainties for the revised predictions are presented as a function of time for intake, body burden and integrated dose to man in Figures 14 to 16, Appendix B.

These figures illustrate clearly the big importance for the foodstuffs milk and meat as the major exposure pathways initially after the deposition. The initial retention and weathering from the surfaces of vegetation give a big contribution to the uncertainties in body burden and integrated dose. In addition the distribution factor to milk gives a significant contribution. The importance for these parameters to intake rates decreases much faster. After this inital phase the aquatic ecosystem gives a significant contribution, see also Figure 13, Appendix B. The doses are integrated while still in 1990 these initial processes play an important role. From the aquatic system two main parameters are identified, bioaccumulation factor and K_d to suspended matter. For bodyburden the biological half-time contributes as well but does not show up in the doses as they are calculated from intake rates of Cs-137.

5 Summary of lessons learned from the scenario

From our results it is obvious that some crucial conclusions can be drawn.

The model does not predict the dynamics satisfactory for the two major pathways milk and meat.

Important to consider more explicitly the fixation of Cs-137 in soils.

Using a simple milk distribution factor seems appropriate when modelling Cs-137 transfer to milk.

The seminatural environment is very important for long term exposures.

Naturally, appropriate values of aggregated transfer factors give good agreements to the observations.

The simplified approach for uptake of cesium in fish seems to give satisfactory results

Compensating effects may give apparently good agreements.

Participation in earlier scenarios would maybe improve the modelling especially of milk, meat and cereals.

General conclusions from participation in model evaluations test like this

Our knowledge about modelling multiple exposure pathways has improved considerably for Cs-137.

Participation in international model evaluations are efficient for model evaluation as well as for identifying crucial components of the model. In addition, discussions in the forum of experts help to improve the models. The most important things are better understanding of important processes going on in order to design a robust model for other circumstances. Of course it would be awkward to evaluate against other scenarios and other radionuclides. It should maybe also be pointed out that the results in many cases also are dependent upon the time to put in such calculations.

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APPENDIX A

Table 1
Parameters and values for describing the migration of Cs-137 in soil.

Parameter	Best estimate	Ranges
u_v	2.6E-1	1.3E-1 - 1.3
K_d	1	0.1 -10
ρ	2.E3	1.5E3 - 2.5E3
Por	0.44	0.4 to 0.5

Table 2
Parameters and values for obtainaing the rate constant for transfer from water to sediment.

Parameter	Best estimate	Ranges
K_d	50	10 - 100
SS	3.E-4	1..E-4 - 9.E-4
S	0.05	0.01 - 0.25
h	7	6 - 8

Table 3
Parameters and values for calculating cows intake and subsequent transfer to milk of Cs-137.

Parameter	Best estimate	Ranges
Cows consumption of pasturage, hay etc (kg d w / day)	14	12 - 16
Cows consumption of soil when grazing (kg / day)	0.3	0.2 - 0.4
Milk distribution coefficient (day/ l)	4.E-3	LN distributed gsd 1.8
Wheathering half-time (days)	10 (first month) 30 thereafter,	LN distributed gsd 1.3
Root uptake factor (kg d w /kg d w soil)	0.5	LN distributed gsd 2.5

Table 4
Aggregated transfer factors for the seminatural environment.

	Game (m^2/kg d w)	Mushrooms (m^2/kg d w)	Berries (m^2/kg d w)
Best estimate	0.02 (1)	1 (2)	0.1 (3)
Ranges	0.01 -0.03	0.5 - 2	0.01 -2

1: Bergman et al, 1991
2: Johansson, 1994
3: Johansson et al, 1991

Table 5
Biological half-time in male, female and child (days), triangularly distributed.

	Best estimate	Min	Max
Male	108	81	135
Female	60	45	75
Child	48	36	60

Table 6
Predicted to observed radios for rye and mixed cereals.

Year	P/O rye	P/O, mixed
1986	0.92	1.6
1987	6	10.8
1988	3.7	6.5
1989	9	14
1990	7	12

Table 7
Integrated doses to man for each exposure pathway and total sum for the periods 1, 5 years and lifetime, respectively.

	Integrated doses (Sv)		
Exposure pathway	April 1987	Dec 1990	Lifetime
Milk	6.65E-05	1.20E-04	4.40E-04
Beef	7.76E-06	2.52E-05	1.14E-04
Pork	1.95E-06	8.83E-06	1.56E-05
Game	7.64E-07	5.23E-06	3.23E-05
F-Fish	5.75E-05	1.88E-04	3.09E-04
S-Fish	8.31E-06	4.12E-05	2.33E-04
Cer	1.57E-05	6.87E-05	1.14E-04
Root	1.69E-06	1.15E-05	7.05E-05
Veg	1.44E-07	2.45E-07	8.63E-07
Fruit	1.28E-07	8.78E-07	5.42E-06
Berr	4.24E-06	1.99E-05	1.15E-04
Mush	1.59E-05	1.09E-04	6.72E-04
TotIng	1.81E-04	5.98E-04	2.12E-03
Exter	9.64E-05	4.22E-04	2.40E-03
Total	2.77E-04	1.02E-03	4.52E-03

APPENDIX B

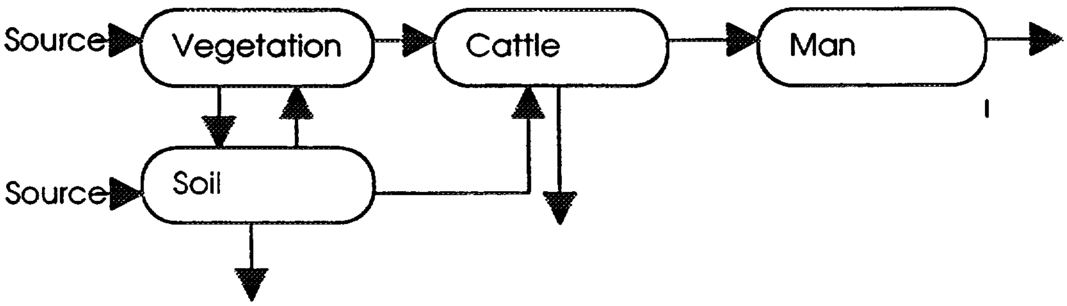


Figure 1
Schematic description of the agricultural part of the model.

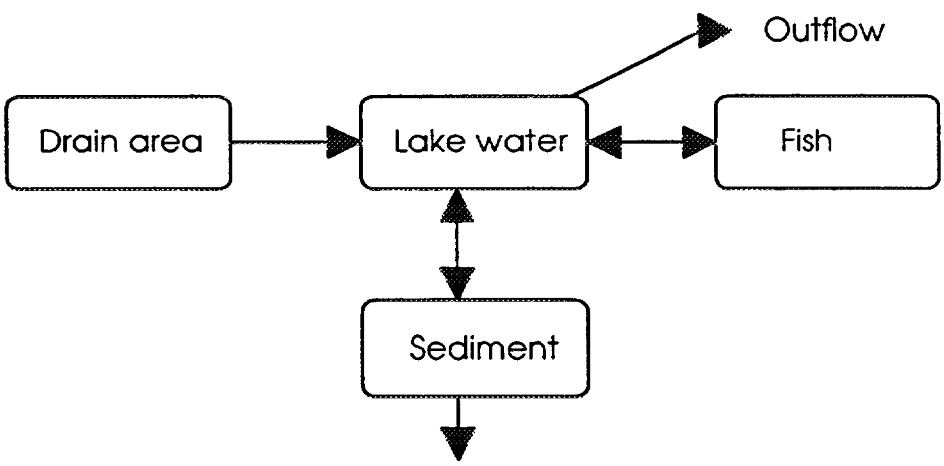


Figure 2
Schematic description of the aquatic part of the model.

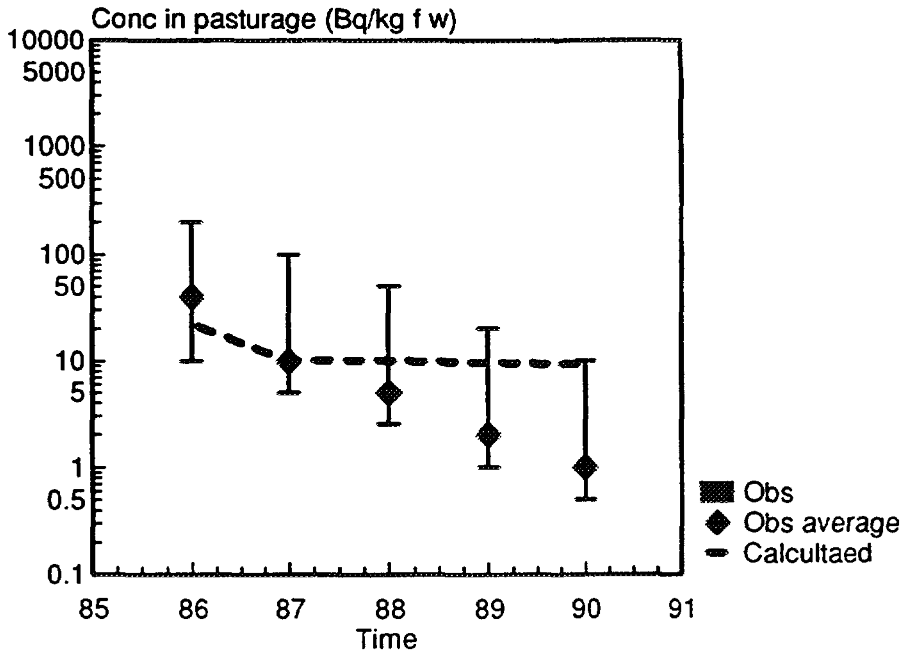


Figure 3
Comparison between initial predictions and observations of Cs-137 concentrations in pasturage.

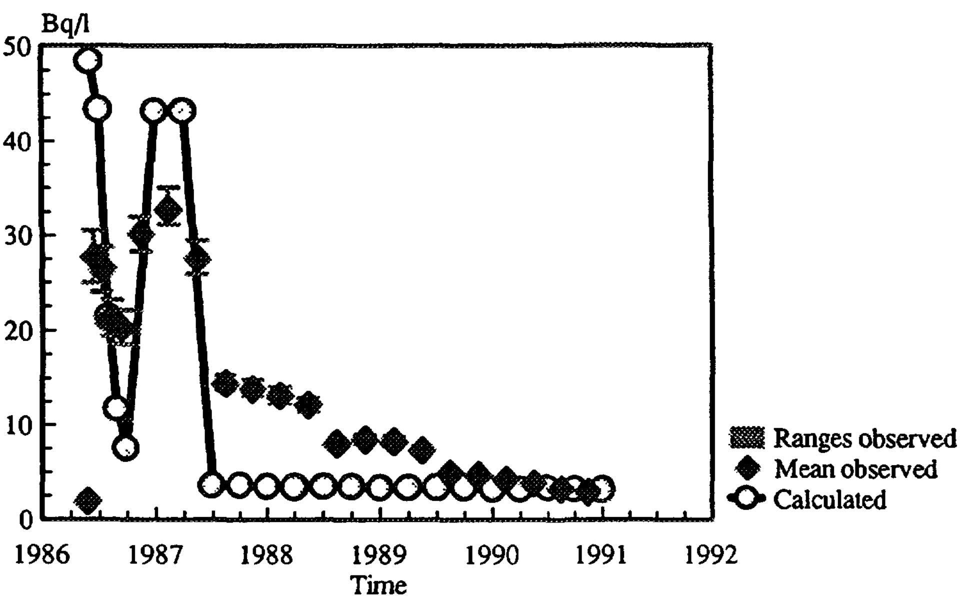


Figure 4
Observed and predicted levels of Cs-137 in milk.

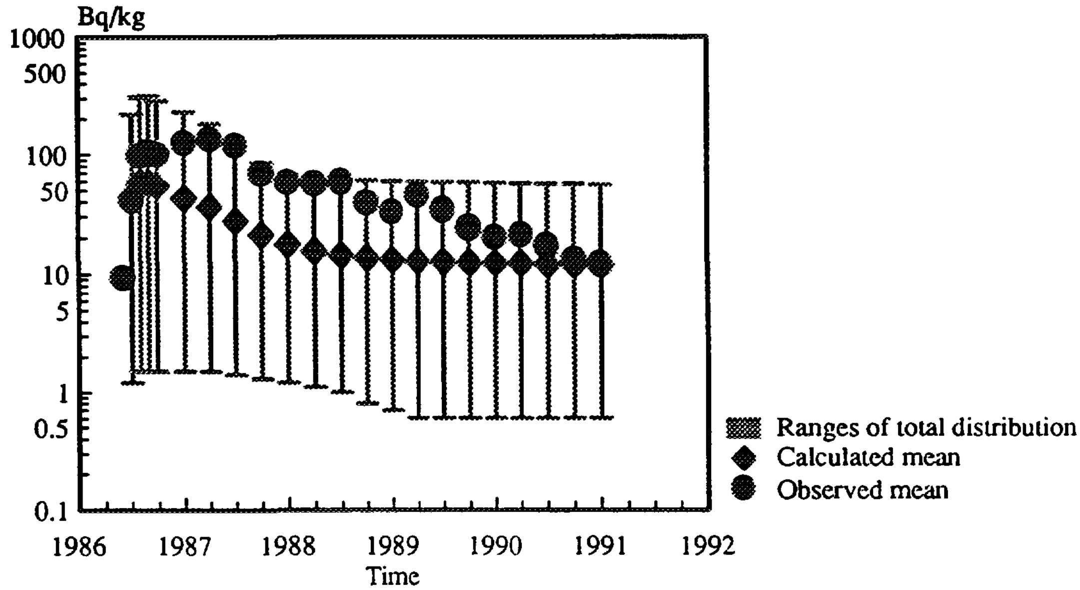


Figure 5
Observed and predicted concentration of Cs-137 in meat.

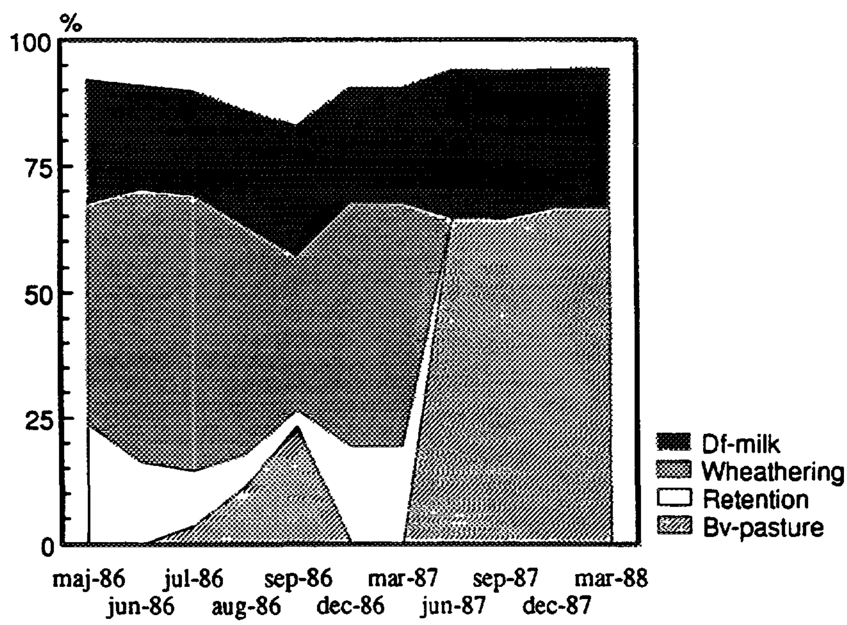


Figure 6
Parameters dominating the uncertainty for the levels of Cs-137 in milk as a function of time.

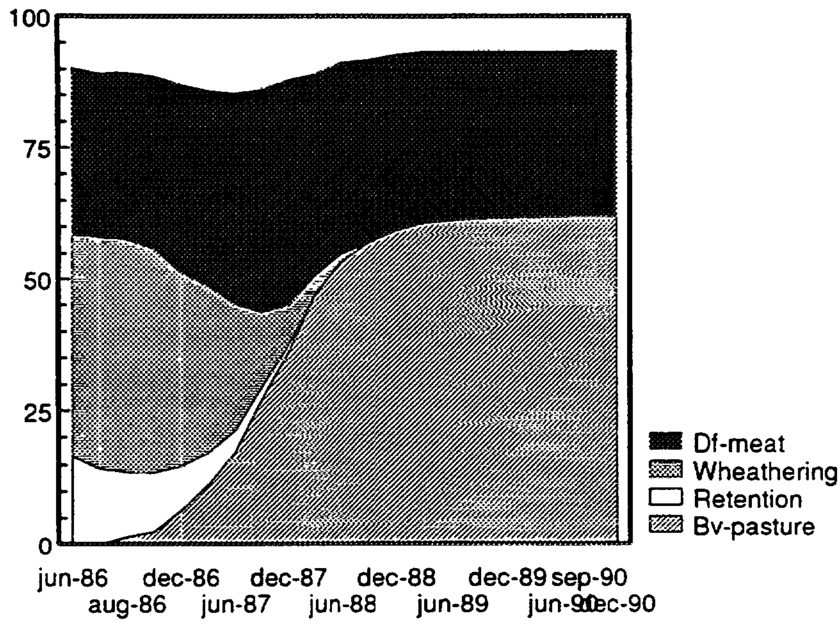


Figure 7
Parameters dominating the uncertainty as a function of time for Cs-137 levels in meat.

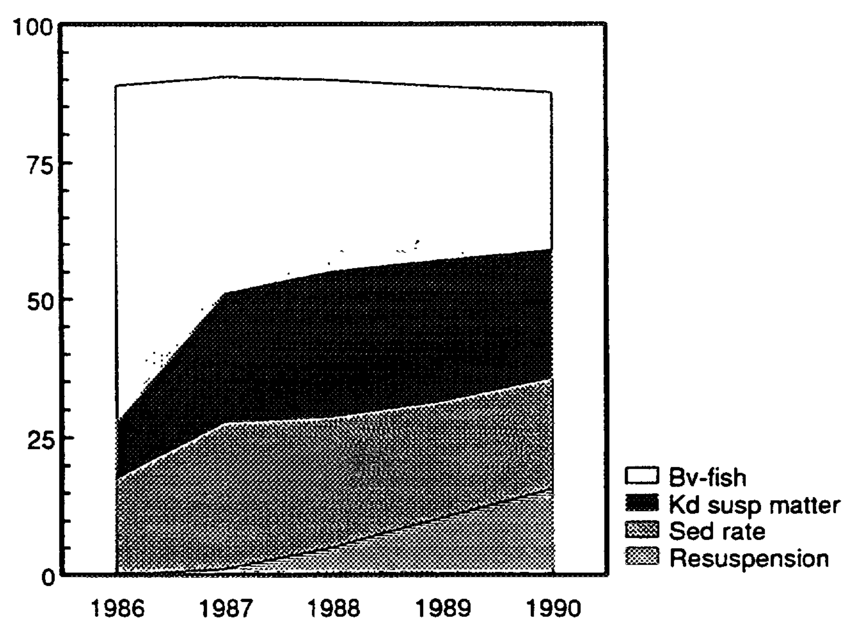


Figure 8
Parameters dominating the uncertainty for the levels of Cs-137 in fish.

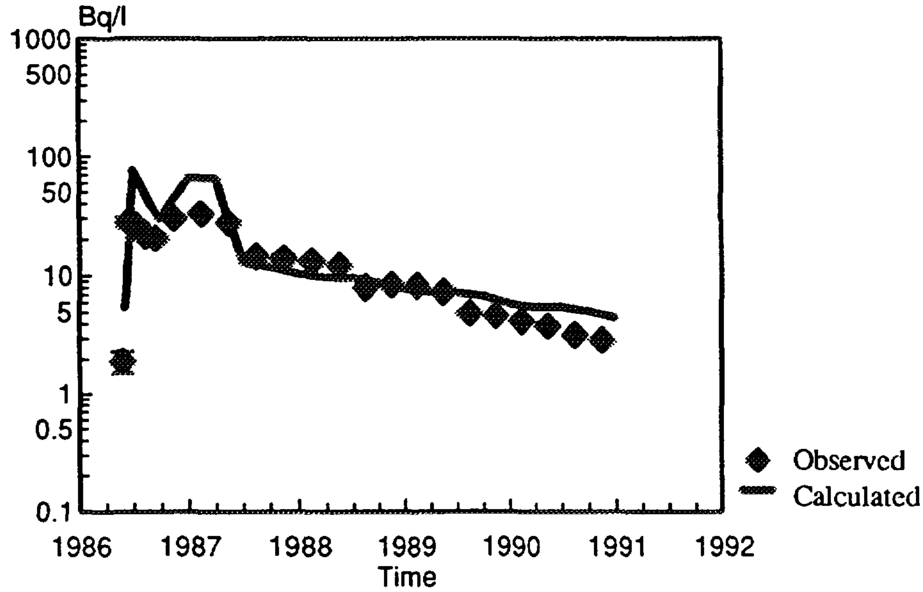


Figure 9
Revised predictions for the concentration of Cs-137 in milk.

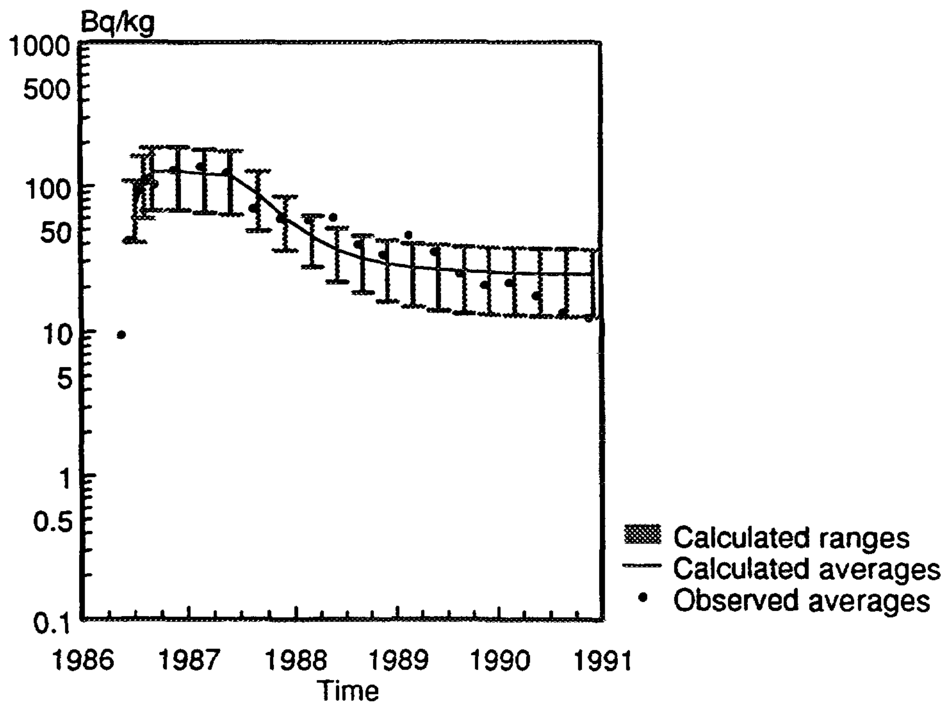


Figure 10
Revised calculations of the concentrations of Cs-137 in beef.

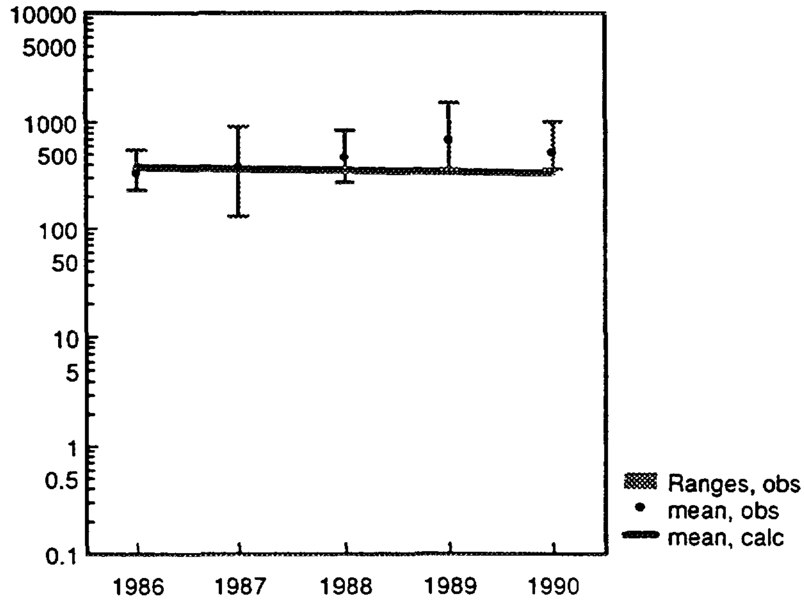


Figure 11
Revised calculations for the concentration of Cs-137 in mushrooms.

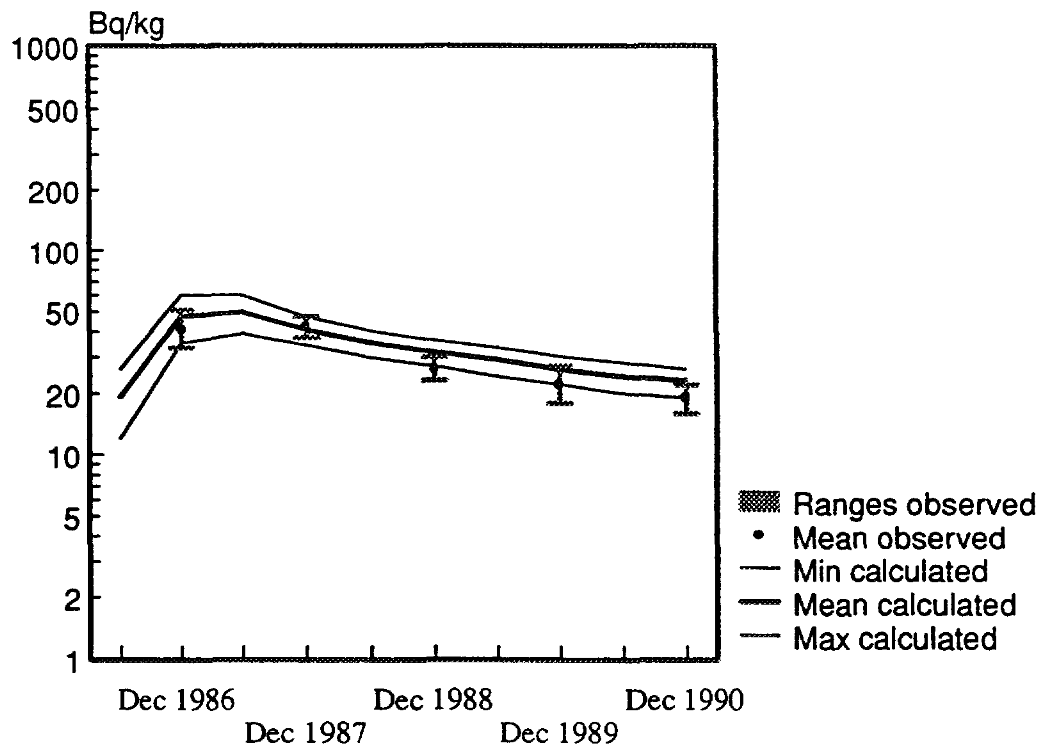
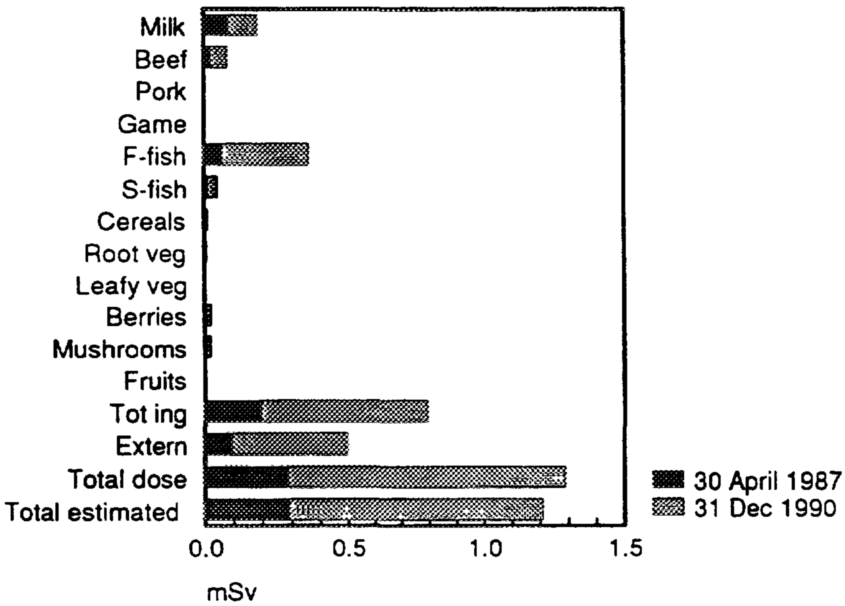


Figure 12
Revised calculations of the bodyburden to man.



Figire 13
Total integrated dose and percentual contribution from the different exposure pathways.

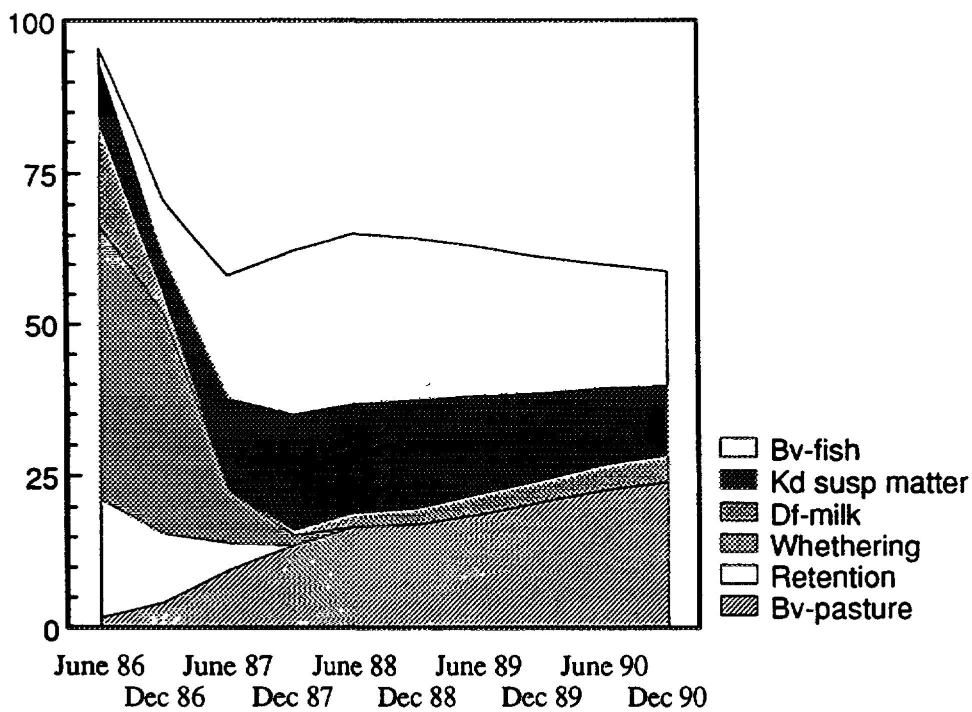


Figure 14
Major parameters contributing to the uncertainty of intake rates.

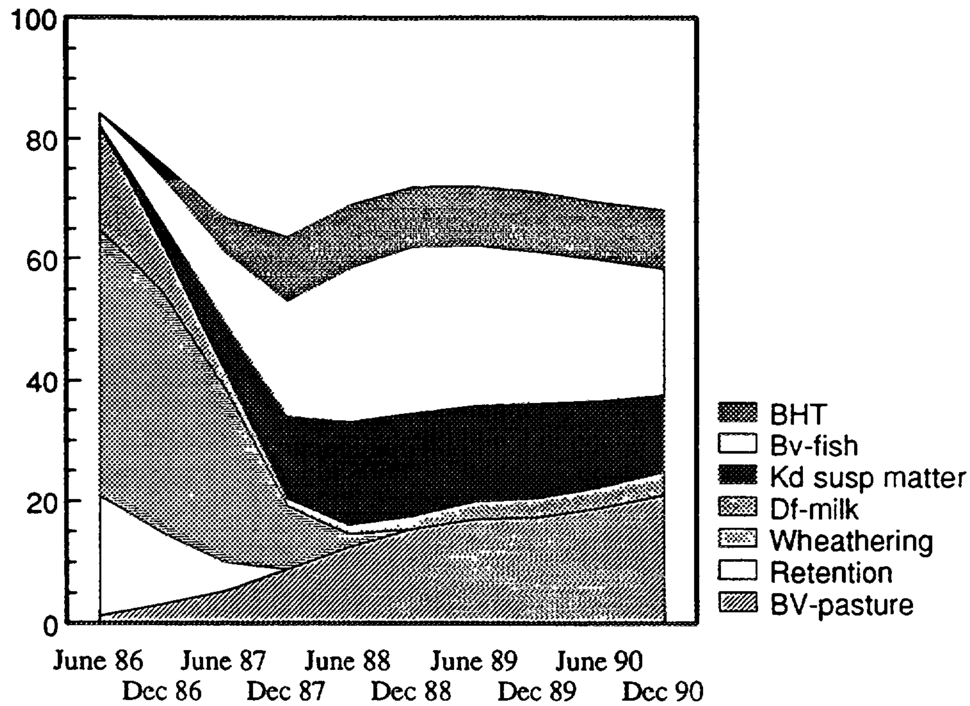


Figure 15
Major parameters contributing to the uncertainties in body burden for man

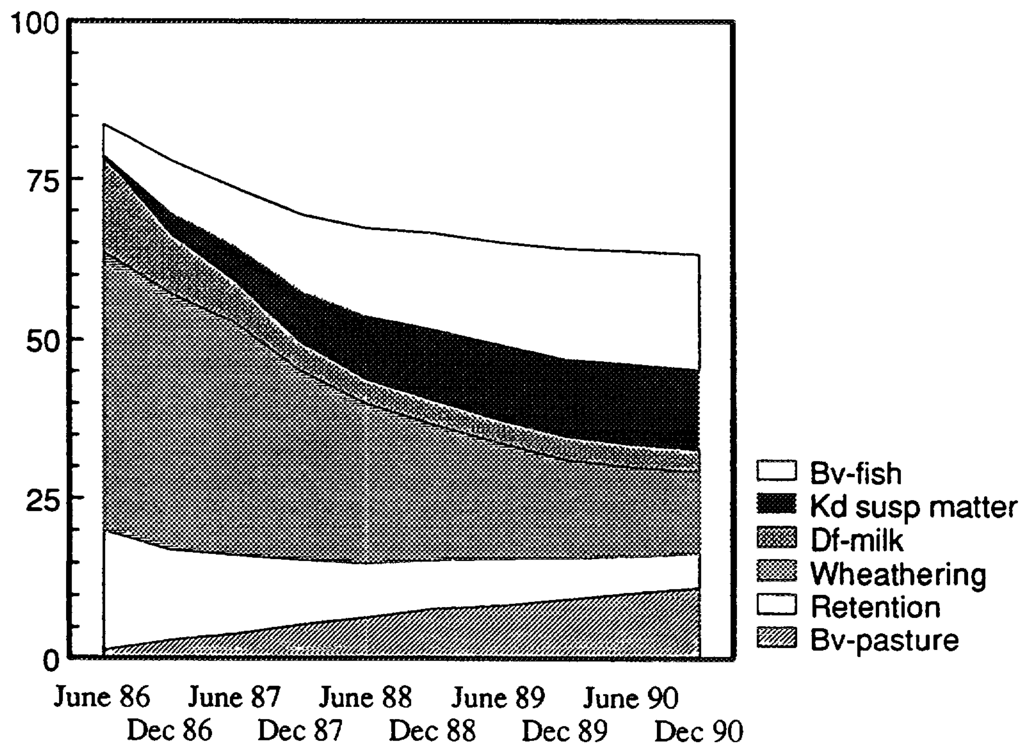


Figure 16
Major parameters contributing to the uncertainties in integrated doses.

II.3. LINDOZ

1. LINDOZ MODEL FOR FINLAND ENVIRONMENT: MODEL DESCRIPTION AND EVALUATION OF MODEL PERFORMANCE

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2. Model description

2.1 Name of the model, model developer, model user

Name of model: LINDOZ (for Finland environment)
Model developers. D Galeriu
Model users: D. Galeriu

LINDOZ model was developed by Dan Galeriu, with support from A I Apostoaei, N. Paunescu, and N. Mocanu. At the moment the only user is Dan Galeriu, until a user friendly version of the code will be available.

2.2 Important model characteristics

LINDOZ is a process-level oriented model That is, the developer has tried to model the contaminant transfer phenomena, rather than using empirical transfer coefficients. The model explicitly consider the physico-chemical form of fallout pollutant, the foliar absorption, the translocation in plants, and the growth dilution.

2.2.1 Intended purpose of the model in radiation assessment.

LINDOZ model was developed as a realistic assessment tool for radioactive contamination of the environment It was designed to produce estimates for the concentration of the pollutant in different compartments of the terrestrial ecosystem (soil, vegetation, animal tissue, and animal products), and to evaluate human exposure to the contaminant (concentration in whole human body, and dose to humans) from inhalation. ingestion and external irradiation The user can apply LINDOZ for both routine and accidental type of releases.

2 2 2 Intended accuracy of the model prediction

LINDOZ model was designed to produce best estimates It is expected from an experimented user to obtain estimates in a factor of 2 or 3 about the real values The accuracy may, however, vary depending on the quantity and quality of the input data and on the site-specific characteristics

2 2 3 Method used for deriving uncertainty estimates

The initial version of the model did not permit numerical evaluation of the uncertainties Confidence intervals were judgment results of an experienced user ("expert judgment") Later versions of the code include propagation of uncertainty using Monte-Carlo method (Latin Hypercube Sampling Technique)

2 2 4 Past experience using this model

The user has experience in using LINDOZ in assessment of the consequences of the Chernobyl accident in Romania. In addition, the model has been tested by the user against data sets from the model testing exercises within BIOMOVS - A4 Scenario, and VAMP - CB Scenario.

2.2.5 Modifications made for this scenario

S Scenario required several improvements of the LINDOZ model. The main modifications of the code consisted of a better sub-model for predicting the contamination of the cereals, a new sub-model for mushroom contamination, and a new sub-model for Cs-137 transfer in aquatic ecosystem (specifically, a fish model). Description of these improvements are provided in the next sections.

2.3. References describing detailed documentation of the model

2.4 Model structure

2.5 Description of procedure, equations and parameters used in different components of the model

Most of the model structure, procedures and equations are already described in the appendices of the CB Scenario final report Therefore, only modifications in the parameter values, description of the new equations, and specific scenario interpretation issues are presented below

2.5 1 Total deposition

An average trend of the concentration in air was derived from the experimental data from the first and second station, as they were reported in the scenario For the period of time when data are missing, a complex bi-gaussian structure of the cloud was assumed From the fit of the known data, daily mean values were derived (1 Bq/m3 for April 27, 5 Bq/m3 for April 28, etc.)

In order to derive the deposition, the detailed data on rain pattern was used The washout ratio was evaluated assuming a gaussian cloud at 1500 m center height, with z increasing from 600 m in the first day to an uniform distribution after 10 days The rain washed out the highly contaminated cloud, which was located at a high altitude. and which was not detected by measurements of air concentrations at soil level This explain high value of 2E+07 for the washout ratio for April 27, The deposition submodel was run. and the washout ratio was scaled until the deposition pattern was reproduced

2.5.2 Food items contributing to the total diet

2.5.2.1 Vegetation.

Plant contamination is influenced by the amount of Cs-137 present in soluble form in the fallout, because this form is readily absorbed by the leaf cuticle. The initial fallout in Finland was assumed to be only partly in soluble form Based on measurements from Norway, 25% of the deposited material was considered in soluble form.

2.5.2.2 Pasture-Cow-Milk, and Pasture-Cow-Beef

Using the information provided by the scenario and the dependence of the vegetation period on the mean temperature, April 25 was considered the starting of vegetation period. Similarly, May 25 was chosen for the beginning of the grazing season. It was assumed that on June 10, 60 % from cow diet was fresh grass. Cow diet (Table 1) was established by analyzing the necessary caloric content of the feed in Nordic climate and by using a milk production of 5000 L/a, which is the average value derived from the scenario.

Table 1. Dairy cow diet

	summer kg fw	winter
pasture	32	0
silage	4	24 (grass and trifolium)
hay	2	4
grain	2	4

The values in Table 1, reduced at 65%, were used for the diet of beef cows.

2.5.2.3 Pork and Chicken

The diet for pigs was assumed to contain 0 3 kg/d of milk residuals

Chicken diet is uncertain. The assumption that only grain is used may underestimate. On the other hand, small amounts of alfalfa concentrate or consideration of ingested soil may largely influence the result.

2.5.2.4 Fish

A submodel for Cs-137 uptake by fish was developed in collaboration with Dr. Ring Peterson The model is based on the following assumptions:

1) the biological removal half live is seasonally variable, having a minimum value during summer and a maximum value during winter (Table 2), and it was adjusted on a sinusoidal pattern between these extremes.

Table. 2. The minimum and the maximum biological removal half-live for fish

	Species	summer days	winter days
fish1	nonpredatory	50	200
fish2	predatory1	200	800
fish3	predatory2	100	400

2) The product of intake rate and biological removal time is constant (Korhonen, Health Physics Journal 59(443) 1990)

3) The bioaccumulation factor is specific for a equilibrium situation, in normal summer temperature.

4) The zooplancton is considered in equilibrium with water.

5) It was assumed that "Predatory 1" fish eats "Nonpredatory" fish, only. "Predatory 2" fish eats both "Nonpredatory" fish (64%) and "Predatory 1" fish (36%)

6) Due to the low solubility of the initial fallout (25% soluble form), the values assigned for the concentration factors are 2 times lower than those usually reported in systematic For S scenario, the bioconcentration coefficients were set to 1000, 3000 and 4000 for the three species of fish, respectively

7) The mean Cs-137 concentration in water was represented by a sum of two exponentials, with coefficients fitted from scenario data

Using these assumptions, the equations for time dependence of fish concentration are

$$dC_{f1}/dt = C_w(t)\, B_{f1}\, \lambda 1(t) - \lambda 1(t)\, C_{f1}$$

$$dC_{f2}/dt = C_{f1}(t)\, (B_{f2}/B_{f1}))\, \lambda 2(t) - \lambda 2(t)\, C_{f2}$$

$$dC_{f3}/dt = [C_{f1}(t)\, f + C_{f2}(t)\, (1-f)] / \{B_{f1}\, f + B_{f2}\, (1-f)\}\, B_{f3}\, \lambda 3(t) - \lambda 3(t)\, C_{f3}$$

where: Bfi = the concentration factor;

λj = the removal rate;

f = the fraction of fish3 ("Predatory 2" fish) diet consisting of fish1 ("Nonpredatory" fish)

2.5.2.5 Mushroom

The time dependency of the concentration of Cs-137 in mushroom was derived assuming that certain mushroom species have the mycelium at a specific depth in the forest soil. It was possible to define a transfer factor from a definite layer of soil to mushroom. Starting from few data available in the literature, the transfer factor was derived for *Boletus* and *Xerocomus* types of mushroom. Using a simple model of radionuclide migration in forest soil, and the depth soil profile for Cs, the time dependency of the concentration in mushrooms was obtained. Unfortunately, there were too little data available to derive probability distributions for the parameters, or to further test the results.

For the forest soil, 4 organic layers of 1 cm each with a density of 800 kg/m2 and 12 mineral layers (1 cm each, 1300 kg/m2) were considered. For *Boletus* type, the mycelium is located in the 4th layer, and it shows a transfer factor of 6 [Bq/kgdw per Bq/kg soil]; for *Xerocomus*, the mycelium is in the 2nd layer and the transfer factor is 20. A hypothetical third type of mushroom, with mycelium in first layer (surface) and a higher transfer factor of 50, was also considered The transfer rate for migration between soil layers were fitted to correspond with the scenario data on depth profile for 1986 and 1990.

2.6 Important processes and parameters.

The main problem for S Scenario was to assess the time evolution of various plant growth in a Nordic climate. The Leaf Area Index of rye was the most difficult issue. It was observed that for rye the vegetation period is shorter and winter losses are higher than in Central Europe. The attempt to use the plant parameters and assumptions (grown restarted in early April and the interception was high at the accident time) considered normal for Central Europe for the weather conditions in Finland produced strange results Finally, I understood that in Finnish conditions the day-light period is longer in summer time and the vernalisation and photoperiod effects are different than in Central Europe In order to reproduce the real conditions, the sowing was assumed to be done in late September (Julian day 250) In late autumn (Julian day 290) the yield should be 0 2 kgdw/m2 and the LAI should be 1 However, after the winter, on about May 1st, the yield is only 0.1 kgdw/m2 and LAI=0.5. After a rapid growth, the maximum LAI is reached about June 15, and it has a value of 5. The harvest for rye was assumed to be on August 5th

For pasture, it is very difficult to evaluate the growth rate at the beginning of vegetation period Moreover, the time when fresh grass is the main feed was of main concern. Based of the mean monthly temperature from the scenario, it was considered that the vegetation period starts on April 25th and the grazing period on 25 May The stabling period started on September 20th

The importance of seminatural product fish, game. berry and mushrooms was a surprise The long removal time for fish is a result of a lower mean temperature and I would like to thanks to Ulla Bergstrom for pointing this issue The forest soil properties are also difficult to evaluate Aggregated transfer parameters obtained as a mean of observations in Sweden were used for game and berries

3. Comparison of observed data and prediction.

3.1 Total deposition

Total deposition was estimated very well, because of the sufficient information provided by the scenario authors. All the information was fully used, as it was described in our contribution at the November 1993(?)

3.2 Food items

3.2 1 Milk

The underprediction for the concentration in milk in August (P/O=0 5) was followed by an severe overprediction in September (P/0+1 7) and late winter (P/O=2-2.2) This result can be explained by the early stabulation date we have considered, corroborated with a high concentration in hay predicted for 1986 harvest. Indeed, pasture data are overpredicted in 1986 by a factor of 4 - 5 The reason for this overestimation can be, probably, found in the assumption of increased retention on grass due to wetting after snow melt is questionable (we assumed that the wet surface intercept 3 times more material) A lower LAI in late April and a lower wet interception would probably produce more realistic results

Starting with January 1st, 1988, severe underpredictions were produced for milk (P/O=0 1 in 1990), while for pasture predictions are quite close to the observed mean (P/0=0 6)

3 2 2 Beef

The underprediction produced for the concentration in beef for May 86 (P/O=0 1) is contrary to result for the concentration in milk at the same time, where the prediction was close to the observation Moreover, the underprediction for summer 1986 (P/O=0 35), and the good prediction for the fourth quarter of 1986 and the first quarter of 1987, are not consistent with the predictions for milk The differences in diet and in transfer parameters values can be invoked, but, at this time there are little information to clearly explain the inconsistency

3 2 3 Pork

Good predictions for the concentration of Cs-137 in pork were produced for 1986 For 1987 some overprediction are present for the spring and the winter time periods (P/O=2) A major underprediction can be observed for 1990 (P/O=0 1) A potential cause for this underprediction can be the milk product component in the pork diet Note that the predictions for the concentrations in cereals are. most of the time, reasonable

3 2 4 Cereals.

The predictions for the concentration in wheat are good for 1987-1990, but they 2 times larger than observations for 1986 The predictions for the concentrations in rye show a similar trend. The concentration in barley was overpredicted with factor 3 in 1986, and good predictions were produced for later years It seems that the systematic overprediction in 1986 is due to the assumption that the contamination of the surface is present (after seeding) on a layer of 3 cm depth In addition, a too high soil-to-plant transfer rate was used.

3.2.5 Leafy vegetable

The concentration in leafy vegetables were systematically overpredicted by a factor 3-6. The reason of the overprediction is a too large amount of peat assumed to be used in the greenhouse

3.2.6 Wild game

The concentration in wild game was only slightly overpredicted (P/O= 1 2-1.6) for any moment of time It seems that the information from Sweden are good for predictions in Finland conditions

3 2 7 Mushrooms

The overprediction of the concentration in mushroom in the first years by only a factor of 2, is very satisfactory, since we have used a new approach and a different data set to derive transfer parameters

3 2 8 Fish

The concentration in fish is underestimated for 1986 (P/O=0.6), and for 1987 (P/O=0.5). Better results were produced for next years 1989 (P/O=0 9),and 1990 (P/O=0.85). Since the fish model is only the first attempt in modeling the aquatic ecosystem, we found the results to be very satisfactory In addition, these results show that a simple model, with good assumptions, can work well

3 2 9 Berries

The overprediction with a factor 2 in 1986 and the underprediction in 1990 (P/O=0.33) clearly show that the migration of Cs-137 in soil and fixation rate are far from Finnish forest conditions. However, the results are acceptable, taking into consideration that again this is only a preliminary attempt to model parts of the forest ecosystem

3.3 Human Intake

For 1986 and 1987 the predictions for the human intake are close to the values estimated by STUK (P/O=0.7-1.3). For the following years, underpredictions (P/0=0.4) are a general rule, for all population groups. This can be related with the milk and meat underpredictions. The seasonal variation predicted for the intake, is not observed in STUK estimations.

3.4 Whole body

Only deterministic calculations were performed for evaluation of the concentration in human body. The predicted values are close to the observations (P/0=1-1.5 for man; 1-1.8 for woman and 1-1.5 for child). The results produced for 1989-1990 are better than the analogue ones for the intake, which is not normal. The key problem is the quality of data about human intake. It is essential to clarify the way in which the human intake was estimated: direct measurement of diet, computed intake from food concentration and assumed diet; or deduced from whole body analysis.

4. Explanation of major sources of misprediction

In analyzing the model performance one must distinguish between the first year results and the results for the next years. The scenario involves a region having for Nordic weather conditions, which is a major difficulty for a realistic prediction Moreover, the deposition occurred in late April, when the vegetation period is exactly at the beginning and when a one week shift in plant growth can induce major misprediction This is the case for grass and rye, the only plants on the field in the fallout time Unfortunately the data on grass are quite scarce and we suspect not to be representative for the milk and meat production area

The inconsistency between the predictions for milk and beef implies that the dairy-cow and beef-cow diets are probable incorrectly assessed The overprediction of milk and meat in winter of 1986 can be explained by the overprediction of pasture Moreover, the overprediction of milk in September 1986 is induced by a too early stabling date for cows

For cereals other than rye, it is difficult to evaluate the depth distribution of Cs-137 after sowing, and the soil-to-plant transfer factor is dependent on the assumptions made. The average soil properties, characteristic for the whole production area, can be established quite accurately from the scenario data, using the distribution of soil types in each agricultural area and the fraction of plant production in each area

The major underpredictions for the concentration in milk, beef and pork in 1988-1990 should be explained by some common factors. The relative overprediction for 1986 shows that the assumption of a 25 % soluble fraction in the initial fallout is not an explanation for the underestimations that occurred in later years, and thus it can not be abandoned. The pasture-animal model was basically unchanged from CB scenario, and by analyzing the observations and the model parameters, some key issues were detected

First issue comes from the comparison of the slope of the model predictions to the slope of the data for pasture, milk and beef. Studying the slopes, one can deduce that the fixation rate of Cs-137 in soil used in the model is not appropriate for Finnish conditions, where less clay fraction is present in the soil, relative to Central Europe. The slope of experimental data indicate a fixation half-time of 4-5 years, while for Romania and Central Bohemia the half-life was set to 1 year, a value characteristic for hard soils.

The second issue appeared after discussions in the workshops, where the possibility of the pasture data being not representative for milk and meat production was analyzed. Initially, a mean soil type was derived by averaging over all agricultural areas Recently, we have noticed that the milk and meat production are not equally distributed over the whole area, fact that might have influenced the model predictions. A more accurate average soil can be obtained by weighting with the production fraction in each agricultural subarea.

4.1 Recommendation for changes to the model

There are several changes that are recommendable for an improvement of LINDOZ predictions for S Scenario.

- It is necessary to use the real growth stage of the vegetation as derived from real condition in Finland 1986 In order to proceed with a revision of model parameters weather information for April 1986 are necessary The additional information provided by Aino Rantvaara starts in May 1st
- More information concerning the diet of dairy-cows, beef-cows, pigs, and chicken are necessary
- Seasonal variability of the consumption rates for fish, mushrooms and wild game are unknown These food items are major contributors for activity intake by humans in 1987-1990

- Soil-to-plant transfer for animal feed The representative soil ("mean" soil) type for S region must be obtained weighting the production fraction in each subarea The mean soil-to-plant transfer factor is established first for each subarea using the distribution of soil types given in the scenario We classify these soils in coarse (sandy and loamy sand) clay and peat and we use the IUR systematic for pasture and forage Finally, the subarea transfer factor is weighted by the milk production fraction and the representative mean soil-to-plant transfer factor is obtained The new estimated values are B_{vp}=0 3 for pasture grass and B_{vf} = 0.25 for forage
- No data for the fixation rate of caesium in soil are directly available from Finland and, at this moment, we have no available methodology to evaluate the fixation rate from the clay content in the soil. From the analysis of data (pasture, milk, meat) a fixation rate of 0 012 d^{-1} has been derived

4.2 Examples of how changes improved calculation

Only the last two recommended changes (soil-to-plant transfer factor, and caesium fixation rate) described in the above section have been made, to date. The revised predictions for the concentrations in milk, beef and pork are now very close to the data for 1987-1990 (see attached figures) confirming our analysis. For the winter 1986, the overprediction is now slightly increased due to the higher transfer from soil to plant (the new values for the transfer factor is 3 times larger than the initial one). However, this effect is less important than the overprediction of the concentration in pasture grass (a factor of 4) for May- July 1986.

Furthermore, the human intake, as well as the whole body content, are now increased by about 40 %, in order to compensate for the seasonal variations in the consumption of mushroom, and wild game.

5. Conclusions

Each pathway, process or transfer rate can have a different role and importance depending on the site specificity. What it is of a minor importance for a scenario, can be of a major importance in other circumstances. The understanding of the processes and of the relationships between the transfer rates and the site specific information is essential.

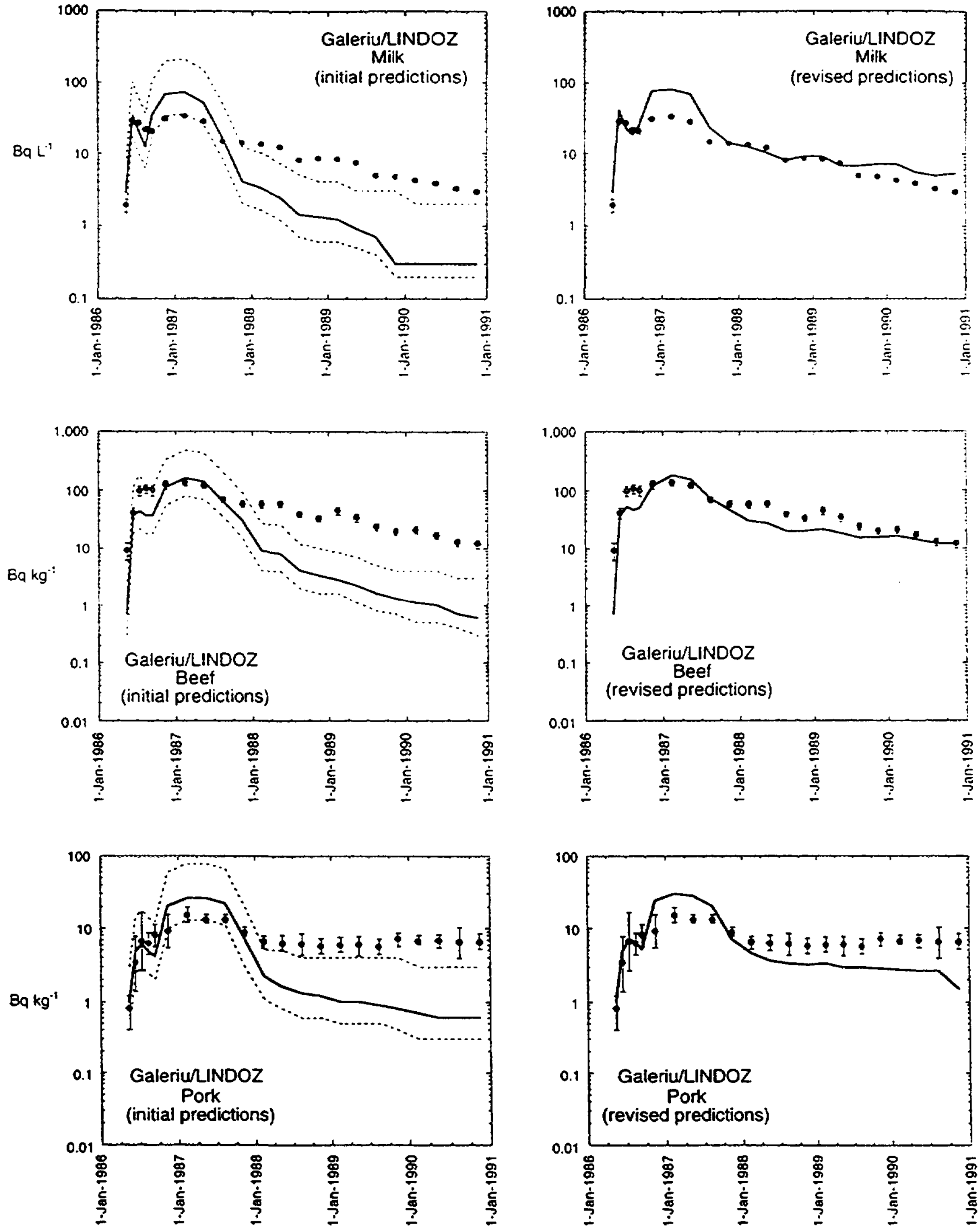

Fig. 1. Comparison of initial (left) and revised (right) predictions for milk (top), beef (center), and pork (bottom) for Galeriu/LINDOZ.

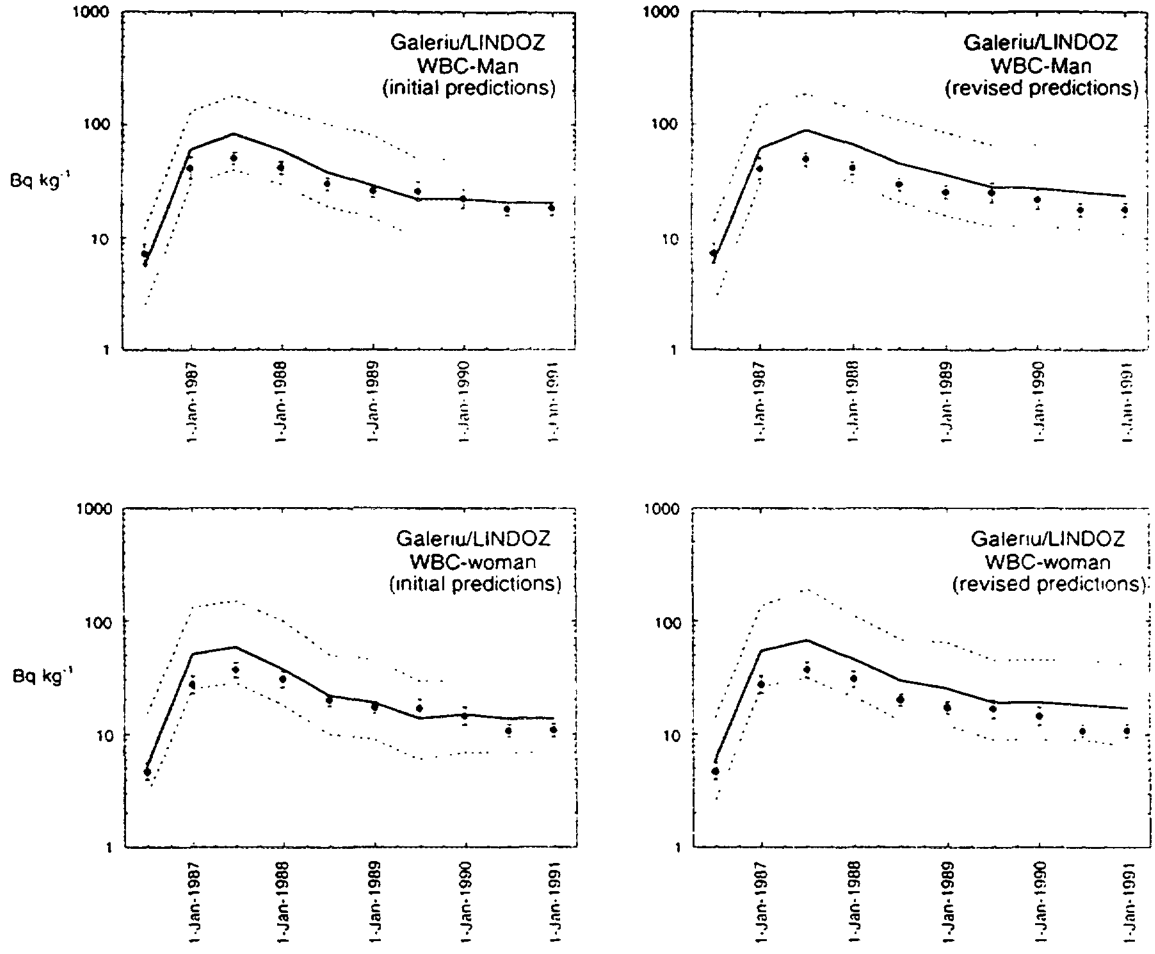

Fig. 2. Comparison of initial (left) and revised (right) predictions whole body concentrations for men (top) and women (bottom) for Galeriu/LINDOZ.

II.4. SCHRAADLO

1. ASSESSMENT OF SCHRAADLO-T PERFORMANCE FOR S SCENARIO

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2. General model description

The model SCHRAADLO has been developed to assess the environmental impact of nuclear facilities. It is a dynamic compartmental model.

The model is driven by daily air concentration and daily precipitation rate. The output are time dependent concentrations in soil, different types of meat and plants, milk and whole body. There are not included aquatic and seminatural food chains. Calculations of contamination of fungi have been performed separately.

The model SCHRAADLO-T is a modification of the model used e.g. in the BIOMOVS A4 exercises. Some parameters of the model have been modified according to the "Chernobyl" experiences. It was used for the calculations of the CB scenario of the VAMP exercises.

It can be used for accidental as well as for routine releases. Intended accuracy is to give best estimate results. Uncertainty in the output is estimated using Monte Carlo analysis. The present version of the model has not been published. Its flow-chart is on the Fig. 1. The previous one is possible to find in "Jaderná energie" 36 (1990) p. 467 - 471.

FLOW CHART THROUGH THE TERRESTRIAL FOOD CHAIN

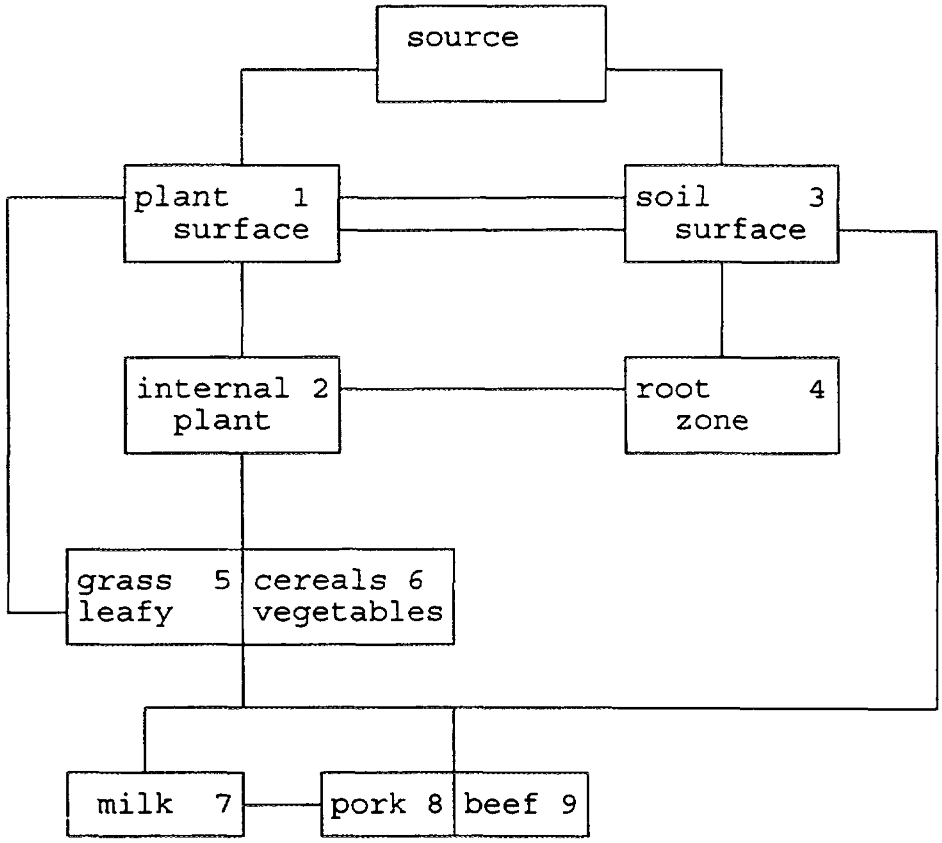


FIG. 1

3. Comparison of test data and model predictions

The P/O ratios for calculated quantities are given in Table 1 and 2.

3.1 Total deposition

The calculated average total deposition was in good agreement to the observed with only 16% of underestimation. The calculated mean value is within the confidence limit of the observed one.

Table 1: Summary of results predicted by the model

	Deposition		Wheat		Rye		Pasture grass		Fungi*	
	P/O	C.I.	P/O	C.I.	P/O	C.I.	P/O	C.I.	P/O	
1986	0.84	+	2.7	+	1.	+	1.3	+	0.52	+
1987			3	+	0.61	+	0.4	-	0.46	+
1988			2.8	+	0.5	+	0.8	+	0.37	+
1989			4	+	1.6	+	2	+	0.3	+

P/O - predicted to observed ratio
C.I.- confidence interval of predictions
+ indicates prediction falls with C.I.
- prediction is out of C.I.
n.a.- not available data
* - Boletus Edulis

Table 2: Summary of time series of results predicted by the model

	Milk		Beef		Pork		W.B.C.	
	P/O	C.I.	P/O	C.I.	P/O	C.I.	P/O*	C.I.
May 1986	3.5	+	1	+	8.8	-		
Jun	1.4	+	1.1	+	5.9	-	n.a.	
Aug	0.8	+	0.26	-	3.3	-		
Sep	0.9	+	0.25	-	3.	-		
IV 1986	1.3	+	0.41	-	2.7	-	0.6/0.9	+/+
I 1987	1.2	+	0.45	-	1.5	+		
II 1987	0.7	+	0.21	-	1.5	+	n.a.	
III 1987	0.7	+	0.22	-	1.4	+		
IV 1987	0.14	-	0.12	-	2.1	-	0.7/1.	+/+
I 1988	0.15	-	0.11	-	2.8	-		
II 1988	0.12	-	0.1	-	2.5	-	n.a.	
III 1988	0.13	-	0.14	-	2.3	-		
IV 1988	0.12	-	0.16	-	2.5	-	0.2/0.2	-/-
I 1989	0.09	-	0.12	-	2.2	-		
II 1989	0.1	-	0.16	-	1.5	+	n.a.	
III 1989	0.14	-	0.22	-	0.89	+		
IV 1989	0.14	-	0.27	-	0.67	-	0.1/0.2	-/-

mean P/O
W. B. C. - whole body concentration (Bq/kg)
* - P/O ratio for man/woman

3.2 Major food items contributing to total diet

3.2.1. Milk

Prediction of Cs concentrations in milk are compared to observed values in Fig. 2. The graph reveals relative good agreement during the first 2 years and an underprediction after 1987. P/O ratios are shown in Tab. 2. The values of P/O are within C.I. for the first 2 years after accident. The underestimation in the following years is possible to explain by the fact, that there has occured feeding by some natural or seminatural plants which amounts has not been given in the scenario. The hypothesis is supported by the fact that the concentration of Cs-137 in grass as well as in cereals has been overestimated which is opposite to the understimation of the milk contamination.

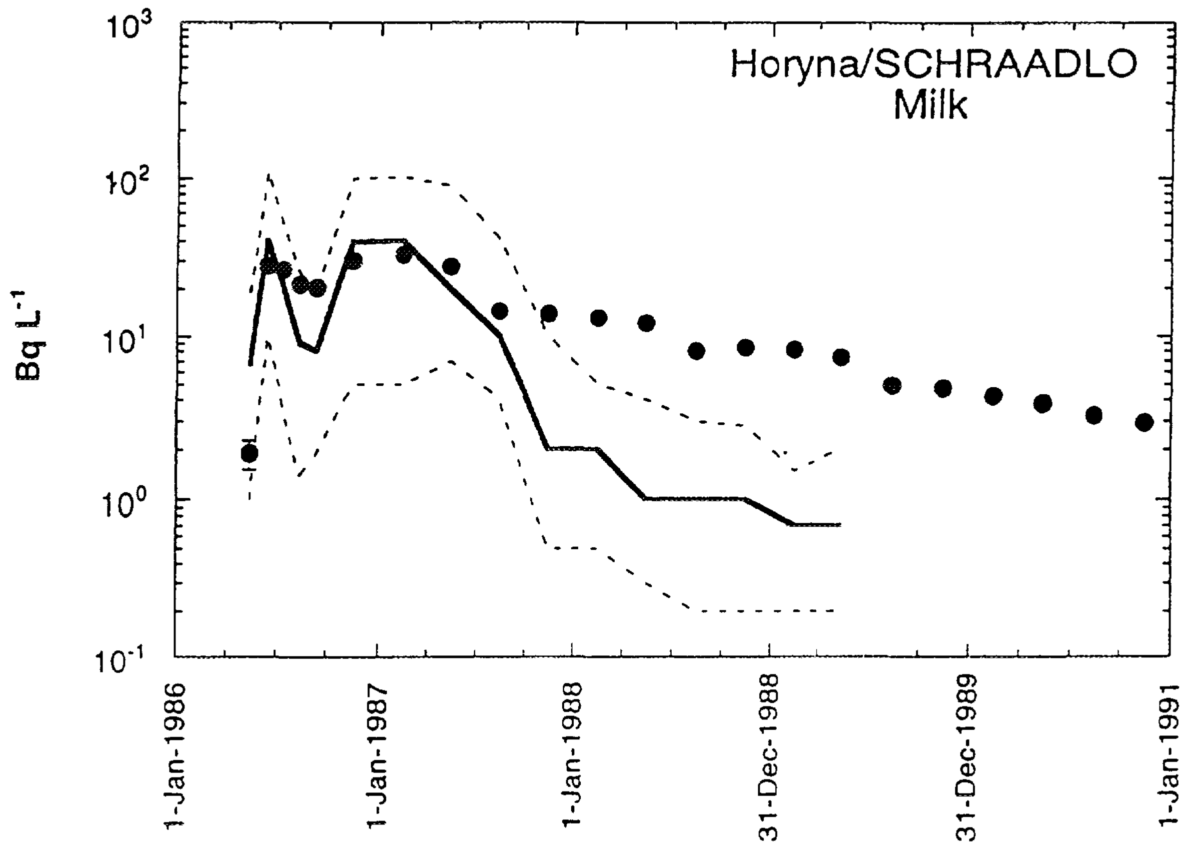


FIG.2

3.2.2. Beef

Predictions of Cs concentrations in beef are compared to observed values in Fig. 3 and Tab. 2. The time course of the predicted values has a similar trend as in the case of milk. The presented results show an underpredition during the period in question. The values of P/O ratios for early time after accident are within C.I . The underestimation in the following years is possible to explain by the fact, that there has occured feeding by some natural or seminatural plants theirs amounts has not been given in the scenario. The hypothesis is supported by the fact that the concentration of Cs-137 in grass as well as in cereals has been overestimated. It is also necessary to refer to the predictions for pork, which has been reasonably acceptable.

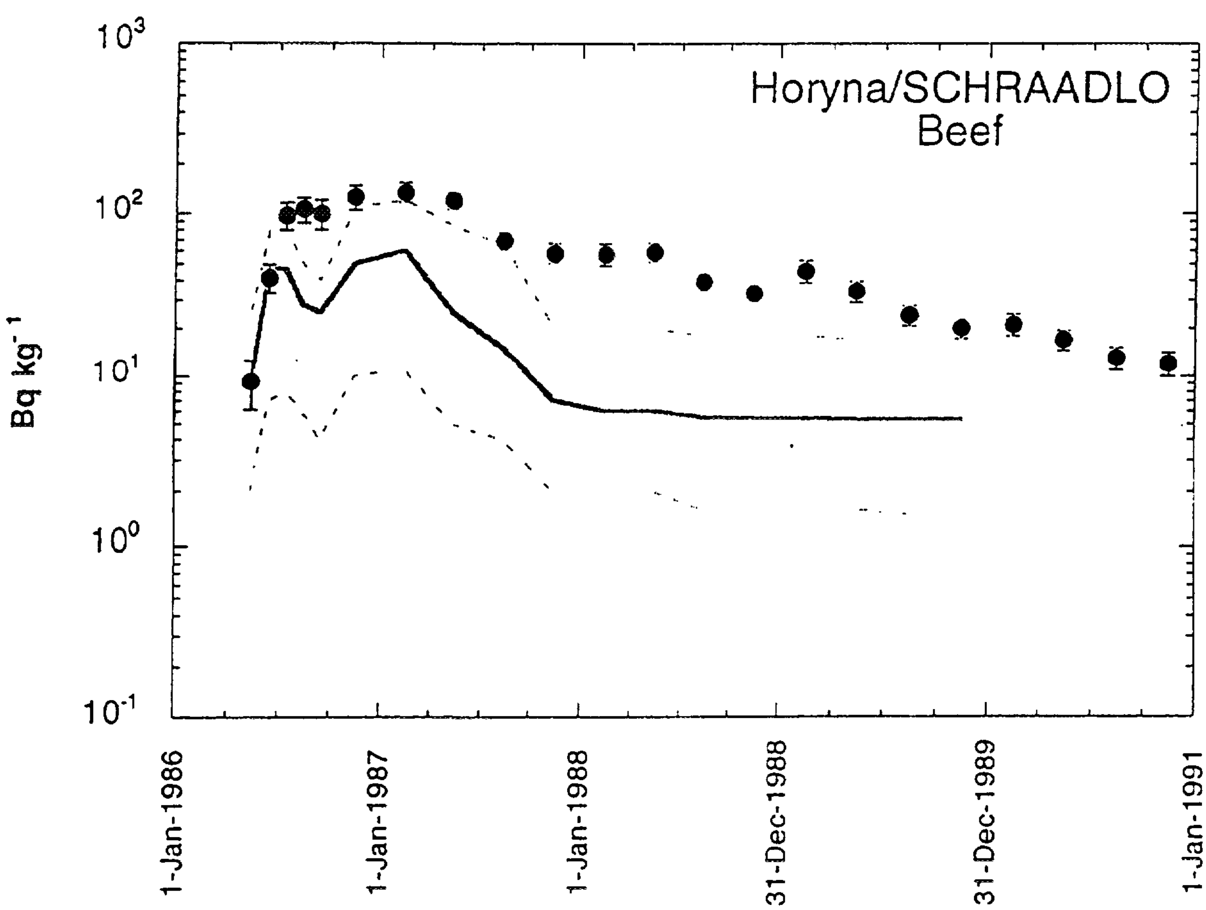


FIG.3

3.2.3. Pork

Predictions of Cs-137 concentrations in pork are compared to observed values in Fig. 4 and Tab. 2. The time course of the predicted values has a quite different trend as in the case of milk or beef. The presented results show an overpredition during the period in question. Fast all values are within factor of 3 of the observations.

3.3. Other comments

As can be seen from Table 1 and Fig. 5 - 8 there were relative good results for grass, Boletus Edulis(fungi) and cereals with the P/O´s within the range 0.3 - 4.

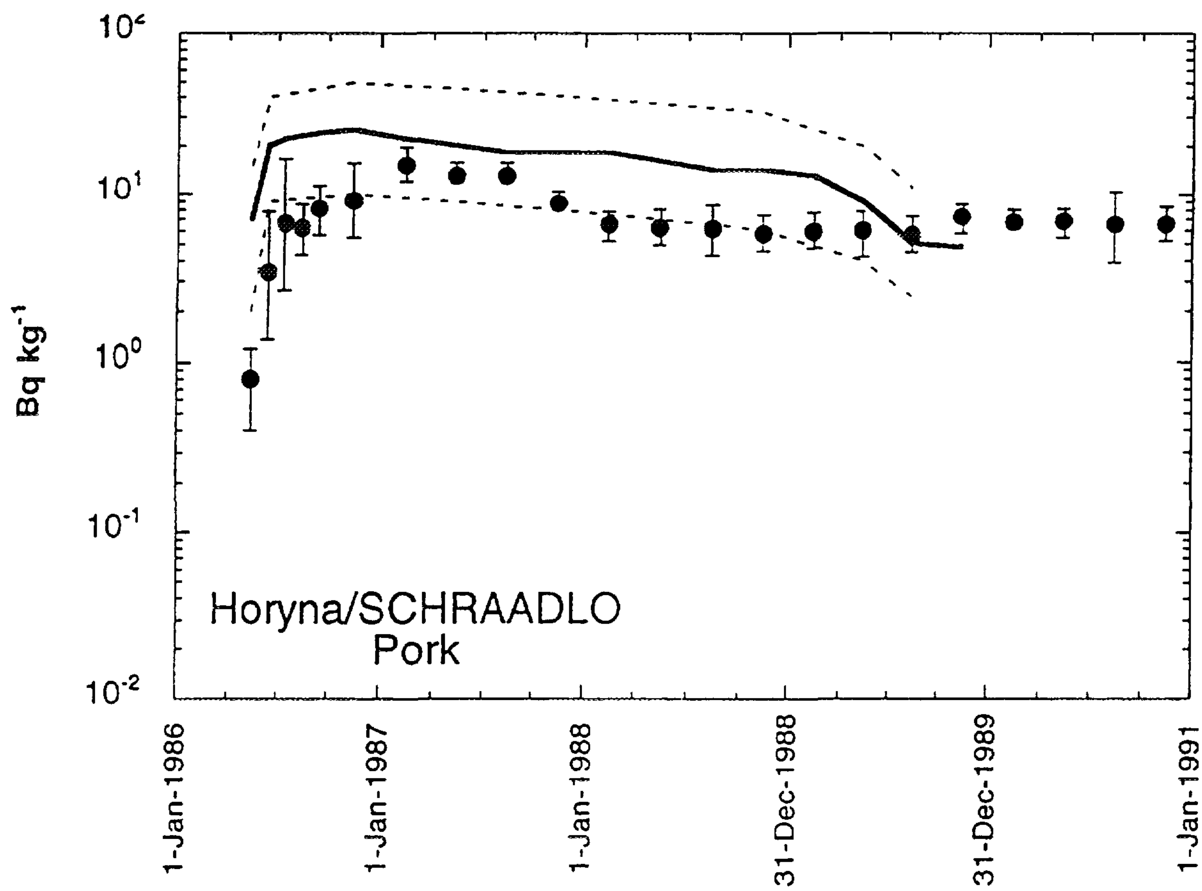
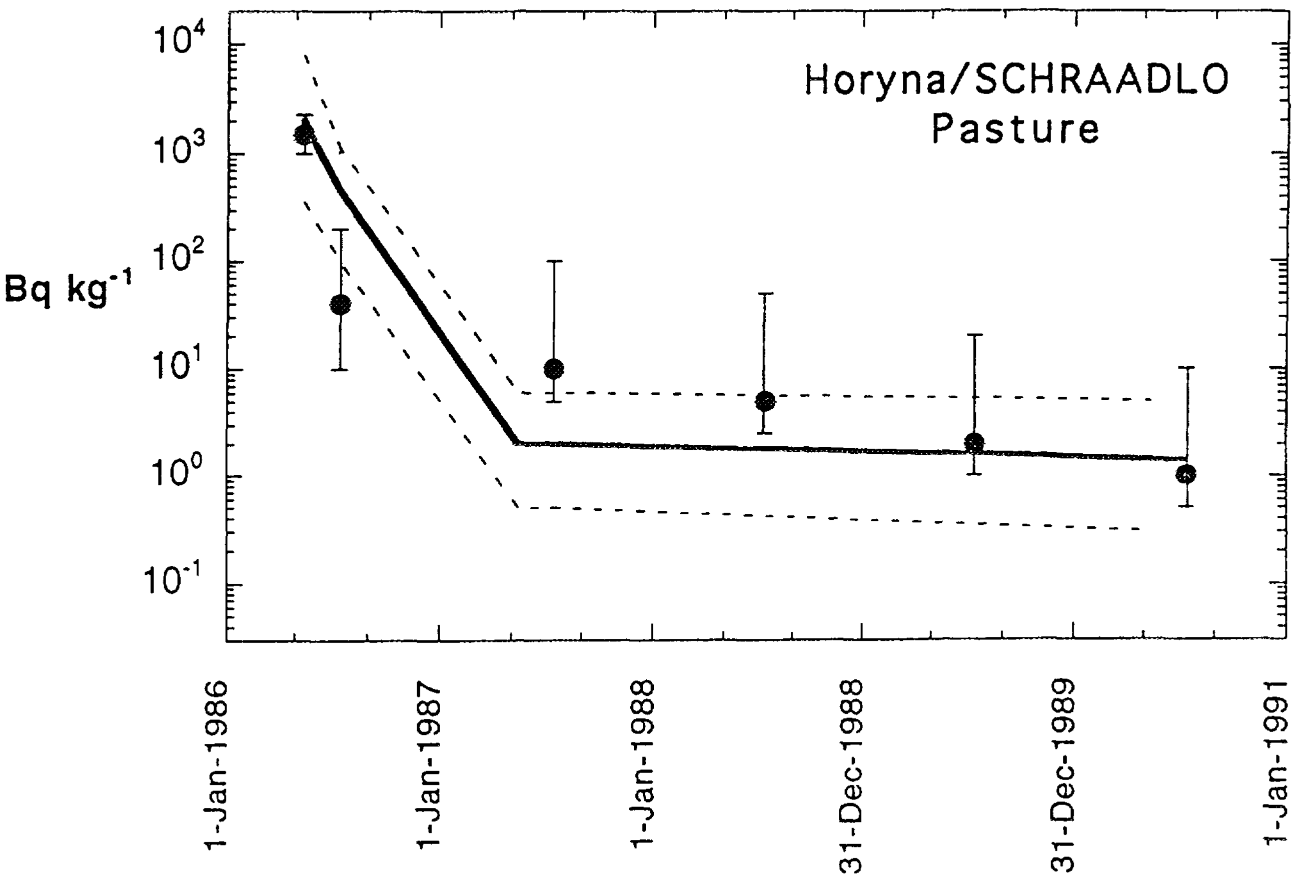
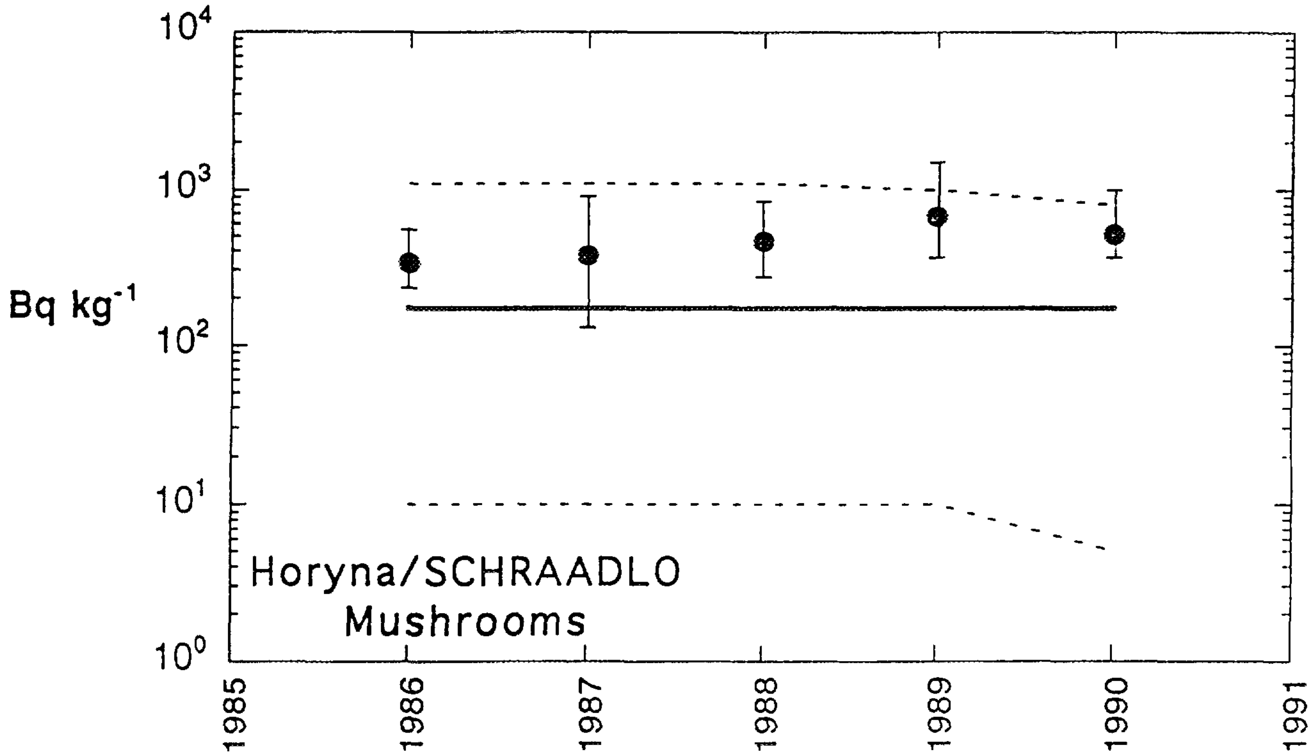


FIG.4



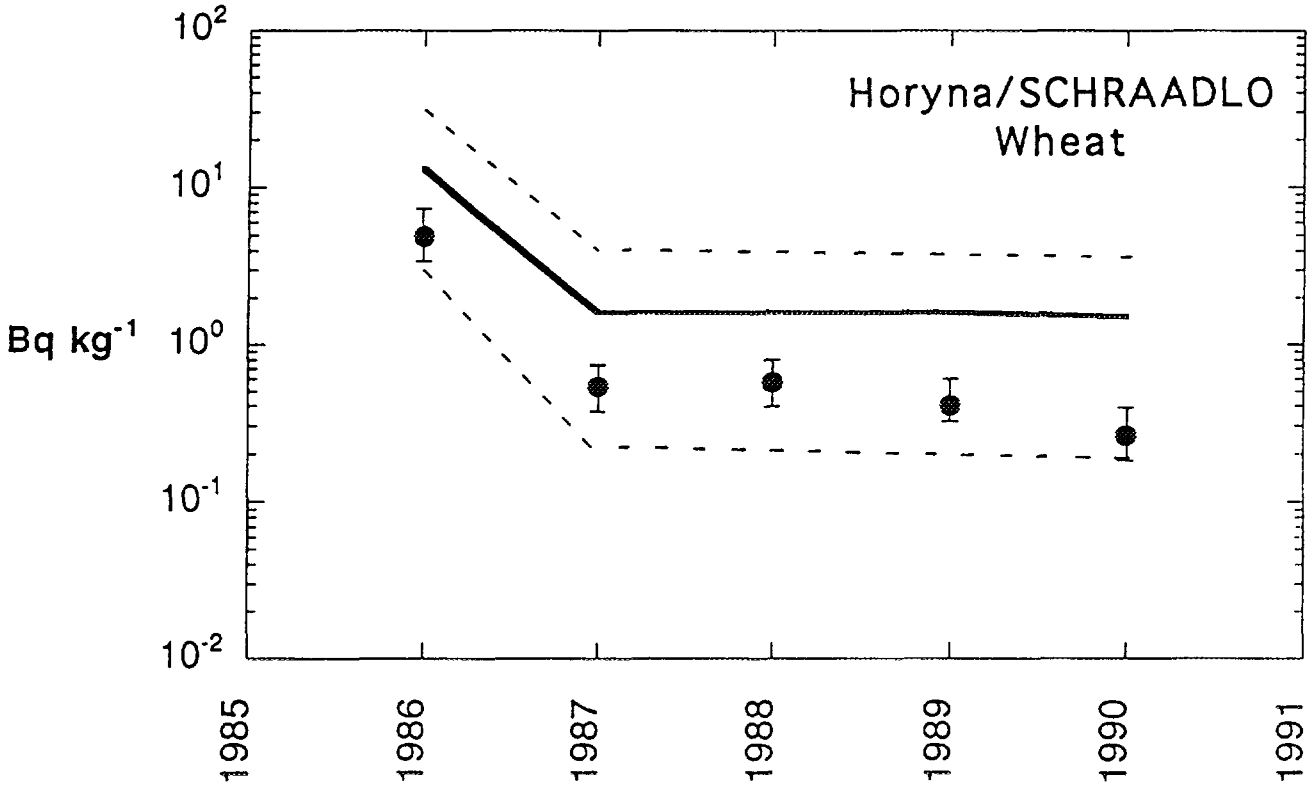
Horyna/SCHRAADLO
Pasture
Bq kg^{-1}
10^4
10^3
10^2
10^1
10^0
10^{-1}
1-Jan-1986
1-Jan-1987
1-Jan-1988
31-Dec-1988
31-Dec-1989
1-Jan-1991

FIG. 5



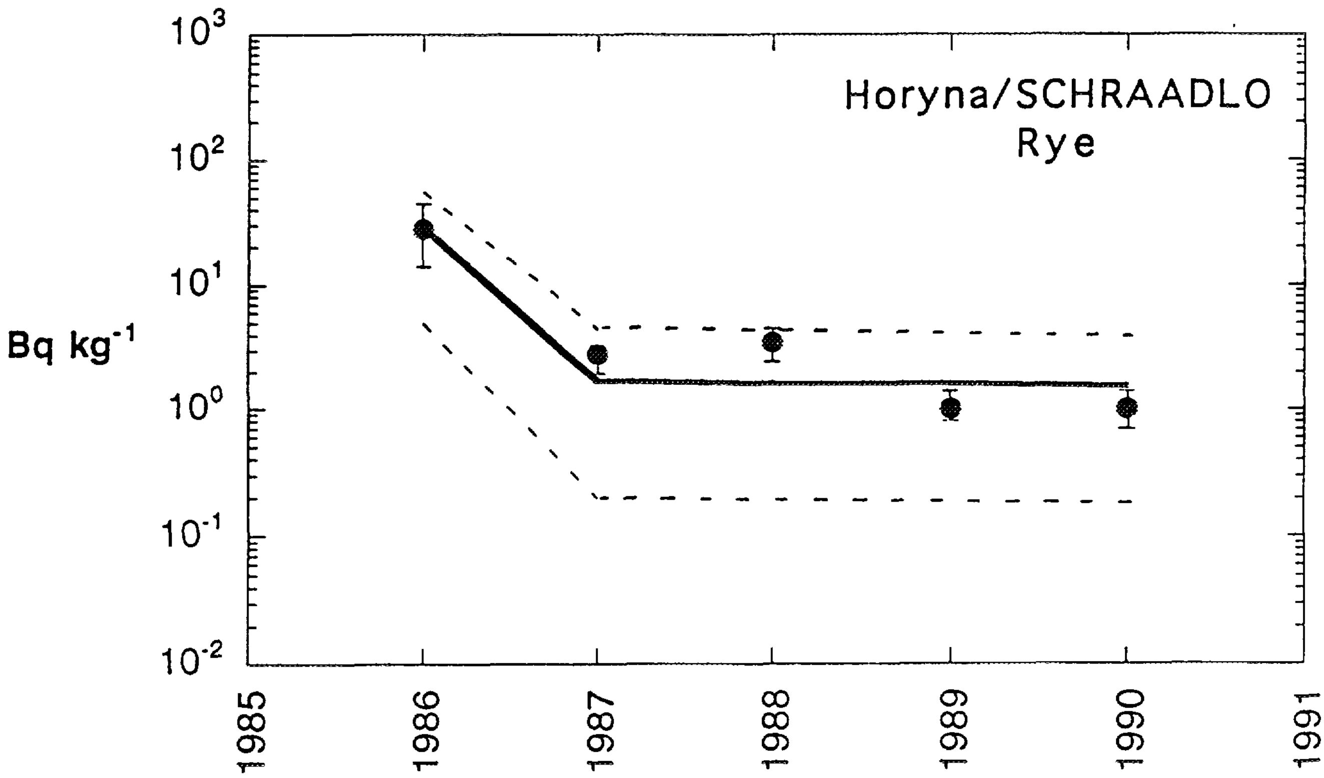
Bq kg^{-1}
10^4
10^3
10^2
10^1
10^0
Horyna/SCHRAADLO
Mushrooms
1985
1986
1987
1988
1989
1990
1991

FIG. 6



Horyna/SCHRAADLO
Wheat
Bq kg-1
10^2
10^1
10^0
10^-1
10^-2
1985
1986
1987
1988
1989
1990
1991

FIG. 7



Horyna/SCHRAADLO
Rye
Bq kg-1
10^3
10^2
10^1
10^0
10^-1
10^-2
1985
1986
1987
1988
1989
1990
1991

FIG. 8

4. Explanation of major sources of misprediction

The time dependence of P/O has shown that the used model tends to underpredict concentrations of ^{137}Cs. The most significant differences has occcured in the period after 1986. The potential sources of differences between model predictions and observations are mentioned below:

Air:

The airborne contamination of the S region was measured by 2 sampling stations. The value of about 16 $Bq.d/m^3$ has been assumed to be representative for the inhalation dose calculations. The uneven distribution of airborne contamination may be expected according to the measured soil contamination. The filtering factor of 0.8 (actįvity concentration of indoor air divided by outdoor concentration) has been assumed. The overestimating of the calculated inhalation dose (2.7E-3 mSv) is difficult to explain taking into account, that no special measures were taken. The airborne concentration and the calculated inhalation dose are comparable to the results obtained in the Central Bohemia (see CB scenario).

Cereals:

The significant over-prediction has occured for the concentration in wheat. The effect of various soil properties has not been taken into account and the conservative concetration factors (soil-plant) have been used.

Milk, beef and pork:

It is probable that the share of green fodder at the beginning of May 1986 was lower as supposed in the scenario. The predictions after 1986 are underestimated. Uncertainities in the timing of harvest of cereals and hay, as well as the beginning of fresh/stored feed consumption has been of special importance due to the fact, that the Chernobyl accident happened at time of the fast development of plants.

The tendency of the model to the underestimation of Cs-137 concentration in milk and beef with increasing time is evident. It seems, that feeding of semi-natural products (lichens, mushrooms, grass growing on peaty soils) may cause the discrepancies in predictions of milk as well as beef contamination. Unfortunately, it has not been recognized from the scenario description. It can be reasoned by the quite acceptable results for pork.

Fungi:

The underprediction for fungi is given by the fact that the transfer factor soil - fungi,is highly dependent on the species of fungi. The calculations were performed for the Boletus Edulis spp. only as asked by the scenario, which is known with a relative small uptake of Cs from the soil.

Whole body concentration:

There is a tendency of the model to the underestimation with increasing time. Here is to repeat, that not all food chains are included in the model, e.g. fish, game nad berries. However, the main reason of underprediction has not been neglecting of semi-natural human food chains but lacking data about animal's feeding practice. Therefore the results for whole body concentration are not subjected to further analysis.

5. Conclusions

The differences between the predicted and the observed values of the concentrations of Cs-137 have increased with time after the accident.

The main reasons of disrepancies has been in model structure concerning of animal's feeding including semi-natural products not given in the scenario description.

It is not only the problem of model structure, but also the problem of input data interpretation including the risk of not detecting input data error or shifting harvest dates. Including more pathways in the model does not decrease the final uncertainty of the WBC due to increasing number of uncertain parameters of the model.

It has appeared that data not significant for the purpose of screening of environmental contamination after the accident will be of special importance for predictions of the accident impact based on model calculations.

II.5. TERNIRBU

1. DESCRIPTION OF MODEL AND INDIVIDUAL EVALUATION OF MODEL PERFORMANCE FOR SCENARIO S

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National Research Institute for Radiobiology and Radiohygiene,
Budapest, Hungary

2. MODEL DESCRIPTION

2.1. Name of model, model developer and model user

Model name:	TERNIRBU (for terrestrial systems, same as for Scenario CB)
Developers:	B.Kanyár and N. Fülöp, National Research Institute for Radiobiology and Radiohygiene, Budapest
Users:	developers

2.2. Important model characteristics

The compartmental model used is realized as a procedure of the general purpose code TAMDYN for simulation, sensitivity and uncertainty calculations of dynamic models. More details of the model structure and parameters are given in the description of the VAMP MP Scenario CB.

The difference between the climate in Finland and Central Bohemia was taken into consideration by shifting the seasonality function with 12 days'according to the weekly average temperature.

The lake system and the contamination of fishes was simulated by the model SIRATEC used and validated in the BIOMOVS Scenario A5. The model was extended to two *fish-compartments* for roach and pike ones as a catanary system. For simulations the code TAMDYN was used.

The doses were estimated from the time integrated concentrations of the proper components multiplied by the dose conversion factor.

3. COMPARISON OF OBSERVED DATA AND MODEL PREDICTIONS

The deposition was calculated from the soil contamination given in the scenario description. Both the mean value and the uncertainty are underpredicted by 20-30%.

The earlier concentrations of the leafy vegetables are overpredicted due to misused scenario description, namely the calculations were provided for vegetables in the open air. The contaminations in vegetations like berries and mushrooms were not predicted because of lack of parameters for them. The underprediction on the concentrations in the pasture following the second year might be due to the rapid diffusion into the deeper parts of the soil. Similar underpredictions are provided for grains except the winter wheat.

The underprediction in the feedstuff of the cows results in the same difference in the milk and beef. In addition to the small concentration of milk and beef the underprediction in the human body could be explained by lack of foods from mushrooms, big and small games and underpredicted concentrations in the fishes. That type of foods became more important after the 1st year.

The corrected values are provided in the Figures 1-4.

4. EXPLANATION OF MAJOR SOURCES OF MISPREDICTION

The underpredicted deposition could be explained by the special mean used, namely the mean value was provided by weighting with the areas of the regions.

In case of using less rapid diffusion into the deeper soils the concentrations in the root soil layer and therefore in the pasture and other vegetations, milk, beef etc. become higher. The correlations among the parameters and predictions obtained from the Monte-Carlo analysis showed a relative large correlation between the transport coefficient of the root soil layer to the deeper layer and the milk concentration, from beginning of the 2nd year.

The corrected values given in Figures 1-4 are provided by the following transfer coefficients in the soil:

k (sosu,soro):	5e-4 d^{-1} (from surface soil to root soil, normalized to 1 m thick layers),
k (soro,sode):	2e-4 d^{-1} (from root soil to deeper soil),
k (sode,soro):	1.5e-4 d^{-1} (from deeper soil to root one, upward diffusion),
k (sode):	1.5e-4 d^{-1} (from deeper soil to sink).

For the corrected predictions, in addition to the modification of the soil parameters the radiocesium content in human was calculated by adding the observed intake from mushrooms and games (they were not predicted) and the recalculated fishes.

The underestimated doses could be explained by

- underestimated deposition,
- underestimated concentration in the surface and root soil layers, followed by the less contamination of the milk, beef, human body etc. after the 1st year.
- because of the uncertainties of the concentrations are mainly overestimated the underprediction of the dose-uncertainty could be explained by taken into consideration of the dose conversion factors without uncertainty.

The relatively large differences between the observed and predicted uncertainties might be derived from the less validated (mainly subjectively determined) uncertainties of the parameters used.

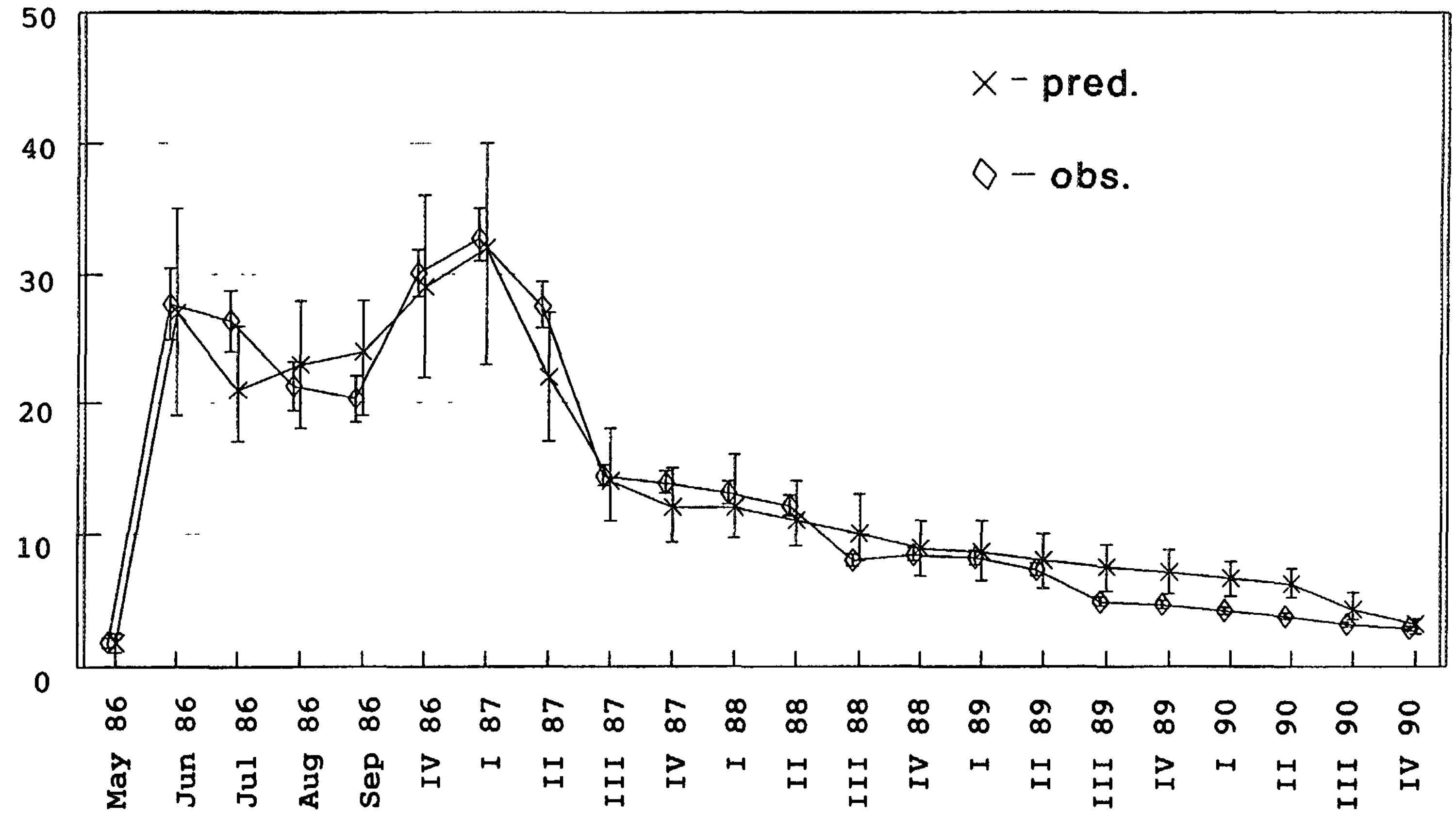


FIG.1. Cs-137 concentration in milk.

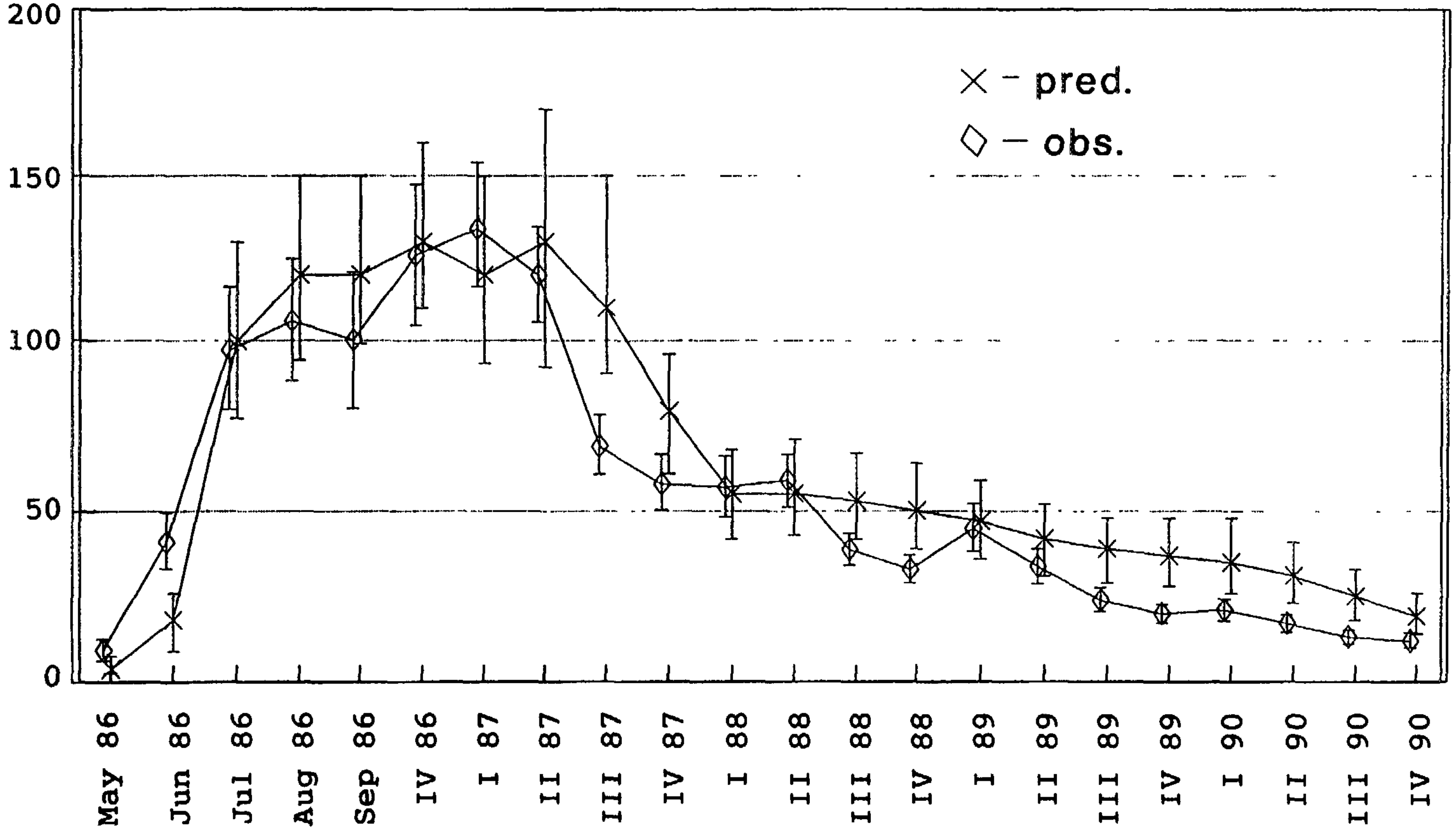


FIG.2. Cs-137 concentration in beef.

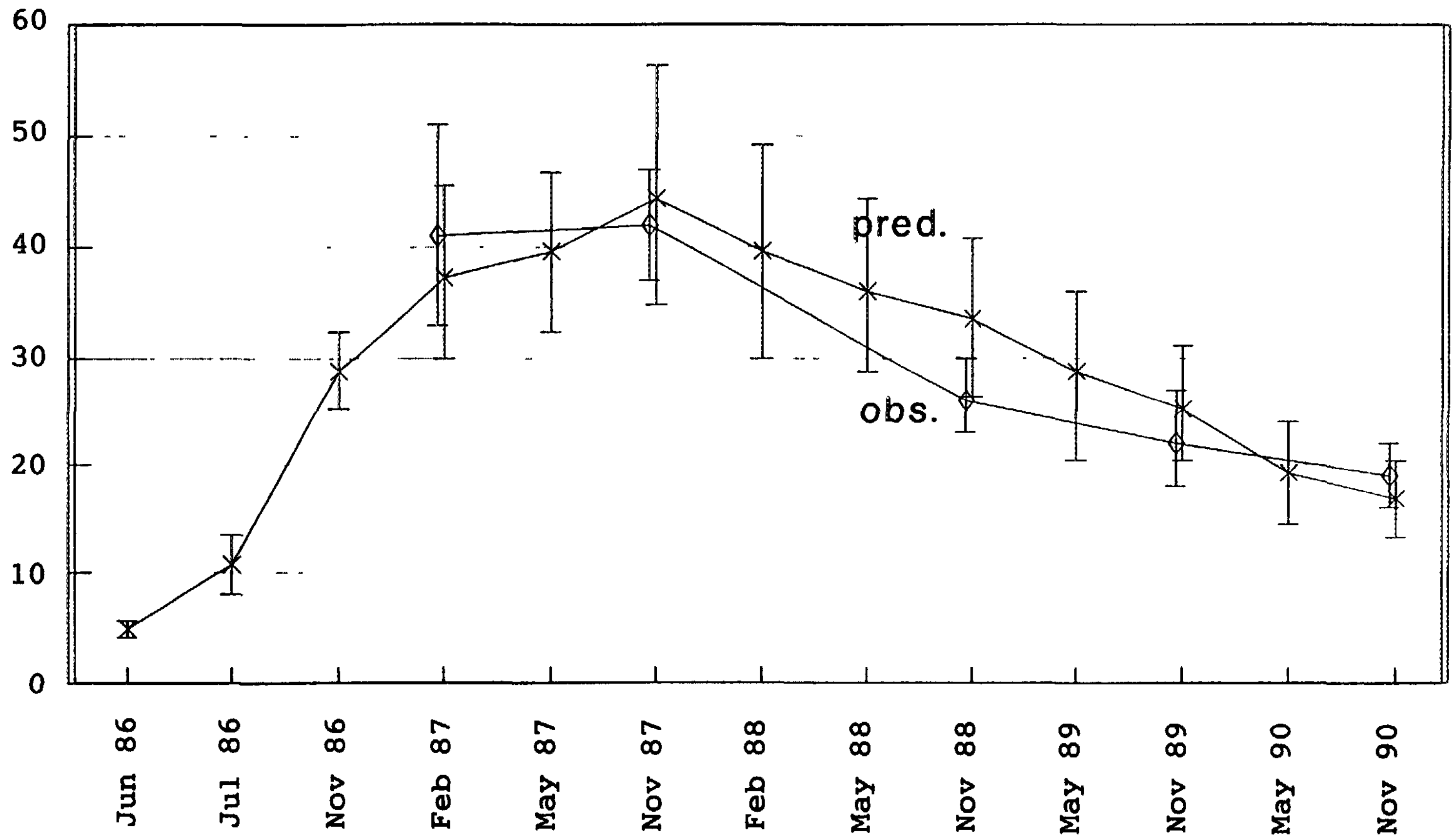


FIG.3. Cs-137 concentration in man.

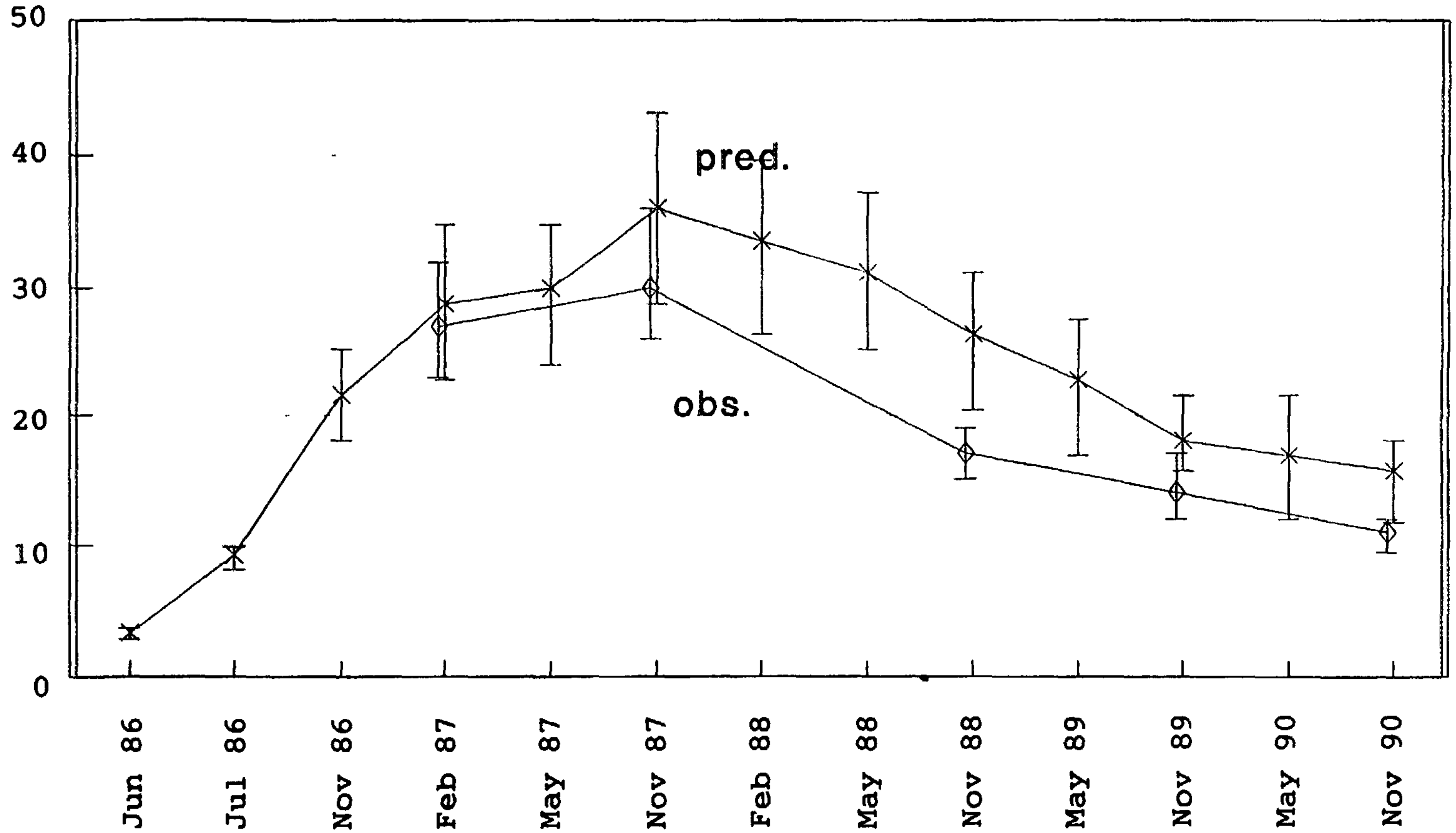


FIG.4. Cs-137 concentration in woman.

1. INDIVIDUAL EVALUATION OF MODEL PERFORMANCE FOR SCENARIO S

P. KRAJEWSKI
Central Laboratory for Radiological Protection, Department of Radiation Hygiene, Warsaw, Poland

2. MODEL DESCRIPTION

2.1 Model Name: CLRP - Concentration Levels Rapid Predictions

Model developer: Pawe³ Krajewski

Model user: Central Laboratory for Radiological Protection

2.2 Important model characteristics

2.2.1 Intended purpose of the model in radiation assessment

The model CLRP was created in 1989 as a part of research project "LONG-LIVED POST-CHERNOBYL RADIOACTIVITY AND RADIATION PROTECTION CRITERIA FOR RISK REDUCTION" performed in coopera tion with U.S. Environmental Protection Agency. The aim of this project was to examine the fate of long-lived radionuclides in the terrestrial ecosystem. Concentrations of Cs-137 and Cs-134 in the particular components of terrestrial ecosystem e.g. soil, vegetation, animal tissues and animal products are calculated as a function of time following deposition from the atmosphere. Based on this data the whole body contents of radionuclide as a function of time is calculated and dose to a specific organ for the radionuclide may be estimated as an inte gral of the resultant dose rate over a sufficient period. In addition, the model allows estimation of inhalation dose from time integrated air concentration and external dose from total deposition using simple conversion factors. The program is designed to allow the simulation of many different radiological situations (chronic or acute releases) and dose affecting countermeasures. Dynamic processes in the model include foliar intercep tion, weathering; plant growth and root uptake, leaching and radioactive decay. The model considers seasonal changes in the biomass of vegetation and animal diets, also specific plowing and crop-harvest dates. Human dietary data are included to permit calculation of time -dependent radionuclide ingestion rates for adult, young ster 10 years old and child 1 years old.

The CLRP model has been designed as a set of Excel worksheets that simulate the transport of radionuclide through agricultural ecosystems to humans.

All dynamic processes are described by exponential formulas and are solved numerically.

2.2.2 Intended accuracy of the model prediction

CLRP model is deterministic and yields single estimates of specified variables.
Intended performance of the model is standard that specifies that model should not under-predict the true value by more than factor of three. Justification of standard model performance has been done based on post- chernobyl data of Poland. Further modification of the CLRP model will be made to run model with stochastic subroutine that enable to perform an uncertainty analysis.

2.2.3 Method used for deriving uncertainty estimates

The uncertainty estimates given for the CB scenario were derived by personal judgement of the authors considering experience with comparisons of predictions and measurements after the Chernobyl accident (on basis post-chernobyl data in Poland) and general radioecological experience. For the revised calculation the uncertainty ranges were kept the same to avoid subjective judgement as the true values of the results had been known.

2.2.4 Past experiences using this model

CLRP model was used for dose evaluation for population in Poland after The Chernobyl accident.
Pietrzak-Flis Z., Krajewski P., Radiocesium in diet and man in northeastern Poland after the Chernobyl acci dent, Health Physics (printing).
Moreover CLRP took part in the VAMP scenario CB

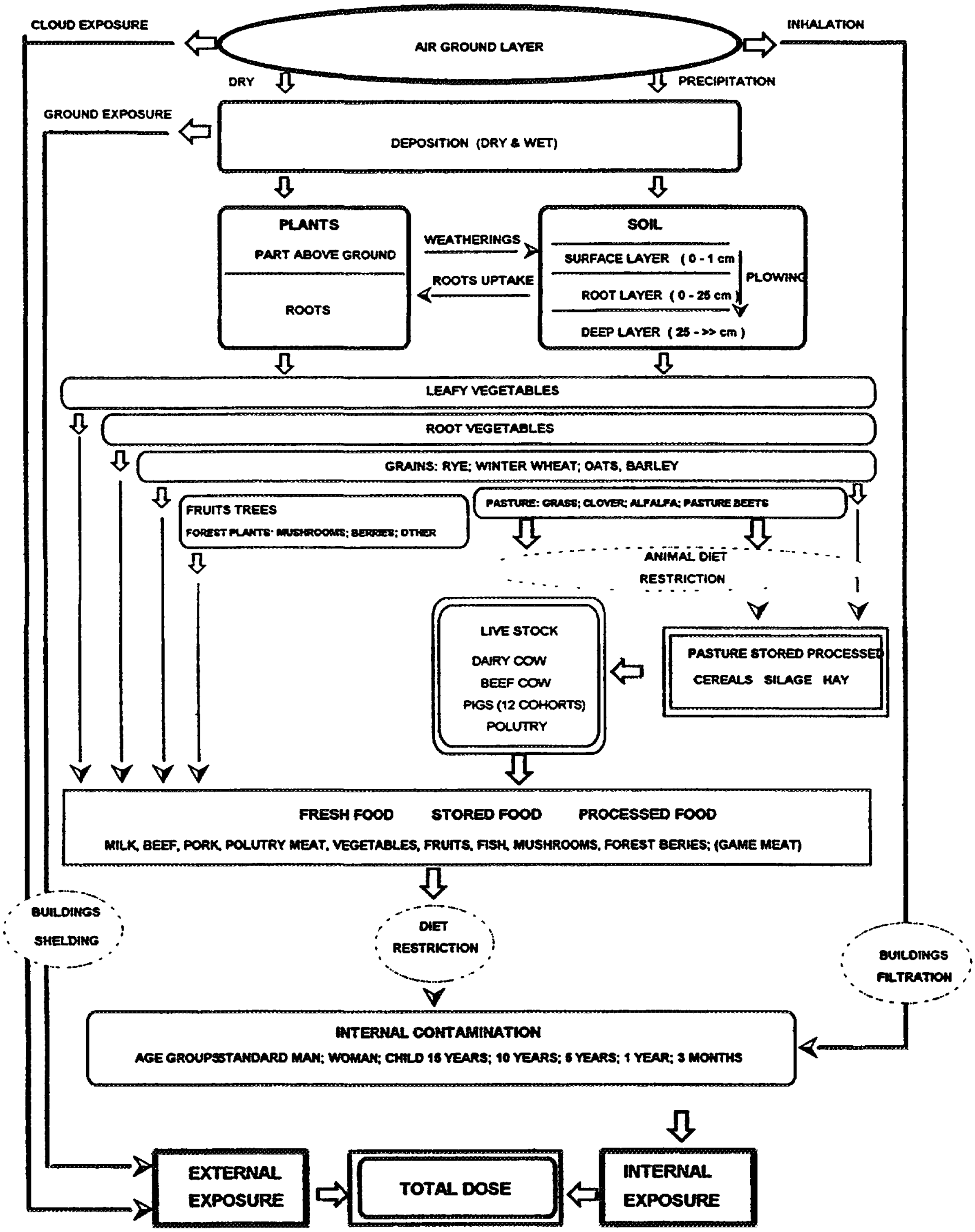
2.2.5 Modifications made for this scenario

Generally model structure has not been changed comparing with CB scenario only some values of numerical parameters have been changed e.g.:
Growing period of vegetation was shifted approximately two weeks later;
Animals and human diet was changed according to VAMP Scenario S;
Soil to plant transfer ratio according to different soil proprieties comparing to CB sce nario.

2.3 References describing detailed documentation of model:

Pawe³ Krajewski; Model of the transfer of radiocesium through terrestrial ecosystem and dose assessment to man; w: Final Report of Long-Term Post Chernobyl Radioac tivity and Radiation Protection Criteria for Risk Reduction; Research Project No. PAA/EPA-89-12; Wa-wa 1993; appendix #.7

2.4 Model structure (flow chart indicating transfer proceses)



2.5. Description of procedures, equations and parameters used in different components of the model.

(Numeric parameters reported below relate to the best estimate of model predictions obtained for VAMP scenario S).

2.5.1 Total deposition - D [Bq m^{-2}].

$$D(t) = \sum_{t_i=1}^{n} \dot{D}_d(t_i) + \sum_{t_j=1}^{m} \dot{D}_w(t_j) \qquad \text{(Eq.1.}$$

Is a sum of daily dry and wet depositions over perod of con tamination t.

2.5.1.1 The daily dry deposition Dd (i) [Bq $m^{-2}d^{-1}$]

$$\dot{D}_d(t_i) = C_a(t_i) \cdot v_d(t_i) \qquad \text{(Eq.2.)}$$

where:

$C_a(t_i)$ - average of the radionuclide concentration in air at the day t_i

v_d (t_i) - the radionuclide dry deposition velocity [m d^{-1}] at the day t_i

v_d (t_i) - is function of (wind speed and distribution of aerosols) at the day t_i

value used by model equal to 860,0 [md^{-1}] (1.0E^{-2} [ms^{-1}] was estimated assuming average wind speed 5 [ms^{-1}] and following aerosols distribution D_{ae} =0,75; SD=1,8; Table 2-1

TABLE 2 - 1: DISTRIBUTION OF THE ESTIMATED 137CS ACTIVITY BOUND TO AEROSOL PARTICLES RELATIVE TO THE AERODYNAMIC DIAMETER .

Dae [μm]	0,01	0,03	0,04	0,06	0,1	0,25	0,4	0,63	1	2,5	4	6,3	10	25	40	63	100
(%)	0,40%	0,70%	0,70%	1,60%	4,90%	6,60%	6,70%	8,20%	16,00%	13,60%	9,60%	8,40%	10,70%	6,60%	2,60%	1,70%	1,00%

2.5.1.2. The daily wet deposition D_W (i) [Bq m-2 d-1]

$$\dot{D}_w(t_j) = h_{mix} * C_a(t_j) * \{1 - \exp\left(-\lambda * t_j^{eff}\right)\} \qquad \text{(Eq.3.}$$

where:

C_a (t_j) - the daily average of the radionuclide concentration in air at the day of precipitation t_j

$t^{eff}{}_j$ - the effective precipitation time [s] calculated as a ratio **$I(t_j)/(I_s(t_j)/3600)$**

$I(t_j)$ - the daily precipitation at the day t_j [mm] (values taken from scenario S)

$I_s(t_j)$ - the precipitation intensity at the day t_j [mm h^{-1}] ; $I_s(t_j)/3600$ [mms^{-1}]

λ - washout coefficient [s^{-1}]

Washout coefficient is function of the precipitation intensity Is [mm h-1] and the aerosol distribution.

The value of equal to 8,82E-05 [s^{-1}] was estimated assuming that the average precipitation intensity is equal to 1 [mm h^{-1}] for each location and aerosol distribution Dae =0,75; SD=1,8; Table 2-1.

2.5.2. Concentration of radionuclide in plants C_X [Bq/kg f.w.]

$$C_x(t_i) = C_{dx}(t_i) + C_{sx}(t_i) \qquad \textbf{(Eq.4}$$

The time dependent concentration in edible parts of the plants x at the day t_i was calculated as a sum of concentration due to deposition C_{dx} and concentration due to root uptake C_{SX}.

2.5.2.1. Due to deposition C_{dx}

$$C_{dx}(t_i) = \sum_{t_j=1}^{t_i} \dot{D}(t_j) \frac{R_x(t_j) \cdot T_x(t_j)}{Y_{cx}(t_i)} \cdot \exp\left[-\lambda_{ed} \cdot (t_j - t_j)\right] \qquad \textbf{(Eq.5}$$

where:

$D(t_j)$ - Daly deposition (dry & wet) at the day t_j

$C_{dx}(t_i)$ - concentration of radionuclide in the edible part of the plant at the day t_i

$T_X(t_j)$ - time dependent translocation function [m2/m2] . Ttanslocation function depends on the day t_j of developing state of the plant X and used to be modified gausian function (see figures)

$Y_{CX}(t_i)$ - the yield of the plant x crops (*for leafy vegetables; grass; alfalfa; clover etc. the same as the yield of the biomass growing above*) at the day (t_i) [kg m^{-2} fresh wight];

for remained plants as cereals; tubers; fruits etc the yield of the plants crops is different

Table 2-3.

λ_{ed} - equal to $\lambda_w + \lambda_r$

-the rate constant for the reduction of radionuclide concentration on vegetation surface

λ_w - the removal rate from crops due to weathering value used by model 0.693/15 days (11,12)

λ_r - radioactive decay constant

$R_X(t)$ - the time dependent interception factor:

$$R_x(t) = 1 - \exp\left[-\mu * DMC_{ax} * (Y^{o}_{ax} + Y^{max}_{ax} * \tanh(Y^{\alpha}_{ax}(t))\right] \quad \text{(Eq.6}$$

where:

μ - an absorption coefficient (Chamberlain's constant 2.8)

Y_{ax}^{max} - the maximal yield of the plant x (biomass growing above) at the time of harvest [kg m-2 fresh weight]

DMC_{ax} - dry matter contents of the biomass growing above

Y_{ax}^{o} - the yield of the plant x biomass growing above that is remaining after harvest or first cut (grass, alfalfa also winter wheat) during a winter time

15 per cent of Y_{ax}^{max} was assumed for pasture grass and alfalfa and 10 per cent for winter wheat.

t_j - the time [day] of the vegetation period

Y^{α}_{ax} - the growing rate constant of the plant x biomass above

$Y_{CX}(t_i)$- the same formula as for Yax(ti) is used with different growing rate Ycx .

In addition the senescence processes are included in calculations. Figure 4, 5 6.

2.5.2.2. Concentration of the radionuclide in the edible part of the plant due to transfer from soil $C_{SX}(t_i)$

$$C_{sx}(t_i) = \sum_{j=1}^{n} C_{soil}(t_j) \cdot \frac{\dot{B}_v(t_j)}{P_s \kappa(t_j)} \cdot \exp\left[\left[-\alpha \cdot \lambda_{mobile}(t_i - t_j) + (1-\alpha) \cdot \lambda_{fixed}(t_i - t_j)\right]\right] \quad \text{(Eq.4}$$

where:

$C_{soil}(t_j)$ - the radionuclide concentration on the bare soil surface [Bq m^{-2}]

$B_V(t_j)$ - the rate function for the soil to plant uptake [Bq kg^{-1} fresh weight plant per Bq kg^{-1} dry weight soil]

P_S - the initial soil bulk density [kg m^{-2}]

λ_{mobile} - the rate of migration below root zone of the mobile component of radioisotope [d^{-1}]

λ_{fixed} - the rate of migration below root zone of the fixed component of radioisotope [d^{-1}]

$\kappa(t)$ - the soil concentration factor, depends on plowing practices for agriculture areas or on movement of radionuclide inside the root area in forest ecosystem.

α - mobile component fraction

Parameters used in calculation are given in Table: 2 - 2. Examples are given in figures.

TABLE: 2 - 2. PAREMETERS USED FOR CALCULATION OF THE PLANTS CONTAMINATION.

PLANT	Start growing date above	Biomass above Y_{ax}^{max} [kg m^{-2}] fresh weight	Dry matter contents above DMC_{ab} [%]	Start growing date crops	Biomass crops Y_{cx}^{max} [kg m^{-2}] fresh weight	Dry matter contents crops DMC_c [%]	Next cut or harvest date	Translocation at the time of maximum depositt 29 04-1 05 T(t) [m^2/m^2]	Weathering half life above $T_{1/2}$ [d]	Weathering half life above $T_{1/2}$ [d]	Soil density [g cm^{-3}] soil type	Soil bulk initial P(t) [kg m^{-2}]	Bv Plant/Soil [illegible]	Soil concentration factor κ(t) (plowing depth cm)	Out of root zone half time mobile component [year]	Out of root zone half time fixed component [year]	Out of root zone factor mobile component
lettuce in a green house	15-May	1,2 1,05 0,75	8%	15-May 10-Aug 25-Sep	1,2 1,05 0,75	8%	30-Jun 10-Aug 25-Sep	1* 0 1 filtrtra tion factor	28	28	0,7 *peat pH= 5*	21	0,05	2 (6)	3	10	0,8
spinach in a green house	15-May	1,2 0,8	15%	15-May 25-Jul	1,2 0,8	15%	25-Jul 20-Oct	1*	28	28	0,7 *peat pH= 5*	21	0,05	2 (6)	3	10	0,8
cabbage	15-May	3,0	15%	15-May	3,0	15%	30-Aug	0,007	14	14	1,3 *loam pH=6*	40(3)	0,01	6,7 (20)	2	5	0,8
carrots	1-May	0,4	25%	5-Jul	2.0	20%	15-Aug	$<10^{-5}$	14	∞	1,3 clay loam pH=6	40 (3)	0,01	8 (25)	2	5	0,5
spring wheat	1-May	0,7	25%	1-Jun	0,3	100%	20-Aug	$3\ 10^{-5}$	14	∞	1,6 *clay*	48 (3)	0,015 0,01				
rye	1-May	0,7	25%	15-July	0,6	100%	1-Aug	0,0019	14	∞	1 3 *sandy loam*	40 (3)	0,05 *(0,01)*	7 (20) 10 (30)	1,5 3	5	0,9 1
barley	1-May	0,7	25%	15-Jul	0,3	100%	10-Aug	$<10^{-5}$	14	∞	1,6 *sandy loam-clay pH=6*	80 (5) 40 (3)	0,02 0,01	4 (20) 10 (30)	2	5	0,9
potatoes	5-Apr	0,17	25%	15-May	1,7	21%	15-Sep	$<10^{-5}$	14	∞	1,3	40 (3)	0,0126	10 (20)	2	5	0,8
cucamber	1-May	1,5	25%	16-Jun	3.0	5%	31-Aug	$<10^{-5}$	14	28	1,3 *Loam pH=6*	40 (3)	0,001	6,7 (20)	2	5	0,8
bean	1-Jun	1.0	25%	1-Jul	0,5	25%	31-Aug	$<10^{-5}$	14	28	1,3 *Loam pH=6*	40 (3)	0,01	6,7 (20)	2	5	0,8
fruits (apple)	15-Apr	24	25%	1-May	5.0	20%	1-Sep	0,1	14	28	1,3 *Loam pH=6*	65 (5)	0,02	no plowing	2	10	0,8

TABLE: 2 - 2. PAREMETERS USED FOR CALCULATION OF THE PLANTS CONTAMINATION. CONT.

PLANT	Start growing date above	Biomass above Y_{ax}^{max} [kg m^{-2}] fresh weight	Dry matter contents above DMC_{ab} [%]	Start growing date crops	Biomass crops Y_{cx}^{max} [kg m^{-2}] fresh weight	Dry matter contents crops DMC_c [%]	Next cut or harvest date	Translocation at the time of maximum depositt 29.04-1.05 T(t) [m^2/m^2]	Weathering half life above $T_{1/2}$ [d]	Weathering half life above $T_{1/2}$ [d]	Soil density [g cm^{-3}] soil type	Soil bulk initial P(t) [kg m^{-2}]	Bv Plant/Soil [Bq kg^{-1} f w] / [Bq kg^{-1} d w]	Soil concentration factor κ(t) (plowing depth cm)	Out of root zone half time mobile component [year]	Out of root zone half time fixed component [year]	Out of root zone factor mobile component
ensilaged hay	25-Apr 15-Jun	0,9 0,6	20%	25-Apr 15-Jun	0,45 0,3	40%	15-Jun 25-Aug	0,6	14	14	1 *peat pH= 5*	30	0,45	plowing after 5y	0,5	10	0,9
hay	25-Apr 15-Jun	0,9 0,6	20%	25-Apr 15-Jun	0,22 0,15	80%	15-Jun 25-Aug	1	14	14	1 *peat pH= 5*	30	0,9	plowing after 5y	1	10	0,9
pasture	25-Apr 15-Jun	0,9 0,6	20%	25-Apr 15-Jun	0,22 0,15	20%	15-Jun 25-Aug	1	14	14	1 *peat pH= 5*	30	0,9	plowing after 5y	1	10	0,9
boletus edulis	1-Jan	4,5	20%	10-Aug	0,5	22%	30-Aug	0,05	56	28	1 peat pH=5	20 (3)	0,5	0,75 (1,5)	1	30	0,1
blackberry	1-Jan	4,0	20%	1-May	1.0	22%	10-Jul	0,03	56	28	1,0 *peat pH=5*	20 (2)	0,1 0,01	0,5 (1)	1	30	0,1

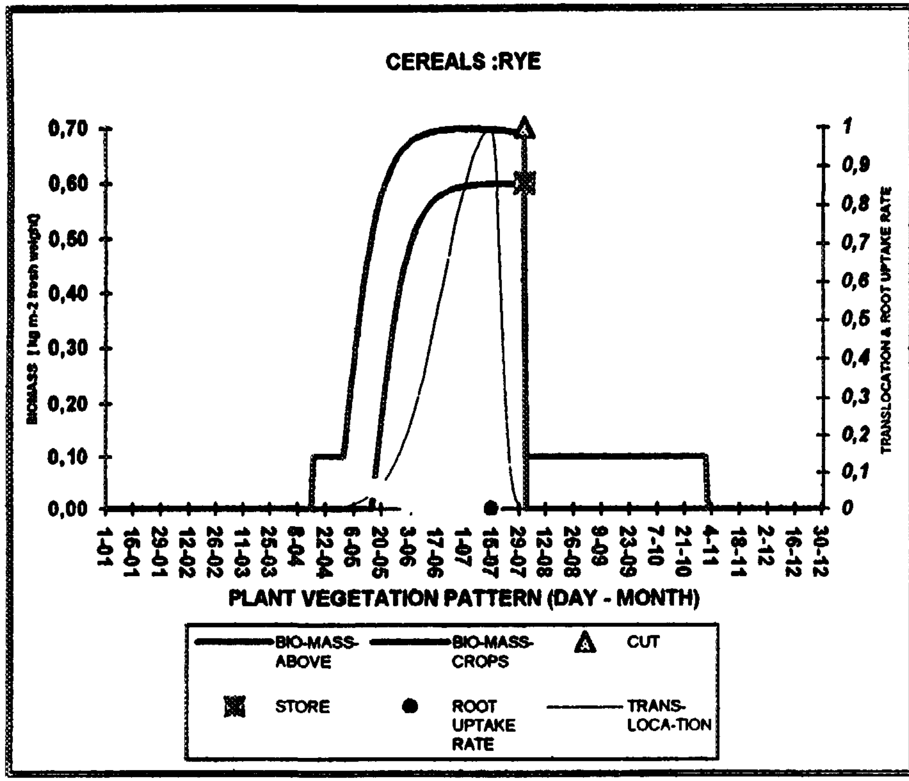


FIGURE: 1

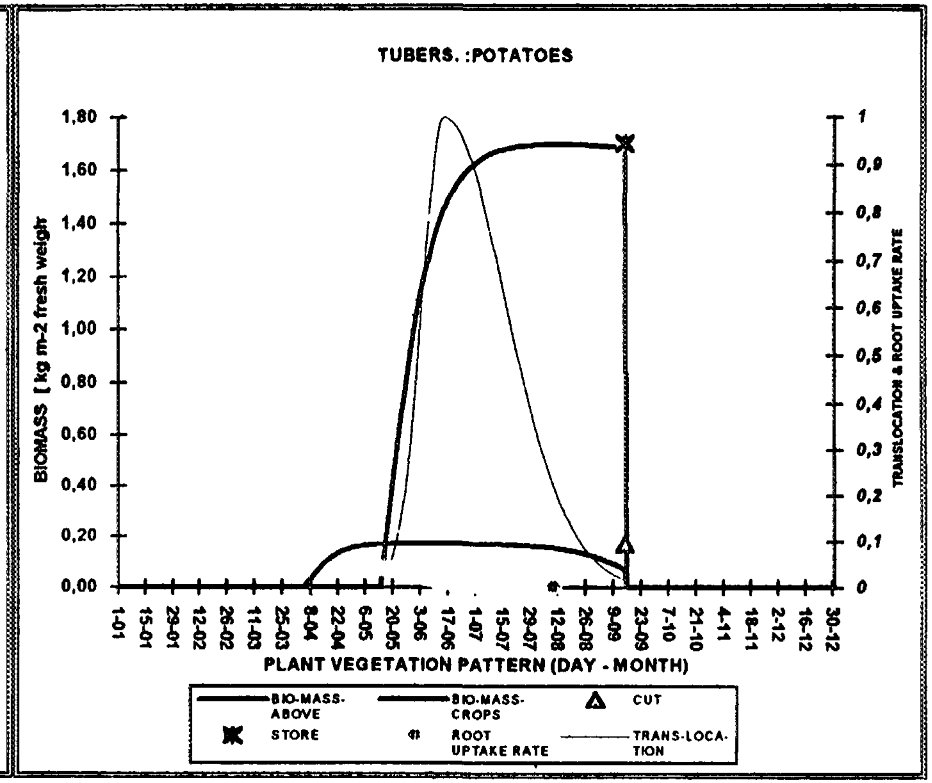


FIGURE: 2

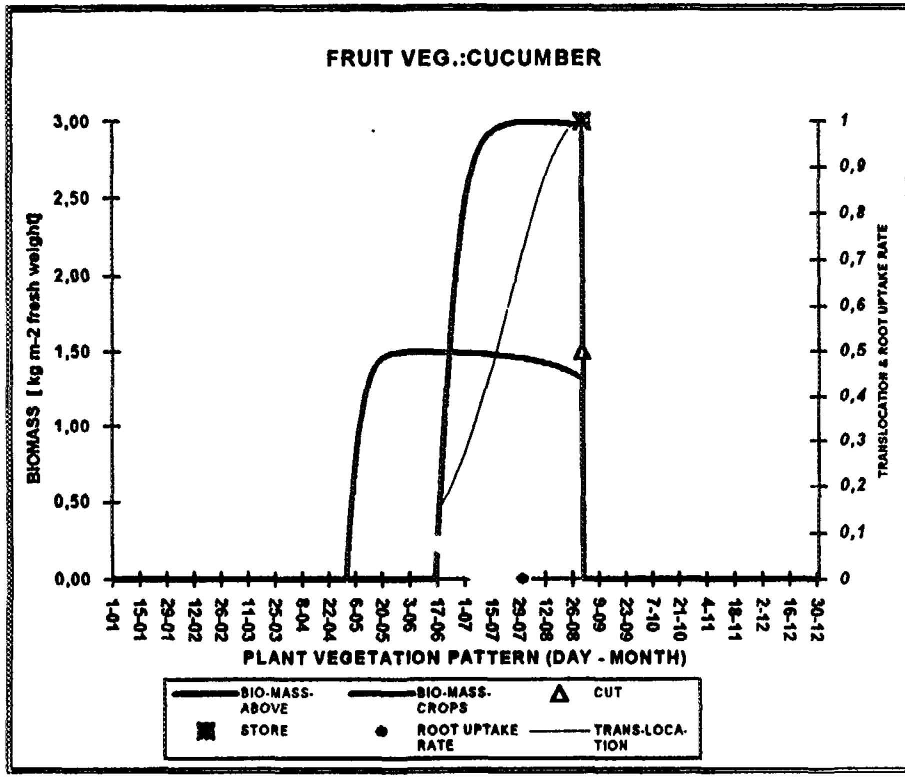


FIGURE: 3

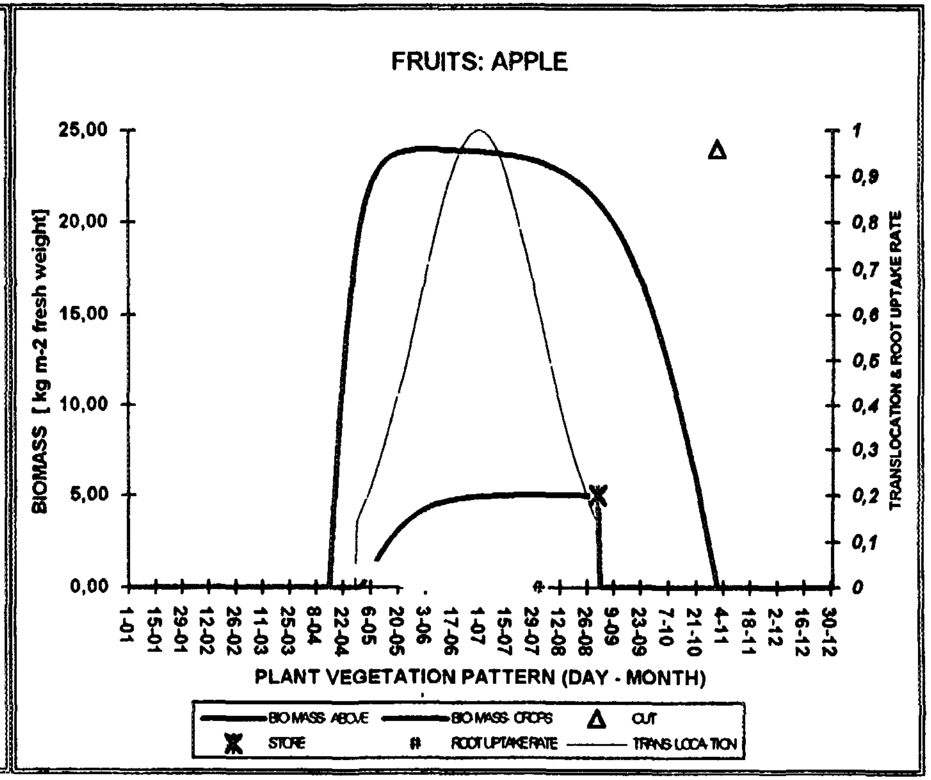


FIGURE: 4

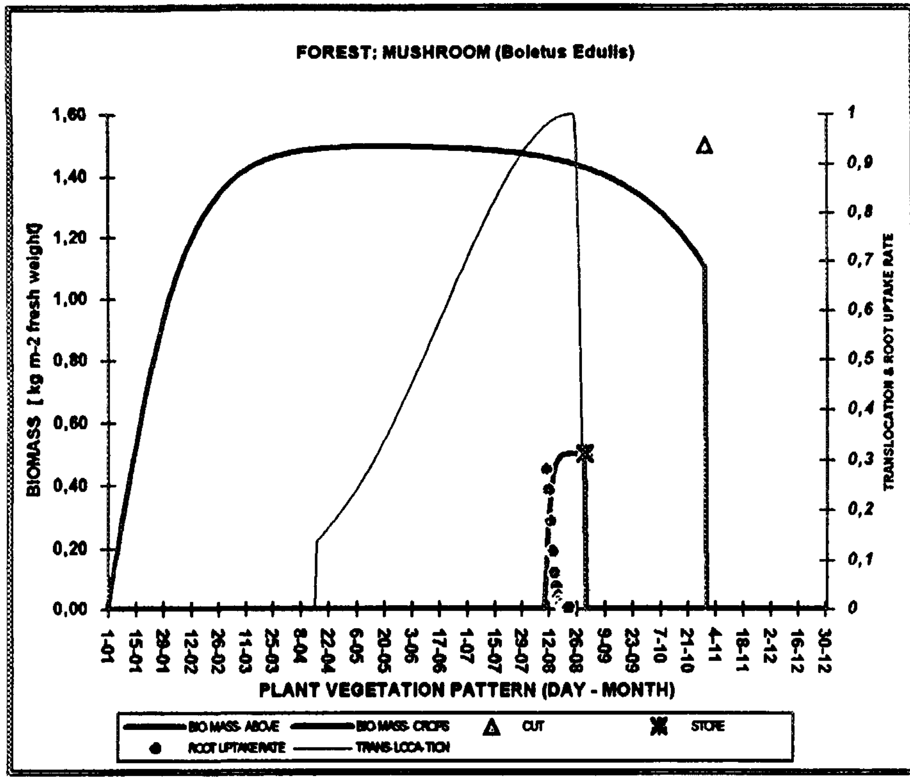


FIGURE: 5

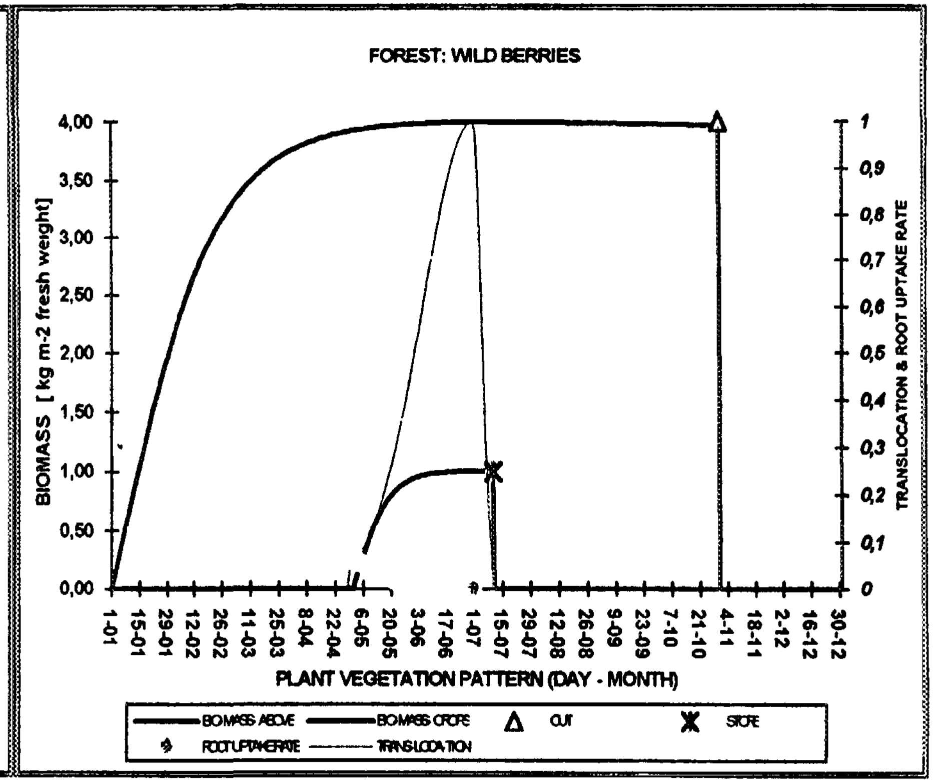


FIGURE: 6

2.5.3. Concentration of radionuclide in milk and animals' products $C_X(t_i)$ [Bq kg^{-1}]

$$C_x(t_i)=\sum_{j=1}^{n} Q_x(t_j) * F_x * \left\{\alpha * \exp\left[-\lambda_{fast} * (t_i - t_j)\right] + (1-\alpha) * \exp\left[-\lambda_{slow} * (t_i - t_j)\right]\right\} \quad \text{(Eq.4}$$

where

$C_X(t_i)$ - concentration of the radionuclide in particular animal products e g milk, beef, pork at the specific period f time t_i

$Q_X(t_j)$ - the animal's radionuclide daily intake at the time tj [Bq d^{-1}]

F_X - amount of animal's daily intake of a radionuclide that appears in each liter of milk or each kilogram of meat at equilibrium [d kg^{-1}]

$\lambda_{f,\,s}$ - the rate constants (fast and slow) of the reduction of radionuclide concentration in an animal due to physiological processes [d-1]

The animal x daily intake of the radionuclide at the time tj

$$Q_x(t_j)=\sum_{z=1}^{I} C_z(t_j) * \left(\bigcup_{t_s}^{\text{seasons of feeding}} \Delta_z^{t_s}\right)$$

where:

$C_{z}(t_j)$ - the time dependent concentration of radionuclide in particular animal's diet component **Z** [Bq kg^{-1} fresh mass]

$\Delta_z^{t_s}$ - an animal daily intake rate of a component **Z** during the season of feeding t_s. [kg d^{-1}]

(for example : dairy cow summer season from 15 May to 15 September;

winter season from 16 September to 15 May

Seasonal feed consumption rate of cattle both for dairy and beef cat as well as for pig are presented in tables. The cesium function retention parameters for particular animal category are shown in Table 2-7.

TABLE 2 - 5. AVERAGE FEED CONSUMPTION RATE OF CATTLE USE IN MODEL CALCULATION

$\Delta_z^{t_s}$ - an animal daily intake rate spring season FROM 15 MAY TO 15 SEPTEMBER					$\Delta_z^{t_s}$ - an animal daily intake rate WINTER season FROM 16 SEPTEMBERTO 14 MAY				
DAIRY COW									
green foder	hay	ensilaged hay	cereals	pasture beets	green foder	hay	ensilaged hay	cereals	pasture beets
45 (45)	1,5 (0)	1,5 (0)	3 (3)	1,2 (1,2)	0 (0)	5 (5)	26 (26)	3,5 (3,5)	1,2 (1,2)
BEEF COW									
green foder	hay	ensilaged hay	cereals	pasture beets	green foder	hay	ensilaged hay	cereals	pasture beets
20 (35)	2 (0)	0 (2)	2,2 (2,2)	0,8 (0,8)	0 (0)	3 (3)	15 (20)	2,2 (2,2)	0.8 (0,8)

TABLE 2 - 6. AVERAGE FEED CONSUMPTION RATE OF PIGS DURING SIX MONTH PERIOD OF FATTENING [KG FRESH WEIGHT PER DAY]

PERIOD OF FATTENING	DIET COMPONENTS			
	Wheat	Barley	Milk	Potatoes
MONTH 1	0,5	1	2,5	0,5
MONTH 2	0,5	1	2	0,5
MONTH 3	0,8	2	1	1
MONTH 4	0,8	2	1	1
MONTH 5	1	2,5	1	1
MONTH 6	1	2,5	1	1

TABLE 2 - 7. CESIUM FUNCTION OF RETENTION PARAMETERS FOR PARTICULAR ANIMAL CATEGORY

Function of retention $R_x(t) = F_x * \{\alpha * \exp[-\lambda_{fast} * t] + (1-\alpha) * \exp[-\lambda_{slow} * (t)]\}$				
ANIMAL	F_X equilibrium	α	λ_{fast} $T_{1/2}$	λ_{slow} $T_{1/2}$
DAIRY COW	0,19% [d L^{-1}]	0,745	2,3 [d]	35 [d]
BEEF CATTLE	1,51% [d kg^{-1}]	- 0,084	3,1 [d]	40 [d]
PIG	33,2 % [d kg^{-1}]	-0,08	2,9 [d]	38 [d]

TABLE 2 - 8. AVERAGE FEED CONSUMPTION RATE OF FOREST ANIMAL USE IN MODEL CALCULATION

$\Delta_z^{t_s}$ - an animal daily intake rate SPRING season FROM 1 MAY TO 30 SEPTEMBER					$\Delta_z^{t_s}$ - an animal daily intake rate WINTER season FROM 1 OCTOBER TO 30 APRIL				
MOOSE									
pine	birh	herbage	milkweed	bilbery	pine	birh	herbage	milkweed	bilbery
0,1	2	5	10	5	10	2	1	0	2
HARE									
birh	herbage	milkweed	bilbery		pine	birh	herbage	milkweed	bilbery
0,1	1	1	0,5	0,8 (0,8)	0 (0)	3 (3)	15 (20)	2,2 (2,2)	0.8 (0,8)

TABLE 2 - 9. CESIUM FUNCTION OF RETENTION PARAMETERS FOR PARTICULAR ANIMAL CATEGORY

Function of retention $R_x(t) = F_x * \{\alpha * \exp[-\lambda_{fast} * t] + (1-\alpha) * \exp[-\lambda_{slow} * (t)]\}$				
ANIMAL	F_X equilibrium	α	λ_{fast} $T_{1/2}$	λ_{slow} $T_{1/2}$
MOOSE	3,48 % [d kg^{-1}]	-0,05	3 [d]	61 [d]
HARE	23% [d kg^{-1}]	- 0,04	2,4 [d]	7,2 [d]

2.5.4. The whole body concentration of the radionuclide - $Ab(t_i)$ [Bq]

$$WHB_a(t_i) = \sum_{j=1}^{n} I_a(t_j) * \{\alpha \exp[-\lambda_{fast} * (t_i - t_j)] + (1-\alpha) * \exp[-\lambda_{slow} * (t_i - t_j)]\} \quad \text{(Eq.9}$$

where:

$WHB_a(t_i)$ - the whole body concentration of the radionuclide at the specific period of time t_i.

$I_a(t_j)$ - the daily activity intake for particular age group at the time tj [Bq d^{-1}]

$$I_a(t_j) = \sum_{k=1}^{l} C_k(t_j) * \Delta_a^k \quad \text{(Eq.10}$$

where:

C_k - the time dependent radionuclide concentration in a particular food category k [Bq kg-1 dry mass]

Δ^k_a - the daily human intake rate of food category k [kg d^{-1}]

TABLE: 2 - 10. THE DAILY CONSUMPTION RATE FOR PARTICULARS FOOD CATEGORIES USED IN CLRP PREDICTION (BASED ON SCENARIO S)

PRODUCTS	Consumption tares for different age group $g\ d^{-1}$							Food processing	RESTRICTION	
	MAN	WOMAN	15 y	10 y	5 y	1 y	3 m		DATE	REDUCTION
cereals	0,2310	0,1790	0,1900	0,1730	0,1000	0,0410	0,0000	65%	29-04-86	100%
lettuce	0,0100	0,0200	0,0150	0,0130	0,0120	0,0100	0,0000	90%	29-04-86	100%
spinach	0,0050	0,0050	0,0150	0,0130	0,0120	0,0100	0,0000	80%	29-04-86	100%
cabbage	0,0200	0,0200	0,0150	0,0130	0,0100	0,0000	0,0000	70%	29-04-86	100%
bin	0,0400	0,0480	0,0200	0,0170	0,0160	0,0000	0,0000	70%	29-04-86	100%
carrots	0,0500	0,0500	0,0300	0,0260	0,0270	0,0200	0,0000	60%	29-04-86	100%
cucumber	0,0100	0,0100	0,0150	0,0130	0,0120	0,0000	0,0000	60%	29-04-86	100%
fruit	0,2260	0,2760	0,2260	0,2500	0,1800	0,0300	0,0000	70%	29-04-86	100%
potatoes	0,2100	0,1500	0,1700	0,1160	0,0800	0,0120	0,0000	60%	29-04-86	100%
milk	0,8700	0,5700	0,5000	0,5000	0,5000	0,0000	0,0000	60%	30-06-86	10%
milkprd.	0,0360	0,0330	0,2500	0,2500	0,2500	0,9800	0,0860	30%	30-06-86	10%
beef	0,0640	0,0490	0,0600	0,0500	0,0400	0,0100	0,0000	70%	30-06-86	10%
pork	0,0880	0,0640	0,0700	0,0650	0,0500	0,0030	0,0000	60%	29-04-86	100%
polutry	0,0500	0,0400	0,0400	0,0300	0,0200	0,0010	0,0000	60%	29-04-86	100%
fresh water fish	0,0160	0,0100	0,0050	0,0050	0,0050			60%	29-04-86	100%
mushrooms	0,0036	0,0036						80%	29-04-86	100%
wild_beries	0,0090	0,0090						80%	29-04-86	100%
big_game	0,0020	0,0020						80%	29-04-86	100%
small_game	0,0020	0,0020						80%	29-04-86	100%

TABLE: 2 - 11. THE BIOCINETIC DATA FOR CAESIUM USED IN CLRP PREDICTION

Biocinetic data for caesium ICRP publ 56; 1989							
Age group	MAN	WOMAN	15 y	10 y	5 y	1 y	3 m
Body weight	70	60	50	40	20	7	3,5
Fast component	0,1	0,1	0,13	0,3	0,45	0	0
T1/2 fast [d]	2	2	2,2	5,8	9,1	1,00E-20	1,00E-20
Slow component	0,9	0,9	0,87	0,7	0,55	1	1
T1/2 slow [d]	110	110	93	50	30	13	16

2.5.6.The doses estimation by CLRP

2.5.6.1. The mean external dose from the cloud for an adult H_{cloud}.

$$H_{cloud} = \left\{\int_0^T C_a dt\right\} \cdot H^0{}_{cloud} \qquad \text{(Eq.11}$$

where

$\left\{\int_0^T C_a dt\right\}$ - integrated air concentration (210 [Bqhm^{-3}] for scenario S

$H^0{}_{cloud}$ - dose conversion factor for ^{137}Cs is equal to 2,232 10^{-06} [mSv m^{-3} Bq^{-1} d^{-1}]

2.5.6.2.The mean external dose from the ground for adult H_g.

$$H_{ground}(T) = \int_0^T D_{eff}(t) \cdot H^0_{ground} dt \qquad \text{(Eq.12}$$

where:

$H_g(T)$ - the maximal (*without shelding*) dose 1m above ground for specified period of time T

$H^0{}_{ground}$ - the gamma dose rate 1m above ground per unit of deposition

(for ^{137}Cs is equal to **3,12010^{-08} [mSv d m^{-2} Bq d^{-1}]**

The effective deposition $D_{eff}(t_i)$ resulting of migration of radionuclide down soil is calculated using the formula:

$$D_{eff}(t_i) = \sum_{t_j=1}^{t_i} \dot{D}(t_j) \cdot \left\{\alpha \cdot \exp\left[-\lambda_1(t_j - t_i)\right] + (1-\alpha) \cdot \exp\left[-\lambda_2(t_j - t_i)\right]\right\} \qquad \text{(Eq.13}$$

where:

$\dot{D}(t_j)$ - daily deposition (dry&wet) at the day t_j

α - weathering constant equal to 0.63;

$1-\alpha$ - weathering constant equal to 0.37

λ_1 - 1.13 $year^{-1}$ ($T_{1/2}$ 223,9 [d])

λ_2 - 0.075 $year^{-1}$ ($T_{1/2}$ 3373,3 [d])

2.5.6.2. The inhalation dose due to cloud H_{inh} .

$$H_{inh} = \left\{ \int_0^T C_a dt \right\} \cdot v_{inh} \cdot H^0_{inh} \qquad \text{(Eq.10}$$

where:

$\left\{ \int_0^T C_a dt \right\}$ - integrated air concentration (210 [$Bqhm^{-3}$] for scenario S

v_{inh} - inhalation rate 24 [$m^3 d^{-1}$] for adult.

H^0_{inh} - dose conversion factor for ^{137}Cs is equal to 8.62 10^{-9} Sv Bq^{-1}

2.5.6.3. The ingestion dose H_i

The ingestion dose to a specific organ (whole body) was estimated as an integral of the resultant dose rate over a sufficient period of time.

$$H_{ing}(T) = F \cdot \int_{t=0}^{T} WBC_a(t)dt \qquad \text{(Eq.10}$$

where:

F - convertion factor 1.0 10^{-10} Svd^{-1} per Bq body burden for ^{137}Cs

$WBC_a(t_i)$ - the whole body concentration of the radionuclide of the specifik age group at the specific period of time t_i.

2.5.6.4. Dose reduction

The dose reduction due to shelding and houses filtration was taken in to account . Average reduction factors for external cloud and ground exposure as well as inhalation dose are in Table 2-12.

TABLE: 2 - 12. DOSE REDUCTION FACTORS FOR DIFFERENT TYP OF BUILDING

EXTERNALL EXPOSURE DOSES									
CLOUD EXPOSURE					GROUND EXPOSURE				
Building type	Time in door	Shielding factor		REDUCTION FACTOR	Building type	Time in door	Shielding factor		REDUCTION FACTOR
	[%]	out door	in door			[%]	out door	in door	
rural	0,6	1	0,3	0,580	rural	0,6	1	0,1	0,460
urban	0,8	0,6	0,05	0,160	urban	0,8	0,3	0,01	0,068
AVERAGE REDUCTION FACTOR				0,370	AVERAGE REDUCTION FACTOR				0,264

INTERNAL EXPOSURE DOSES					
INHALATION EXPOSURE					INGESTION EXPOSURE
Building type	Time in door	Filtration factor		REDUCTION FACTOR	For calculation of Life dose from ingestion an extrapolation was made
	[%]	out door	in door		$\int_{1986}^{2056} WBC_a(t)dt = \int_{1986}^{1990} WBC_a(t)dt + \int_{1991}^{2056} WBC_a^{t=1991} \cdot \exp(-\Lambda_{enw} \cdot t)dt$
rural	0,6	1	0,3	0,580	where: $WBC_a^{t=1991}$ Whole body contents in 1991.
urban	0,8	1	0, 6	0,680	Efective environmental half life $T_{1/2\ enw}$
AVERAGE REDUCTION FACTOR				0,630	501,6 [d]

3. The comparison of test data and model prediction

3.1. Total deposition

The average deposition for whole region S was calculated both on the base of deposition scenario S data (Table 3-1.) and using formulas 1,3 and parameters described in the chapter 2. The dry deposition to bare soil for whole S was obtained equal to 19,3 $kBqm^{-2}$ and wet deposition with very small contribution equal to 0,13$kBqm^{-2}$. However in our opinion, this estimation might have been representative for area where air sampling had been made because of lack some detailed information about weather conditions and aerosol distribution in the period of interest for remained areas. Nevertheless, the good agreement with predicted and observed data has been obtained.

3.2. Major food items contributing to total diet.

he comparison of predicted (both first and second prediction) concentrations in milk; beef and pork are compared to observed values and are presented in Table 3-2 as well as in figures. In each figure the first prediction values are drown as a low contrast line. The second prediction values are graphed as higher contrast line and observed valuės are graphed as thick dots with attached 95%

confidence limits. Predicted to observed ratios (P/O) as well as indications if predicted values falls with confidence interval are shown.

3.2.1. Milk

There is correct-prediction in the first calculations in Jun-86 but during the summer 1986 the P/O factor is about 0,4 and even more in the IV-th Quarter 1986. In the subsequent years 1987 and 1989, the P/O factor is on the same level with exception of III-rd Quarter when prediction is close to observed values (e.g. when cows grazing on pasture areas).

In 1990 the P/O factor is higher (0,5) but still below one. It becomes clear that if we assumed correct retention function for dairy cow than only reason for miss-prediction might be cows daily diet and under-prediction of cesium concentration in diets components especially for ensilaged hay and hay. The first correction was made for soil to plant transfer factor for hay and ensilaged hay, assuming that peat soil has higher caesium avail ability and lower half life for removing caesium from the root zone. The second correction was made related to higher dry matter content in hay and ensilaged hay. The third correction was made concerned to dairy cow diet e.g. during summer the some additional feed of ensilaged hay and hay . Unfortunately, there is no information about ensilaged hay and hay in the observed data for scenario S, therefore it can introduce possibility of compensation errors. Predicted values for hay and ensilaged hay are included to make possible model inter-comparison. After parameters correction the predictions improved remarkably in the period from Summer 1987 to winter 1990. There is only sligtly overpredictions in a period of Winter 1987 that may indicate that hay contamination in this period was overpredicted.

3.2.2 Beef

The comparison of predicted and observed data gives high discrepancy P/O factor in June 1986 for initially predicted data. It was caused by assumption of higher beef cow diet of green fodder than it was reported in scenario and that grass from the first cut was directly supplied to the cow. The results of the second prediction after correction of beef diet are gives much better dynamic response to the observed values.

3.2.3 Pork

The comparison of predicted and observed Cs-137 concentrations in milk and pork shows that milk prediction have strong influence on concentration Cs-137 in pork as whey was additional component that was added to the pigs diet in S scenario. Therefore, there is also over-prediction in June 1986 in initially predicted data. Correction was made for barley contamination that improved prediction for pork in the period 1987-1990 but there is still under-prediction for long-term period that indicate that additional higher contaminated component of pigs diet should be taken in to account.

3.2.4 Grain

The predicted and observed Cs-137 concentrations for spring wheat; rye and spring barley are presented in Tables. There is slightly underestimation both for the first and second predicted values for harvest 1987-1990. In 1987 and following years, when only root uptake and resuspension had influence on plant contamination, the possible reason might be the that model does not consider resuspention processes.

3.2.5 Leafy vegetables

The task of the validation was to predict the yearly mean of Cs-137 concentration in leafy vegetables. Similar to the CB scenario there are observed values consisted of a mixture of vegetables and we can observe different ^{137}Cs concentrations depending on the type of leafy vegetables as lettuce, cabbage; spin ach and other.

Comparison of predicted and observed data for lettuce are presented . In the second prediction some model correction was made assuming that plant is growing only in a green house with filtration factor 0,1 . Although this correction improved predictions, from point of view the model validation, it seems to be more valuable to carry out a comparison between particular plants' types then comparing yearly averages of some unknown mixture..

3.3 Human intake and Whole body concentration.

The comparison of predicted (both initially and finally) and observed values for standard man intake are presented in Tables 3-9 and for standard man whole body concentration in Table 3-10 and in Figure. In the second prediction fresh water fish consumption was added taking on account reported ob served data .(CLRP model does not have water compartment). Although in this case the best model response to observed data was obtained, but it was still under-prediction by factor of about 0,6-0,8. Despite of that, the over prediction of whole body concentration was obtained with P/O factor about 1,3. It became clear that data of human intake and whole body concentration for scenario S are not very consistent and both intake data are not representative for region S or whole body measurements. On the basis of intakes data we tried to calculate whole body concentration using function of retention from ICRP 56, 1989. Results of calculation show that predicted whole body concentration exceeded by factor of two observed data Table 3-11 and figure . If we believe in whole body measurement data and retention function parameters we have to conclude that intakes data reported in Scenario S are overestimated.

TABLE: 3 -1. COMPARISON OF THE DEPOSITION DATA INCLUDED IN VAMP SCENARIO S

Population area	Agricultural areas			Average deposition [kBq m^{-2}]
pop1	agri4	agri5	agri12	37,40
	25,30	43,20	43,60	*37,37*
pop2	agri7			28,00
	26,90			*26,90*
pop3	agri8			11,70
	11,70			*11,70*
pop4	agri1	agri9		19,10
	6,97	32,50		*19,74*
pop5	agri10			17,10
	14,20			*14,20*
pop6	agri13			3,20
	3,22			*3,22*
pop7	agri3	agri14	agri16	20,50
	3,66	24,70	14,50	*14,29*
pop8	agri11	agri15		13,80
	8,00	18,70		*13,35*
pop9	agri2	agri6	agri17	23,20
	26,00	14,40	21,90	*20,77*

Average deposition:

for agricultural areas 19,97 [kBqm^{-2}]

for population areas 19,33 [kBqm^{-2}]

TABLE: 3 - 2. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

PERIOD	CLRP MILK PREDICTION				CLRP BEEF PREDICTION				CLRP PORK PREDICTION			
	FIRST PREDICTION		SECOND PREDICTION		FIRST PREDICTION		SECOND PREDICTION		FIRST PREDICTION		SECOND PREDICTION	
	P/O	C	P/O	C	P/O	C	P/O	C	P/O	C	P/O	C
May-86	0,0	NO	0,3	NO	0,0	NO	0,1	NO	0,0	NO	0,0	NO
Jun-86	1,1	NO	1,5	NO	4,1	NO	0,9	YES	1,6	NO	0,1	NO
Jul-86	0,4	NO	0,9	YES	1,6	NO	0,7	NO	1,5	YES	0,8	NO
Aug-86	0,4	NO	1,0	YES	1,2	NO	0,8	YES	1,1	YES	1,0	YES
Sep-86	0,3	NO	1,4	NO	1,2	NO	0,9	YES	1,1	YES	1,0	YES
IV 1986	0,2	NO	1,4	NO	0,9	YES	1,2	NO	1,4	YES	1,8	NO
I 1987	0,2	NO	1,4	NO	0,9	YES	1,3	NO	0,9	YES	1,4	YES
II 1987	0,2	NO	1,2	NO	0,9	YES	1,4	NO	1,0	YES	1,6	NO
III 1987	0,4	NO	0,9	YES	1,2	NO	1,2	NO	0,8	NO	1,3	YES
IV 1987	0,2	NO	1,0	YES	0,9	YES	1,0	YES	0,4	NO	0,9	YES
I 1988	0,2	NO	1,0	YES	0,8	YES	1,0	YES	0,3	NO	0,9	YES
II 1988	0,2	NO	1,0	YES	0,8	NO	0,9	YES	0,3	NO	0,9	YES
III 1988	0,6	NO	1,0	YES	1,5	NO	0,9	YES	0,6	NO	0,7	NO
IV 1988	0,3	NO	1,0	YES	1,4	NO	1,0	YES	0,3	NO	0,7	NO
I 1989	0,3	NO	1,0	YES	0,9	YES	0,8	NO	0,3	NO	0,6	NO
II 1989	0,3	NO	1,0	YES	1,1	NO	1,0	YES	0,3	NO	0,6	NO
III 1989	0,9	YES	1,1	NO	2,2	NO	1,0	YES	0,5	NO	0,6	NO
IV 1989	0,5	NO	1,1	NO	1,9	NO	1,1	NO	0,2	NO	0,4	NO
I 1990	0,5	NO	1,3	NO	1,6	NO	1,1	YES	0,2	NO	0,4	NO
II 1990	0,5	NO	1,3	NO	1,9	NO	1,3	NO	0,2	NO	0,4	NO
III 1990	1,2	NO	1,2	NO	3,5	NO	1,3	NO	0,4	NO	0,4	NO
IV 1990	0,6	NO	1,2	NO	2,8	NO	1,2	NO	0,2	NO	0,3	NO

TABLE: 3 - 3. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

PASTURE VEGETATION						
PREDICTED AVERAGES				MEASURED		
MONTHS	X (Bq l -1 f.w.)	P/O	C	X (Bq l -1 f.w.)	95% confidence interval lower bound	upper bound
May-86	995,24	0,7	NO	1500,00	1000,00	2300,00
Jun-86	484,48	12,1	NO	40,00	10,00	200,00
Jul-86	131,60					
Aug-86	123,92					
Sep-86	119,23					
May-87	58,42					
Jun-87	102,47					
Jul-87	94,87	4,7	YES	20,00	10,00	200,00
Aug-87	89,29					
Sep-87	84,69					
May-88	42,03					
Jun-88	73,71					
Jul-88	68,24	6,8	YES	10,00	0,50	100,00
Aug-88	64,23					
Sep-88	60,92					
May-89	30,23					
Jun-89	53,02					
Jul-89	49,09	12,3	NO	4,00	2,00	40,00
Aug-89	46,20					
Sep-89	43,82					
May-90	21,75					
Jun-90	38,14					
Jul-90	35,31	17,7	NO	2,00	1,00	20,00
Aug-90	33,23					
Sep-90	31,52					

TABLE: 3 - 4. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

PASTURE: Hay				
HARVEST	FIRST X (Bq kg -1 f.w.)	SECOND X (Bq kg -1 f.w.)	95% confidence interval lower	upper
25-06-86	1852,54	2422,14	1781,01	3294,04
25-08-86	1130,44	1677,68	1233,61	2281,60
25-06-87	42,96	425,02	312,52	578,01
25-08-87	42,25	412,19	303,09	560,57
25-06-88	37,41	297,71	218,91	404,88
25-08-88	36,78	288,73	212,30	392,66
25-06-89	32,57	208,53	153,34	283,60
25-08-89	32,03	202,24	148,71	275,04
25-06-90	28,36	146,07	107,41	198,65
25-08-90	27,89	141,66	104,17	192,66

TABLE: 3 - 5. PREDICTED VALUES FOR VAMP SCENARIO S

PASTURE: Ensilaged hay				
HARVEST	FIRST (Bq kg -1 f.w.)	SECOND (Bq kg -1 f.w.)	95% confidence interval lower	upper
25-06-86	465,4	631,5	464,4	858,9
25-08-86	298,1	481,7	354,2	655,1
25-06-87	41,2	171,7	126,2	233,5
25-08-87	40,5	163,8	120,4	222,7
25-06-88	34,5	101,5	74,6	138,0
25-08-88	34,0	96,8	71,2	131,7
25-06-89	29,0	60,0	44,1	81,6
25-08-89	28,5	57,2	42,1	77,9
25-06-90	24,3	35,5	26,1	48,3
25-08-90	23,9	33,8	24,9	46,0

TABLE: 3 - 6. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

	SPRING WHEAT				RYE				SPRING BARLEY			
HARVEST	FIRST		SECOND		FIRST		SECOND		FIRST		SECOND	
	P/O	C	P/O	C	P/O	C	P/O	C	P/O	C	P/O	C
1986	1,06	YES	1,2	YES	1,21	YES	1,04	YES	2,62	NO	1,30	YES
1987	0,75	YES	0,94	YES	0,18	NO	1,01	YES	1,07	YES	1,38	YES
1988	0,53	NO	0,74	YES	0,10	NO	0,63	YES	0,84	YES	1,14	YES
1989	0,5	NO	0,90	YES	0,25	NO	1,74	·NO	0,31	NO	0,44	NO
1990	0,77	YES	1.18	YES	0,21	NO	1,37	YES	#N/A	#N/A	#N/A	#N/A

TABLE: 3 - 7. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

LETTUCE IN A GREEN HOUSE				
	FIRST		SECOND	
HARVEST	P/O	C	P/O	C
1986	7,42	NO	1,45	YES
1987	0,64	YES	0,78	YES
1988	0,92	YES	1,36	YES
1989	0,26	NO	0,50	YES
1990	1,30	YES	2,25	YES

TABLE: 3 - 8. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

STANDARD MAN intake [$Bq d^{-1}$]												
DATE	FIRST PREDICTION			SECOND PREDICTION						VAMP Scenario S OBSERVED VALUES		
	without fish			without fish			with fish			95% confidence interval		
	X	P/O	C	X	P/O	C	X	**P/O**	C	X	lower	upper
Jun-86	35,1	1	YES	23,0	0,67	NO	23,4	**0,67**	NO	35	31,2	39,2
QIV-86	28,3	0,60	NO	34,6	0,74	NO	38,5	**0,82**	NO	47	44,7	50,8
QII-87	26,6	0,51	NO	30,6	0,59	NO	35,3	**0,68**	NO	52	49,4	57,2
QIV-87	6,5	0,22	NO	10,8	0,36	NO	19,3	**0,64**	NO	30	27,9	33,9
QII-88	6,1	0,16	NO	9,4	0,24	NO	17,9	**0,46**	NO	39	36,7	45,6
QIV-88	5,4	0,25	NO	6,7	0,30	NO	15,1	**0,69**	NO	22	20,5	23,5
QII-89	5,2	0,20	NO	6,2	0,24	NO	14,6	**0,56**	NO	26	24,2	30,4
QIV-89	4,6	0,29	NO	4,3	0,27	NO	12,8	**0,80**	NO	16	14,6	19,5
QII-90	4,5	0,26	NO	4,1	0,24	NO	12,6	**0,74**	NO	17	15,8	23,0
QIV-90	4,1	0,32	NO	3,3	0,25	NO	11,4	**0,88**	NO	13	11,8	16,0

TABLE: 3 - 9. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

WHOLE BODY CONCENTRATION STANDARD MAN [Bq/kg]												
DATE	FIRST PREDICTION			SECOND PREDICTION						VAMP Scenario S OBSERVED VALUES		
	without fish			without fish			with fish			95% confidence interval		
	X	P/O	C	X	P/O	C	X	**P/O**	C	X	lower	upper
Jul-86	4,85	0,67	NO	10,6	1,47	NO	10,8	**1,50**	NO	7,2	5,8	8,9
Dec-86	31,4	0,76	NO	40,0	0,97	YES	45,4	**1,10**	YES	41,1	33	51,1
Jul-87	48,4	0,96	YES	55,9	1,11	YES	65,2	**1,29**	NO	50,4	44,2	57,4
Dec-87	38,9	0,94	YES	36,1	0,87	NO	50,3	**1,21**	NO	41,6	36,5	47,3
Jul-88	20,2	0,67	NO	23,5	0,78	NO	39,9	**1,33**	NO	30,1	26,3	34,4
Dec-88	16,3	0,63	NO	17,2	0,66	NO	34,1	**1,32**	NO	25,9	22,6	29,7
Jul-89	12,1	0,47	NO	13,7	0,53	NO	30,8	**1,20**	YES	25,8	21,3	31,3
Dec-89	12,4	0,56	NO	10,8	0,49	NO	28,0	**1,26**	NO	22,2	18,3	26,9
Jul-90	9,8	0,54	NO	9,0	0,50	NO	26,2	**1,45**	NO	18,0	15,7	20,7
Dec-90	102	0,56	NO	7,2	0,40	NO	24,4	**1,35**	NO	18,1	15,8	20,8

TABLE: 3 - 10. COMPARISON OF CALCULATED WBC (from reported INTAKES in VAMP Scenario S) AND MEASURED WBC.

DATE	INTAKES	WBC	P/O	WBC	lower 95%	upper 95%
Apr-86		0				
May-86	0.3	0				
Jun-86	5	0.13				
Jun-86	35	1.6				
Jul-86	35	8.02	1.11	7.2	5.8	8.9
Aug-86	35	18.65				
Sep-86	35	28.04				
Oct-86	47	35.92				
Nov-86	47	46.31				
Dec-86	47	55.11	1.34	41.1	33	51.1
Jan-87	49.5	62.16				
Feb-87	49.5	69.05				
Mar-87	49.5	74.69				
Apr-87	52	78.95				
May-87	52	83.73				
Jun-87	52	87.54				
Jul-87	41	90.62	1.80	50.4	44.2	57.4
Aug-87	41	89.32				
Sep-87	41	88.24				
Oct-87	30	87.19				
Nov-87	30	82.6				
Dec-87	30	78.72	1.89	41.6	36.5	47.3
Jan-88	34.5	75.69				
Feb-88	34.5	74.7				
Mar-88	34.5	73.88				
Apr-88	39	73.3				
May-88	39	74.37				
Jun-88	39	75.22				
Jul-88	30.5	75.81	2.52	30.1	26.3	34.4
Aug-88	30.5	73.38				
Sep-88	30.5	71.34				
Oct-88	22	69.53				
Nov-88	22	65.19				
Dec-88	22	61.52	2.38	25.9	22.6	29.7
Jan-89	24.0	58.62				
Feb-89	24	56.86				
Mar-89	24	55.41				
Apr-89	26	54.35				
May-89	26	54.08				
Jun-89	26	53.86				
Jul-89	21	53.6	2.08	25.8	21.3	31.3
Aug-89	21	51.69				
Sep-89	21	50.07				
Oct-89	16	48.67				
Nov-89	16	45.85				
Dec-89	16	43.46	1.96	22.2	18.3	26.9
Jan-90	16.5	41.56				
Feb-90	16.5	40.12				
Mar-90	16.5	38.94				
Apr-90	17	38.06				
May-90	17	37.43				
Jun-90	17	36.93				
Jul-90	15	36.47	2.03	18	15.7	20.7
Aug-90	15	35.42				
Sep-90	15	34.54				
Oct-90	13	33.78				
Nov-90	13	32.49				
Dec-90	13	31.40	1.73	18.1	15.8	20.8

TABLE: 3 - 11. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

MUSHROOMS: BOLETUS EDULIS				
	FIRST		SECOND	
HARVEST	P/O	C	P/O	C
1986	3,28	NO	1,36	YES
1987	2,68	NO	1,16	YES
1988	2,05	NO	0,89	YES
1989	1,34	YES	0,78	YES
1990	1,67	YES	0,99	YES

TABLE: 3 - 12. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR VAMP SCENARIO S

WILD BERIES: BLACK BERIES				
	FIRST		SECOND	
HARVEST	P/O	C	P/O	C
1986	0,41	NO	0,99	YES
1987	0,33	NO	0,96	YES
1988	0,1	NO	1,1	YES
1989	0,12	YES	1,21	YES
1990	0,13	YES	1,27	YES

TABLE: 3 - 13. OF PREDICTED VALUES FOR VAMP SCENARIO S

Cs137 Concentration in region:S FOREST:PINE NEEDLE TREES			
	X	**95% confidence interval**	
HARVEST	**(Bq kg -1 f.w.)**	**lower bound**	**upper bound**
11-08-86	**88,01**	***64,72***	***119,70***
11-08-87	**202,92**	***149,21***	***275,97***
11-08-88	**307,73**	***226,28***	***418,51***
11-08-89	**387,90**	***285,22***	***527,53***
11-08-90	**450,96**	***331,60***	***613,30***

TABLE: 3 - 14. PREDICTED VALUES FOR VAMP SCENARIO S

Cs137 Concentration in region:S FOREST: BIRCH			
	X	95% confidence interval	
HARVEST	(Bq kg -1 f.w.)	lower bound	upper bound
29-05-86	484,92	*365,25*	*643,80*
29-05-87	136,26	*102,64*	*180,91*
29-05-88	129,57	*97,60*	*172,03*
29-05-89	123,21	*92,80*	*163,58*
29-05-90	117,16	*88,25*	*155,55*

TABLE: 3 - 15. PREDICTED VALUES FOR VAMP SCENARIO S

Cs137 Concentration in region:S FOREST: herbage			
	X	95% confidence interval	
Quarterly averages	(Bq l -1 f.w.)	lower bound	upper bound
Q_II-86	1863	*1116*	*3828*
Q_III-86	1812	*1350*	*2183*
Q_II-87	1411	*1296*	*4248*
Q_III-87	1703	*1269*	*2052*
Q_II-88	1327	*1219*	*3993*
Q_III-88	1601	*1193*	*1929*
Q_I-89	1247	*1146*	*3754*
Q_II-89	1506	*1122*	*1814*
Q_III-89	1493	*1114*	*1801*
Q_I-90	1415	*1055*	*1705*

TABLE: 3 - 16. PREDICTED VALUES FOR VAMP SCENARIO S

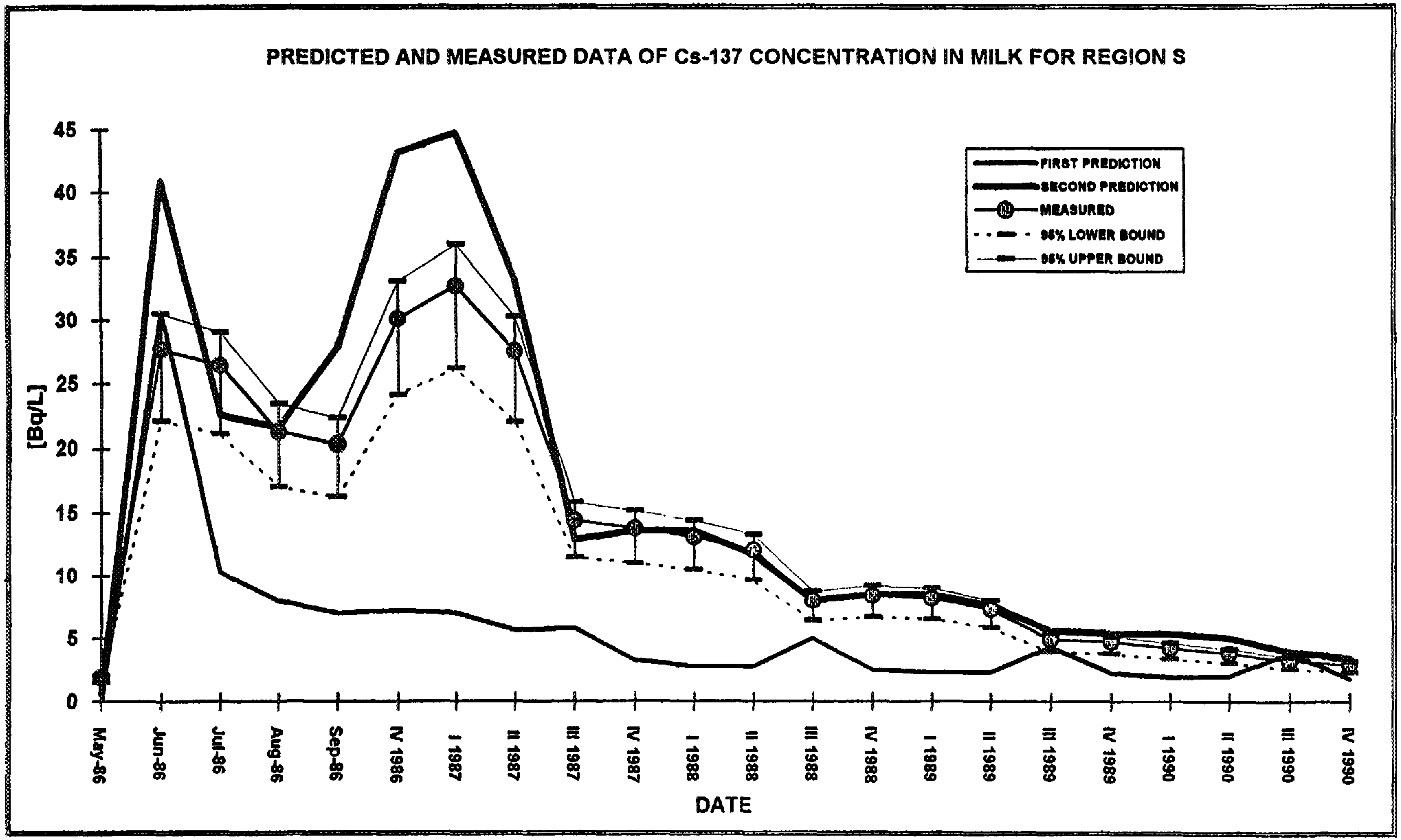
Cs137 Concentration in region:S FOREST: MILKWEED			
	X	95% confidence interval	
HARVEST	(Bq kg -1 f.w.)	lower bound	upper bound
01-06-86	106,14	*78,04*	*144,34*
01-08-86	110,57	*81,31*	*150,38*
01-06-87	45,94	*33,78*	*62,47*
01-08-87	136,24	*100,18*	*185,28*
01-06-88	42,71	*31,41*	*58,09*
01-08-88	126,81	*93,24*	*172,46*
01-06-89	39,96	*29,38*	*54,34*
01-08-89	118,72	*87,30*	*161,46*
01-06-90	37,55	*27,61*	*51,06*
01-08-90	111,62	*82,07*	*151,80*

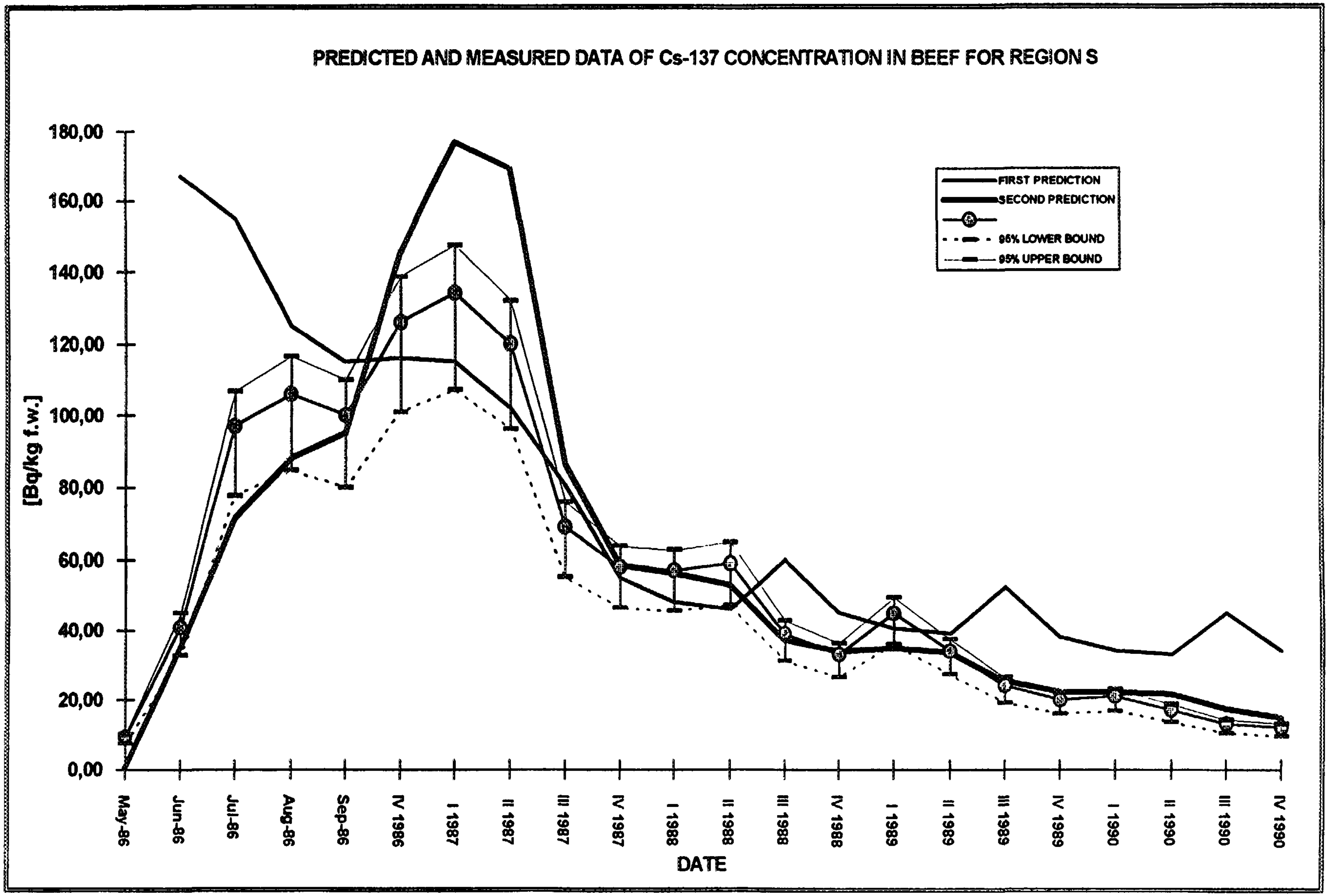
TABLE: 3 - 17. PREDICTED VALUES FOR VAMP SCENARIO S

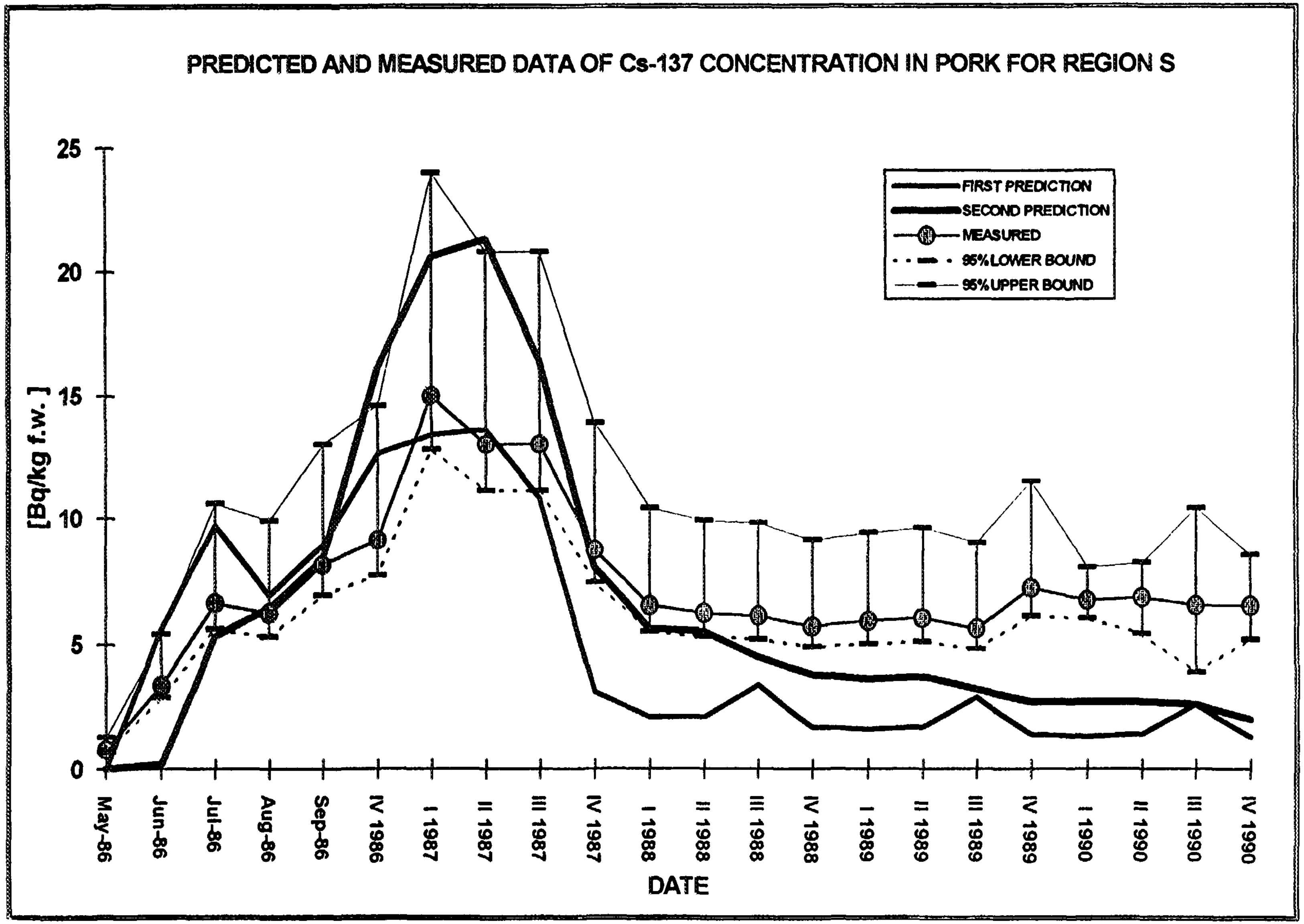
Cs137 Concentration in region:S FOREST: MUSHROOM (Boletus Edulis)			
HARVEST	X (Bq kg -1 f.w.)	95% confidence interval lower bound	upper bound
30-08-86	448,11	*142,78*	*1406,35*
30-08-87	428,46	*136,52*	*1344,69*
30-08-88	409,29	*130,41*	*1284,52*
30-08-89	524,46	*167,11*	*1645,96*
30-08-90	506,19	*161,29*	*1588,63*

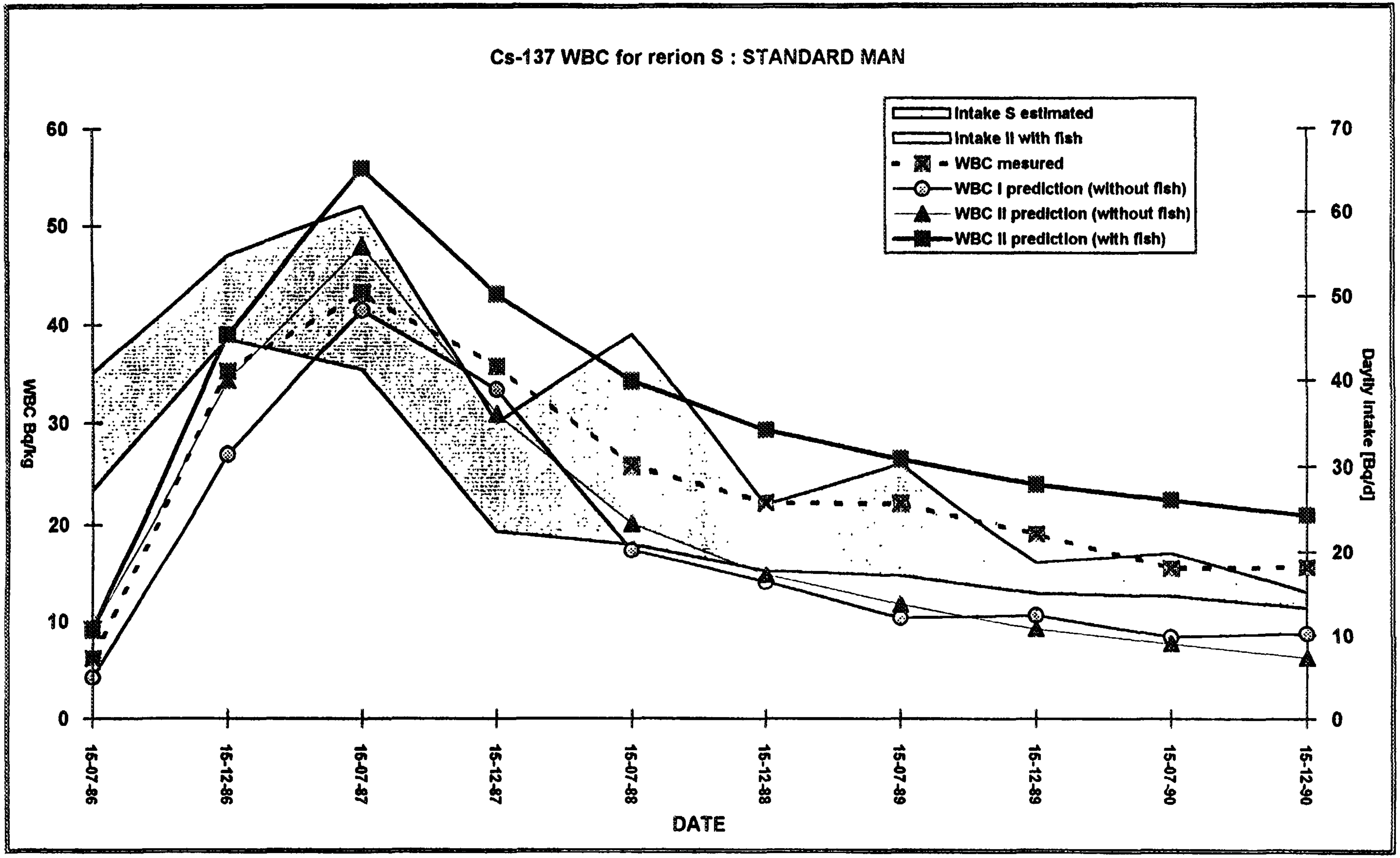
TABLE: 3 - 18. PREDICTED VALUES FOR VAMP SCENARIO S

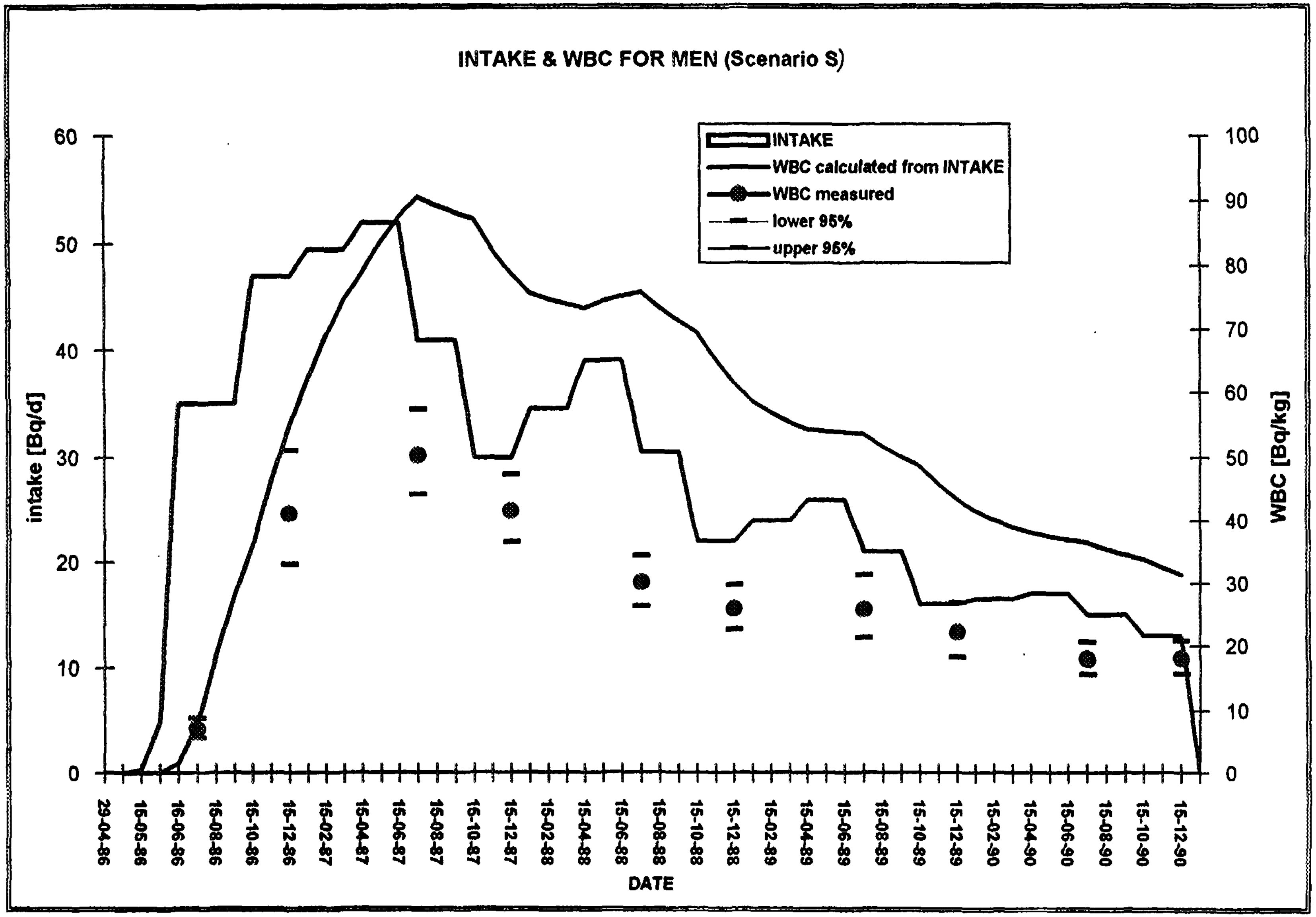
Cs137 Concentration in region:S FOREST: Cantharellus tubaeformis			
HARVEST	X (Bq kg -1 f.w.)	95% confidence interval lower bound	upper bound
30-08-86	1941,15	*2577,15*	*1462,11*
30-08-87	1794,53	*2382,49*	*1351,67*
30-08-88	2844,01	*3775,82*	*2142,16*
30-08-89	2704,35	*3590,40*	*2036,96*
30-08-90	2571,55	*3414,09*	*1936,94*


PREDICTED AND MEASURED DATA OF Cs-137 CONCENTRATION IN MILK FOR REGION S
FIRST PREDICTION
SECOND PREDICTION
MEASURED
95% LOWER BOUND
95% UPPER BOUND
[Bq/L]
0
5
10
15
20
25
30
35
40
45
May-86
Jun-86
Jul-86
Aug-86
Sep-86
IV 1986
I 1987
II 1987
III 1987
IV 1987
I 1988
II 1988
III 1988
IV 1988
I 1989
II 1989
III 1989
IV 1989
I 1990
II 1990
III 1990
IV 1990
DATE


PREDICTED AND MEASURED DATA OF Cs-137 CONCENTRATION IN BEEF FOR REGION S
180,00
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
[Bq/kg f.w.]
FIRST PREDICTION
SECOND PREDICTION
95% LOWER BOUND
95% UPPER BOUND
May-86
Jun-86
Jul-86
Aug-86
Sep-86
IV 1986
I 1987
II 1987
III 1987
IV 1987
I 1988
II 1988
III 1988
IV 1988
I 1989
II 1989
III 1989
IV 1989
I 1990
II 1990
III 1990
IV 1990
DATE


PREDICTED AND MEASURED DATA OF Cs-137 CONCENTRATION IN PORK FOR REGION S
FIRST PREDICTION
SECOND PREDICTION
MEASURED
95% LOWER BOUND
95% UPPER BOUND
[Bq/kg f.w.]
25
20
15
10
5
0
May-86
Jun-86
Jul-86
Aug-86
Sep-86
IV 1986
I 1987
II 1987
III 1987
IV 1987
I 1988
II 1988
III 1988
IV 1988
I 1989
II 1989
III 1989
IV 1989
I 1990
II 1990
III 1990
IV 1990
DATE


Cs-137 WBC for rerion S : STANDARD MAN
Intake S estimated
Intake II with fish
WBC mesured
WBC I prediction (without fish)
WBC II prediction (without fish)
WBC II prediction (with fish)
WBC Bq/kg
Daylly Intake [Bq/d]
0
10
20
30
40
50
60
70
15-07-86
15-12-86
15-07-87
15-12-87
15-07-88
15-12-88
15-07-89
15-12-89
15-07-90
15-12-90
DATE


INTAKE & WBC FOR MEN (Scenario S)
INTAKE
WBC calculated from INTAKE
WBC measured
lower 95%
upper 95%
intake [Bq/d]
WBC [Bq/kg]
DATE
0
10
20
30
40
50
60
100
90
80
70
29-04-86
15-05-86
15-06-86
15-08-86
15-10-86
15-12-86
15-02-87
15-04-87
15-06-87
15-08-87
15-10-87
15-12-87
15-02-88
15-04-88
15-06-88
15-08-88
15-10-88
15-12-88
15-02-89
15-04-89
15-06-89
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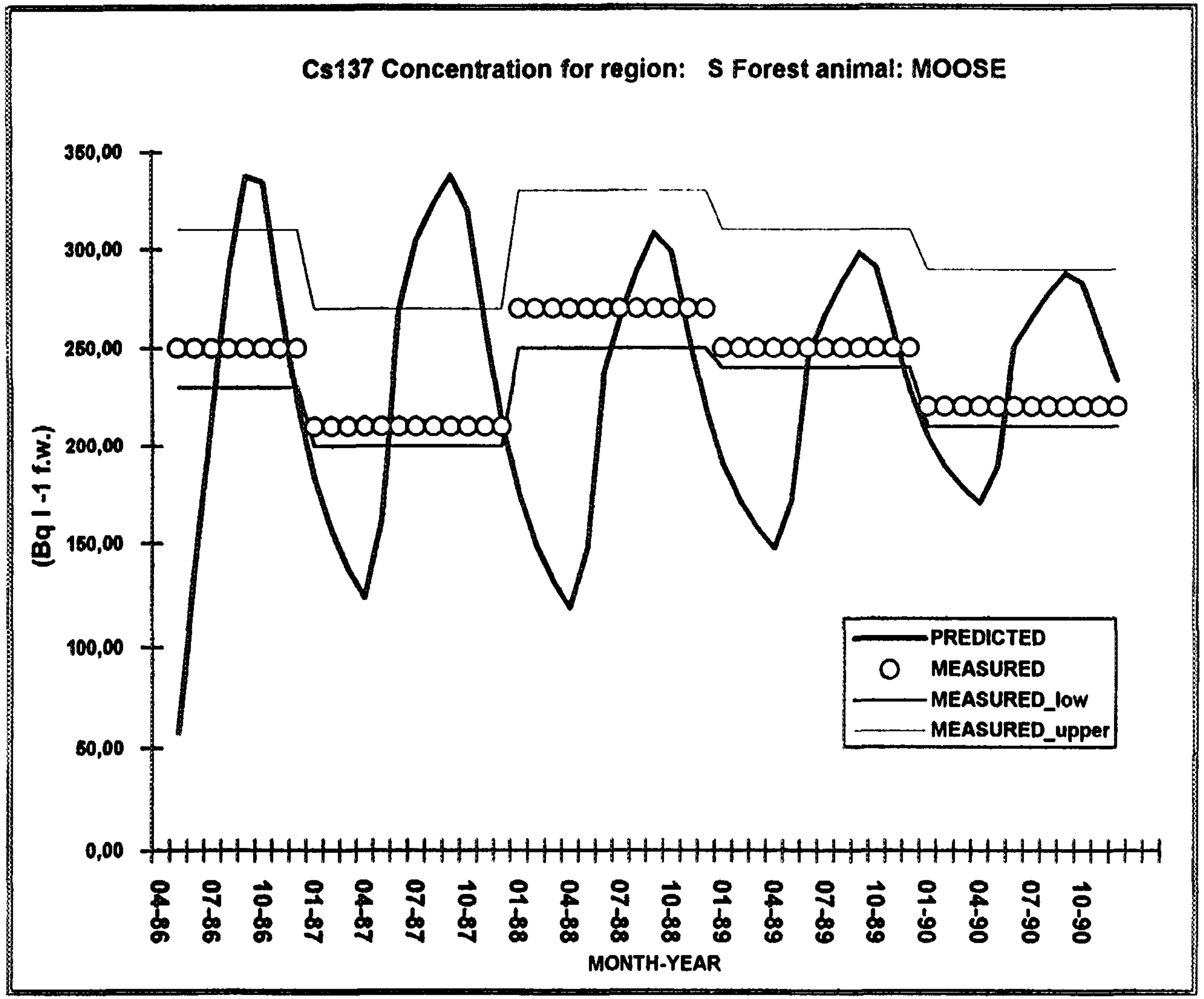
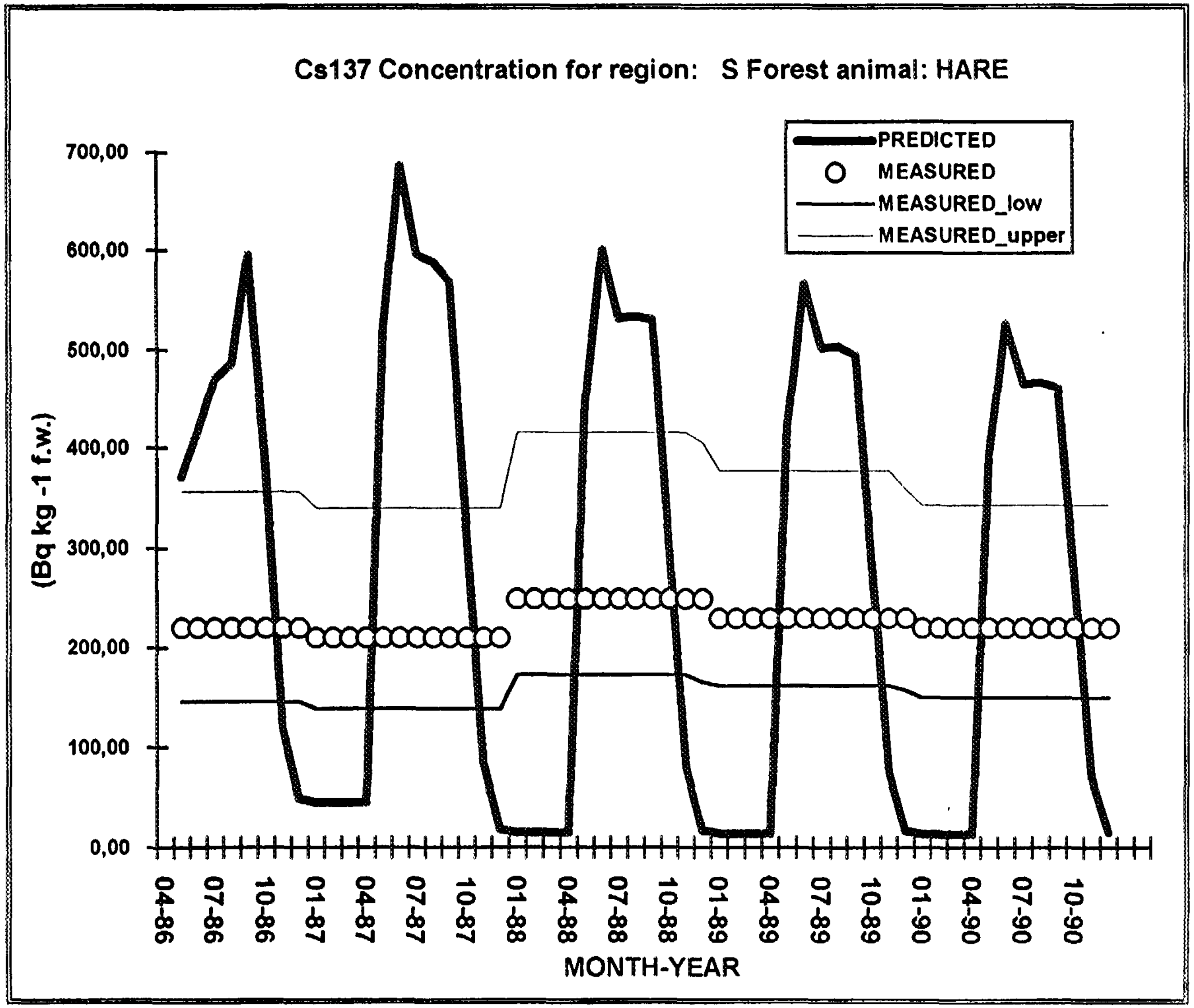
15-10-90
15-12-90


Cs137 Concentration for region: S Forest animal: MOOSE
(Bq l -1 f.w.)
350,00
300,00
250,00
200,00
150,00
100,00
50,00
0,00
04-86
07-86
10-86
01-87
04-87
07-87
10-87
01-88
04-88
07-88
10-88
01-89
04-89
07-89
10-89
01-90
04-90
07-90
10-90
MONTH-YEAR
PREDICTED
MEASURED
MEASURED_low
MEASURED_upper


Cs137 Concentration for region: S Forest animal: HARE
PREDICTED
MEASURED
MEASURED_low
MEASURED_upper
700,00
600,00
500,00
400,00
300,00
200,00
100,00
0,00
(Bq kg -1 f.w.)
04-86
07-86
10-86
01-87
04-87
07-87
10-87
01-88
04-88
07-88
10-88
01-89
04-89
07-89
10-89
01-90
04-90
07-90
10-90
MONTH-YEAR

4. Recommendations for changes to the model

Designing a stochastic version of the model to be able to perform an uncertainty analysis .

Perform intensive testing of forest compartment.

5. SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

The prediction made by CLRP model were reasonable although initial results seams to be too conservative. The correct deposition calculations need additional detailed information about aerosol distribu tion activity and weather conditions and it is still crucial point of the model predictions. The next parameters of model sensitivity are growing and harvest date of the plants but these factors are more combined with proper interpretation of the scenario input data and they are less critical for well known region (for instance own country). Generally, in further model comparison, the voluntary interpretation of input data should be minimized by making scenario more simple- may be limited to the smaller region with the best evaluated input and observed values.

Despite of lack of some detailed information concerning measured data of particular components (for in stant :pasture grass; ensilaged hay end hay, particular species of leafy vegetables) and discrepancy between whole body and intake data, comparison between models on the base of scenario S has given unique opportu nity to check the model performance and gain additional knowledge about processes occurring in terrestrial ecosystem. We might believe that a model's performance will improve as many different scenarios it passes but the most profitable advantage of the VAMP Multi-pathway-task is the exchange of knowledge and experiences during the discussions among the international participants as well as quick access to the latest re sults of scientific work performed by other VAMP groups.

II.7. CHERPAC

1. EVALUATION OF CHERPAC'S PERFORMANCE FOR SOUTHERN FINLAND

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2. MODEL DESCRIPTION

2.1 Name of Model, Model Developer, Model User

The version of CHERPAC (Chalk River Environmental Research Pathways Analysis Code) used in the S Scenario was developed by S-R. Peterson and S. Chouhan. CHERPAC is still under development. The user is S-R. Peterson.

2.2 Important Model Characteristics

CHERPAC is a time-dependent stochastic (Latin Hypercube Sampling) compartment model using a combination of differential equations and transfer factors to calculate daily concentrations of ^{137}Cs in some foodstuffs and average monthly concentrations in others. Body burden and ingestion dose are calculated from modelled diets for an average man, woman and non-growing child (age 10). Dose is calculated also from inhalation, immersion in the plume and external irradiation from surfaces. Monthly average concentrations in soil, leafy vegetables (both field and greenhouse), non-leafy vegetables (field and greenhouse), potatoes, rootcrops other than potatoes, fruit, winter and spring grains, milk, cheese, beef, pork, eggs and poultry are calculated. Non-domestic pathways include monthly output for wild berries, big game (moose and deer), small game (rabbits, waterfowl, upland game birds), and mushrooms. Concentrations in freshwater fish are calculated from concentrations of ^{137}Cs in water. Dietary input of contaminated saltwater fish, as provided in the scenario description, was added. In addition, monthly average concentrations in the food fed cattle and in human diet are given as output.

The terrestrial pathways of the food chain code are driven either by daily ground-level air concentrations (Bq m^{-3}) and daily rainfall (mm) or measured deposition (average Bq m^{-2}) as input; the aquatic pathways, at the moment, need water concentrations as input. CHERPAC is designed to handle input for short-term releases of radioactivity (specifically accidents) on a daily basis. Reliable predictions with uncertainty bounds are limited to a few years, although the deterministic code can run for up to 50.

2.2.1 Intended Purpose of the Model in Radiation Assessment

When completed, CHERPAC will be able to assess average dose as well as dose to a critical individual from routine and accidental releases of radionuclides to the atmosphere and to bodies of water. Based on its predictions, decisions can be made to implement appropriate counter-measures. It is not a screening model.

2.2.2 Intended Accuracy of the Model Prediction

Intended accuracy of predictions is to within a factor of 5.

2.2.3 Method Used for Deriving Uncertainty Estimates

Uncertainty in the output is estimated statistically using Latin Hypercube Sampling for distributions of all 222 parameters.

2.2.4 Past Experiences Using This Model

CHERPAC, in this form, has never been used for tests other than this one. The user has participated with CHERPAC in its earlier, simpler forms in the BIOMOVS A4 Scenario [1] and the CB Scenario of VAMP [2]. Changes both in parameter values and in model structure have occurred after each test.

2.2.5 Modifications Made for this Scenario

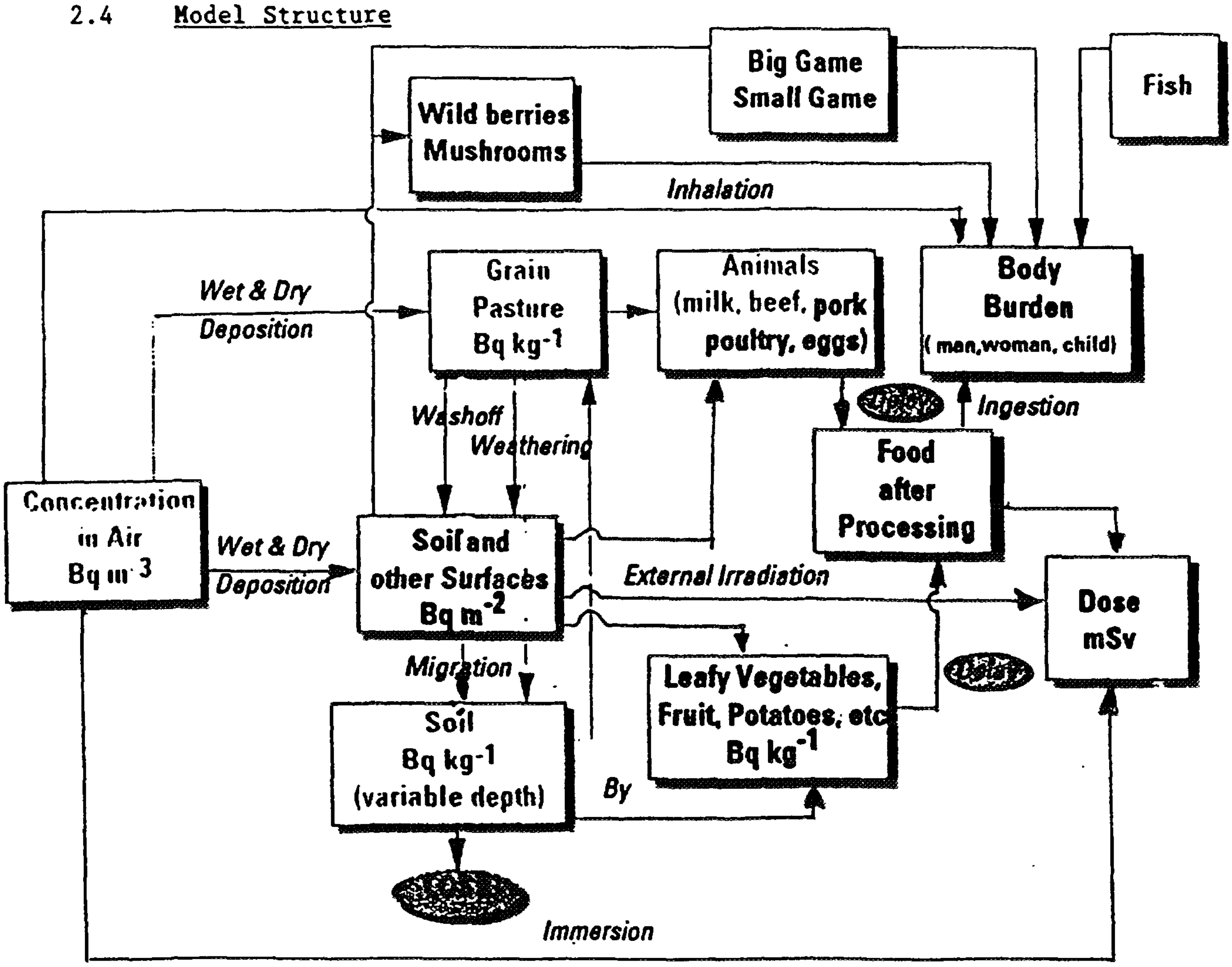
- Treatment of total deposition.
- Concentrations in fish were calculated from water concentrations.
- Pathways for big and small game, wild berries and mushrooms were added.
- Modifications to diet and calculation of body burden and dose were added for woman and child.
- Cheese was added to the diet.

- Delays between harvest or production and ingestion have been introduced: 1 month for beef, pork, eggs and chicken, 3 months for cheese, rootcrops and potatoes, and 4 months for grain.
- Dry deposition and wet deposition to bare soil were added.
- Greenhouse leafy and non-leafy vegetables were added.
- Site-specific parameter values were used.

2.3 References Describing Detailed Documentation of the Model

The model was also described in the previous IAEA TecDoc on Scenario CB of VAMP [3]. Additions and changes made to the code for the S Scenario are mentioned in Section 2.2.5. A complete description of the equations and parameter values used for Scenario S may be found in Peterson [2].

2.4 Model Structure



2.5 Descriptions of Procedures, Equations, Parameters and Assumptions Used in Different Components of the Model

2.5.1 Total Deposition

To estimate deposition from air concentrations, it was assumed that air concentrations over all of southern Finland were the same as the daily averaged values of the two air monitoring stations given in the scenario description. Daily average rainfall from the numerous rainfall monitoring stations around Finland was calculated for each of the twelve rainfall areas. Thus twelve sets of output were generated, all having the same dry deposition but with wet deposition varying over about a factor of 60. The predicted best estimates for all foodstuffs, body burden and dose were weighted averages based on the proportions of crops harvested or relative numbers of people living in these twelve areas. Because of the large amount of time it would have taken to calculate average confidence intervals for the twelve data sets, uncertainty bounds were calculated only for the single set of input (for rainfall stations #121-155) that best predicted the average deposition for all of southern Finland.

Dry deposition velocity (0.005 m s^{-1}) and washout ratios ($8.5x10^5$) were higher than generic values to account for larger particle size in Finland, assuming the same cloud that passed over Sweden [4]. Total deposition must be estimated in CHERPAC from the calculated deposition to pasture. The assumptions for this are that dry deposition to forests is 5 times that to pasture and dry deposition to lakes is 0.5 times. The conversion factor from pasture deposition to total deposition is based on the site-specific fraction of surface area devoted to forests, lakes, and agricultural land. This factor is about 2 for southern Finland, giving an overall deposition of ~20,000 Bq m^{-2} which is in excellent agreement with the observed estimated deposition of 19,600 Bq m^{-2}. The figure for average deposition over the land area (which is calculated as a factor of 2.4 times deposition to pasture) was estimated in order to calculate mushrooms, wildberries, big game and small game using the code's bulk transfer parameters (m^2 kg^{-1}).

2.5.2 Food Items Contributing to Total Diet

2.5.2.1 Milk

To calculate the concentration in food for cows between January and March inclusive, all deposition is considered to be to bare ground and the concentration in harvested pasture (hay) is considered equal to that from the previous July; grain equals that of the previous August. Between April and September inclusive, all deposition falls on growing pasture which is the source of the cows' non-grain diet. Grain consumed is still from the previous August. Finally, between October and December, hay has the concentration of fresh hay harvested in July, and grain has the concentration of grain harvested in August. This introduces a small delay in receiving the food. Cows are assumed to ingest soil only when they are on pasture (i.e., April through September). Following the scenario description, dairy cows receive 1% contaminated food while stabled 7-26 May and no contaminated food from the time of the accident until 7 May. Quantities of food ingested were taken from the scenario description.

2.5.2.2 Beef

Quantities of hay and grain consumed were from the scenario description. For beef cows, between January and June, hay consumed was harvested the previous July, while grain consumed was harvested the previous August. For July through September, the beeves receive hay harvested in June and grain harvested a year earlier in August. For October through December, the hay comes from the July harvest and grain comes from the August harvest. Since beeves are stabled, it is assumed that they ingest no soil.

2.5.2.3 Pork

Diet for pigs (exclusively grain) was taken from the scenario description, but it was assumed that piglets would consume milk with a concentration equal to cow's milk for the first month of life. Pigs are assumed to ingest no soil and are slaughtered at 6 months. The fraction of pig's daily intake by ingestion which appears in each kg of pork is 0.29.

2.5.2.4 Fish (freshwater)

The equation to calculate the concentration in fish is [5]:

$$dC_{ffs}/dt = k_{wf} * C_w - k_{fw} * C_{ffs}$$

where $k_{wf}/k_{fw} = BF$

Assuming the largest lakes in Finland are oligotrophic and have less than 50 ppm sediment in unfiltered water, three bioaccumulation factors (BF) were assumed [6]:

$1.5 \times 10^{+04}$/equilibrium concentration of K (ppm in water) for pisciverous fish,
$1 \times 10^{+04}$/ppm K for an intermediate fish
$5 \times 10^{+03}$/ppm K for non-pisciverous fish
k_{fw} = $1.73 \times 10^{-3}\ d^{-1}$ for piscivores
$3.47 \times 10^{-3}\ d^{-1}$ for intermediate fish
$6.93 \times 10^{-3}\ d^{-1}$ for non-piscivores.

Average water concentrations over time were supplied. Fish are assumed to be eaten fresh during the season (May through September) and frozen (averaged) for the rest of the year. Intake was reduced to 75% of average for the first six years post accident, according to the scenario description.

2.5.2.5 Wild Produce

2.5.2.5.1 Wild berries

Calculation of concentrations in berries uses empirical bulk transfer coefficients ($m^2\ kg^{-1}$) averaged from the literature for 1986 to 1988 [7,8,9,10,11]; in 1989 an estimated loss rate factor is added to the radiological loss already present:

$$C_b = C_{ba} * T_{fb}$$
$$C_{ba} = D_{land} - \lambda_{E(w,after\ 1989,+r)} * C_{ba}$$

where D_{land} = 2.4 * deposition to pasture (see Section 2.5.1)

Berries are harvested in July and August; for the rest of the year, they are preserved in some form, and the concentration of these stored berries for eating is an average of the July and August concentrations.

2.5.2.5.2 Mushrooms

Calculation of concentrations in Boletus and Cantharellus mushrooms uses empirical bulk transfer coefficients averaged from the literature for 1986 to 1990 [10,11,12]; in 1991 a loss rate factor, other than radiological, is added:

$$C_m = C_{ma} * T_{fm}$$
$$C_{ma} = D_{land} - \lambda_{E(w,after\ 1991,+r)} * C_{ma}$$

where D_{land} = 2.4 * deposition to pasture (see Section 2.5.1)

The mycelial zone is considered to be the top 5 cm, and activity is assumed lost from this zone with a half-life of 3.1 years once the transfer parameter value stabilizes in 1990. Mushrooms are collected and eaten fresh between April and September. During the rest of the year, they are preserved, and the concentration in the mushrooms eaten is the average of the growing season.

2.5.2.5.3 Big and small game

Calculation of concentrations in game (big: moose and deer, and small: rabbits, waterfowl and upland game birds) uses empirical bulk transfer coefficients averaged from the literature for 1986 to 1989 [7,8,11,13,14]; in 1990 a loss rate factor, other than radiological, is added:

$$C_{gm} = C_{gm} * T_{fgm}$$
$$C_{gma} = D_{land} - \lambda_{E(w,after\ 1990,+r)} * C_{gma}$$

where D_{land} = 2.4 * deposition to pasture (see Section 2.5.1)

Big game is harvested from October to December, while small game is harvested September to February. From the scenario description, 85% of the game eaten is assumed to be big game, and the remaining is small game. Game is eaten fresh when collected and preserved in some fashion. The concentration during the rest of the year is considered the average of the harvest months. Intake was restricted to 75% of normal average for the first six years post-accident (per scenario description).

2.5.2.6 Other Items

2.5.2.6.1 Grain

Both direct deposition to growing grains and root uptake are modelled. However, deposition to spring grain was so far before harvest (in fact, the seeds had not been sown), that there was no contribution to the activity in the grain. Grain for both people and animals is assumed to be have a weighted concentration based on proportions of winter (0.1) and spring grain (0.9) grown in the Finland. The harvest date of spring grain is Julian day 238 and Julian Day 200 for winter grain. To model the Finnish grain failure of 1987, it was assumed that, once the poor 1987 crop was harvested, for the next year the daily intake consisted of 2/3 grain from 1986 and 1/3 grain from 1987. Activity in the soil is distributed in the top 8 cm for spring grain due to cultivation after deposition and in successive years the activity is redistributed in the top 20 cm after plowing. Soil in which winter grain is grown has deposition to the first centimetre in the first year.

For calculating the four grain types, rye was considered 100% winter grain, oats were 100% spring grain and barley and wheat were 10% winter and 90% spring. A single concentrtion ratio (0.03) was used for all grains (fresh weight).

2.5.2.6.2 Vegetables

2.5.2.6.2.1 Greenhouse leafy and non-leafy vegetables

Concentration in vegetables per unit area is calculated

$$\frac{dC_{va}}{dt} = (0.05C_a * 0.3V_{d,vl} * T) * (1 - \lambda_{E(w,r)}) * 86400$$

where T = 0.25 for non-leafy and 1.0 for leafy vegetables

$\lambda_{E(w,r)}$ = 0.0496

0.05 = fraction of outside activity (C_a) reaching greenhouse plants

$0.3(V_{d,vl})$ = reduction in deposition velocity due to being indoors. V_d=0.0067 $m.s^{-1}$

The concentration in vegetables per kg is calculated:

$$C_v = C_{va} / Y_{vl,vf,f} + (B_{vvl,vf,f} * C_s)$$

The deposition is distributed in the top cm of soil. It is assumed that 10% of all vegetables eaten (leafy and non-leafy) from March through October are grown in the greenhouse and that all greenhouse vegetables are eaten fresh. During the rest of the year, this same 10% of consumption is assumed to come from non-contaminated areas. From the second year on, the soil in the greenhouse is the same as outside (mixed to 20 cm and brought into the greenhouse). The concentration ratio (0.029) selected for leafy vegetables was higher than the generic value due to the preponderance of peaty soils in Finland.

2.5.2.6.2.2 Field leafy, non-leafy, potatoes, and rootcrop vegetables

Vegetables are harvested and eaten fresh during a few months of the summer and are preserved (frozen, canned or simply stored) and eaten as averages of the summer months during the rest of the year. Leafy vegetables, potatoes and rootcrops are harvested July through September. Non-leafy vegetables are harvested in August and September. Processing occurs year round. Deposited cesium is assumed to be in the top 2 cm of soil for all field vegetables. Concentration ratios were selected to be higher than the generic values due to the preponderance of peaty soils in Finland.

2.5.3 **Human Intake**

Intake of man, woman and child is calculated daily using monthly average food concentrations. Processing losses are factored in as reductions to the daily ingested activity. Diet is as close as possible to that provided in the scenario description for man, woman and child. Garden berries are combined with fruit. The ten year old child's diet was averaged from that given for the 9 and 12 year old boy and girl. Other assumptions were made in preparing the child's diet [2].

For both adults and children, no account was made for consumption of beverages, sugars or other fats.

Processing reduction factors (fraction of activity remaining in the food) were included for berries and fruit, meats, fish, grain, and vegetables.

2.5.4 Whole Body Concentrations

2.5.4.1 Mean whole body concentrations

The body burden includes contributions from inhalation and ingestion. Rates of inhalation, ingestion and loss from the body are different for man, woman and child, as are weights.

2.5.4.2 Distribution of whole body concentrations (man)

To calculate the distribution of individual body burdens (as distinguished from the average calculated above), new distributions for dietary intake were created to account for those people whose diet is skewed in one way or another, e.g., fishermen who eat mostly fish, hunters who eat more wild game, vegetarians, etc. For each item in the male diet, the values of the .001 and the .999 percentiles of the lognormal distributions were decreased or increased (based on personal judgement) by factors of from 2 to 30 depending on the food. The average intake was left unchanged. Correlations were added so that, for example, if an individual was assumed to be getting his protein mostly from wild game, his intake of beef, pork and chicken would be very low.

A mean complementary cumulative distribution function (CCDF) of individual body burdens within the population was generated by varying those parameters that directly affect body burden (daily intake of various foodstuffs, inhalation rate, length of exposure to plume, etc. - Type B uncertainty) while leaving all other parameters set at their best estimated values. Then 59 randomly generated sets of parameter values for the parameters that effect the concentrations of foodstuffs in the diet (all others in the model - Type A uncertainty) were run, one at a time, combined with sets of randomly generated intake parameters. This generated 59 distributions of individuals. The lowest and highest of the sets were chosen as the 2.5% and 97.5% CI on the distribution [15].

2.5.5 Dose Calculations

Dose calculations have been described for the CB scenario [3] and in Peterson [2].

2.6 Identification of important processes and parameters

A statistical sensitivity analysis (partial rank correlation coefficients) was carried out on CHERPAC for the S Scenario. The parameters important to body burden (male) were calculated for five time periods: August 1986, December 1986, July 1987, July 1988 and December 1990. Of the 120 varying parameters that affect body burden, six were important ($r^2 > 0.6$) for at least one of the time periods. In Figure 1 the relative contributions of each parameter to the total contributed by the six is shown for each time period. Since the freshwater fish pathway is so important in Finland, it is not surprising that body burden is very sensitive to the amount of fish consumed and the processing losses for fish. This points out that sensitivity analysis cannot be done on a code in isolation: it must be dependent on the scenario description.

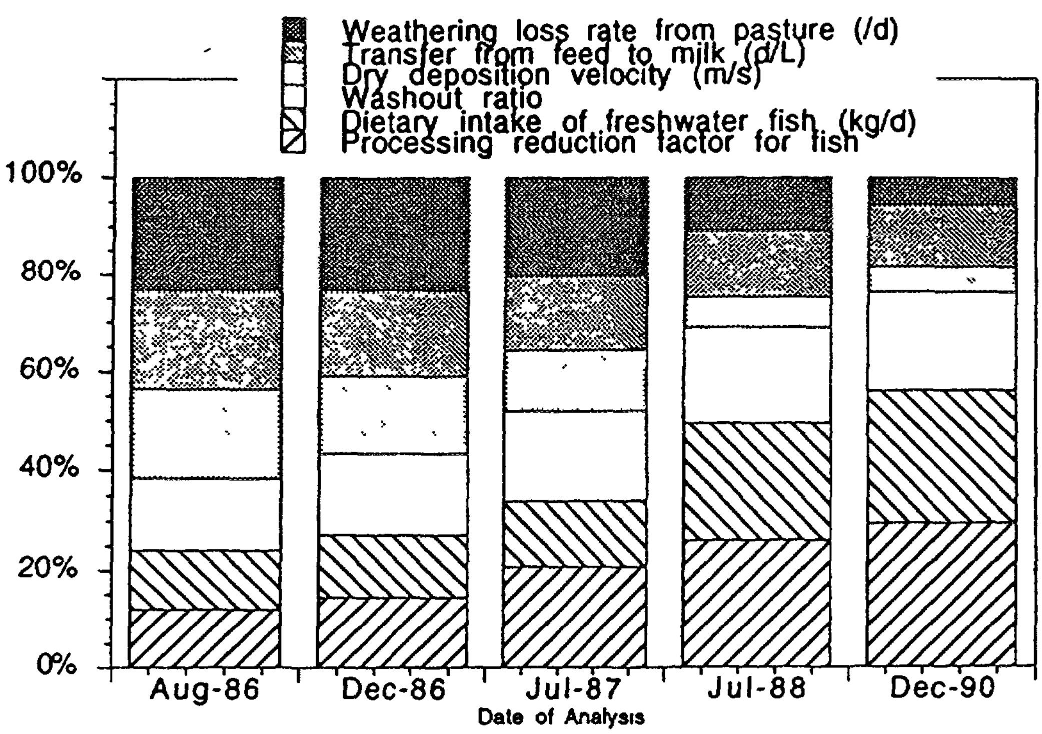


Figure 1. Importance over time, relative to each other, of the six parameter values to which CHERPAC is most sensitive

3. COMPARISON OF OBSERVED DATA AND MODEL PREDICTIONS

Predicted best estimates for all the required concentrations were submitted with the 95% confidence intervals (CI) calculated about mean values. Most of the confidence intervals were calculated with deposition as input, since deposition was known and using it as input eliminated the uncertainty associated with dry deposition velocity and washout ratios. However, the code was also run with air concentrations as input, since otherwise there was no way to estimate the uncertainty about inhalation and concentrations in greenhouse vegetables and grain. Concentration in soil is the output variable most affected by whether uncertainty is estimated starting with air concentrations or deposition; starting with deposition reduces uncertainty on either side of the mean by just less than a factor of 2. For body burden the decease is about a factor of 1.2.

3.1 Total deposition

Although the mean deposition calculated in CHERPAC was 19,600 Bq m^{-2} compared with the observed 19,900 Bq m^{-2}, the uncertainty on the predictions was relatively large - about a factor of 2 on either side of the mean.

3.2 Food Items Contributing to Total Diet

3.2.1 Milk

Because the CI's on the observations are so narrow, only one of the best estimates matches the observations (see Figure 2). The dynamic for the first three months is reasonable, but CHERPAC's predictions show a rapid decrease over the first summer not shown by the observations. A rise in the fall is similar to that observed but underpredicted. After the first year, the predictions underestimate by as much as a factor of 8. Furthermore, 9 of the observations fall outside the 97.5% confidence limit of the predictions.

3.2.2 Beef

Only the concentrations in beef for the months of July through September are reasonably simulated (Figure 3). Beginning in the fourth quarter of 1986, the predictions begin to diverge from the observations and

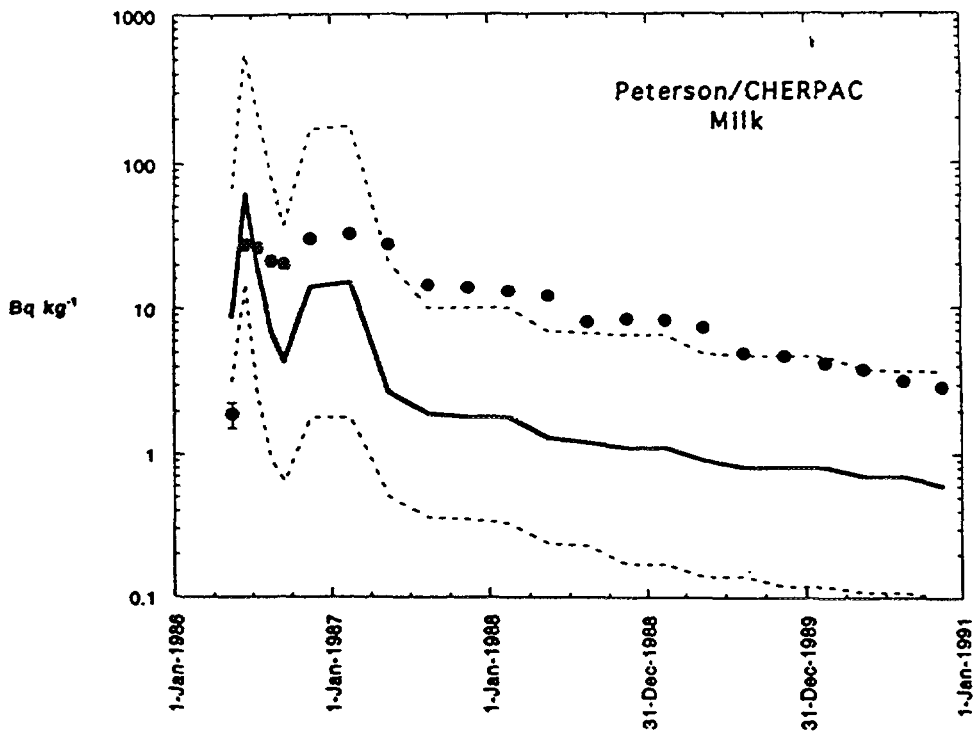


Figure 2. Comparison of observations (·) and predictions (-) for ^{137}Cs concentrations in milk; 95% confidence intervals are shown both on observations (-) and predictions (-----).

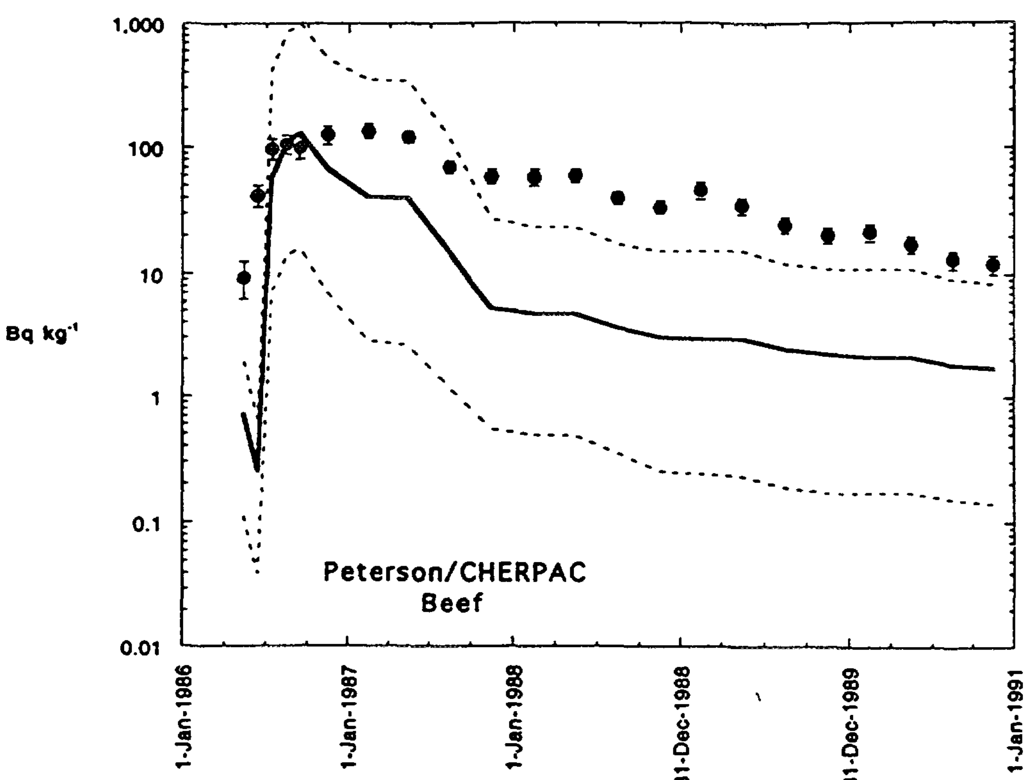


Figure 3. Comparison of observations and predictions for ^{137}Cs concentrations in beef; 95% confidence intervals are shown

underestimate by as much as a factor of 15. All observations after the fourth quarter of 1987 fall outside the 97.5% confidence limit.

3.2.3 Pork

After a major deviation in dynamic for the first five months of 1986 (Figure 4), the predictions underestimate the observations by about a factor of 3.5 for a period of two years. After that, the predictions drop and underestimate by a factor of about 13. The CI's of observations and predictions overlap except for June through September 1986 and for all of 1989 and 1990.

3.2.4 Freshwater fish

The predictions all fall within the CI's about the observations (Figure 5) and the CI's on the predictions are about a factor of three about the mean.

3.2.5 Wild produce

3.2.5.1 Berries

After 1987 the concentration in berries is underestimated by about 30%, and in 1989 and 1990, the predictions fall just outside the lower confidence limit on the observations (Figure 6). The CI's on the predictions either include those on the observations or overlap them.

3.2.5.2 Mushrooms

Predictions are just about identical with the observations initially and are slightly below the observations in 1989 and 1990 (Figure 7). The uncertainty on the predictions is very large, however. The very low value for the 2.5% confidence limit in 1988 is due to an error in the parameter distribution input for uncertainty.

3.2.5.3 Big Game

Except for a near-perfect best estimate in 1987, the predictions fall just below the 2.5% confidence limit of the observations (Figure 8), but the underestimation is only about 20%. The uncertainty on the predictions is within a factor of 4 of the mean.

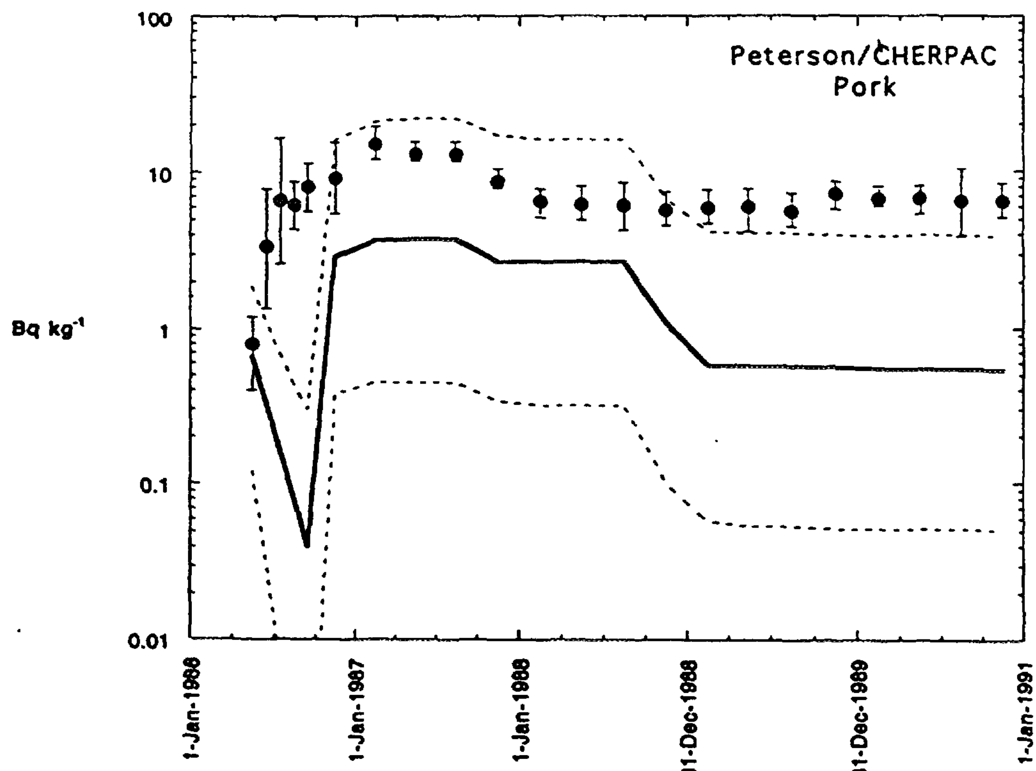


Figure 4. Comparison of observations and predictions for ^{137}Cs concentrations in pork; 95% confidence intervals are shown

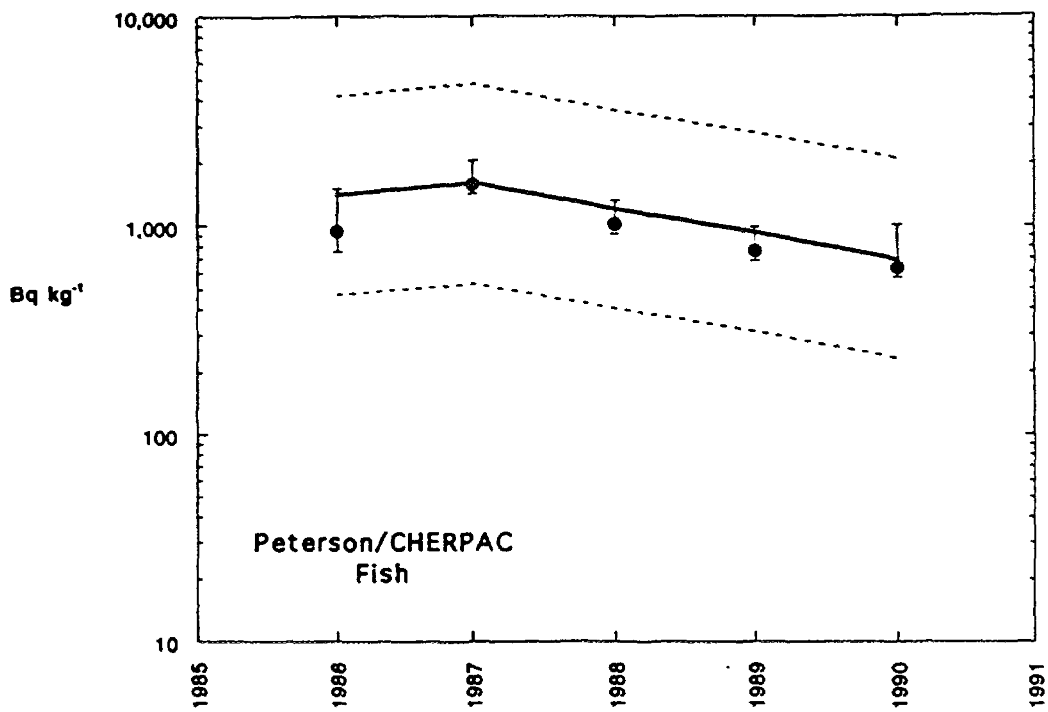


Figure 5. Comparison of observations and predictions for ^{137}Cs concentrations in freshwater fish; 95% confidence intervals are shown

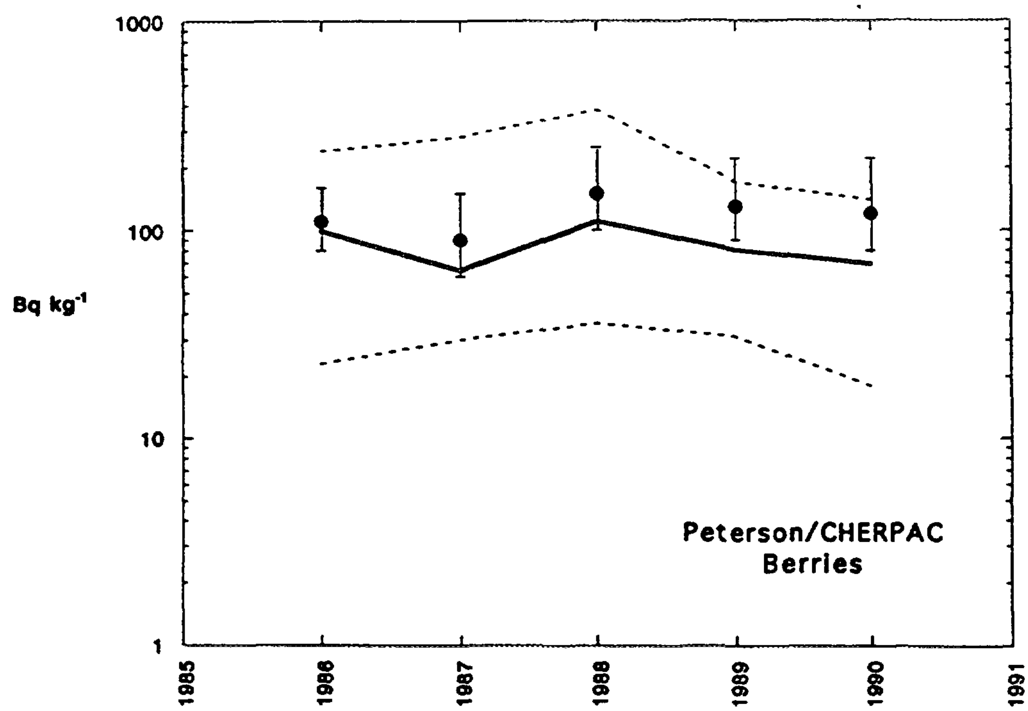


Figure 6. Comparison of observations and predictions for ^{137}Cs concentrations in wild berries; 95% confidence intervals are shown

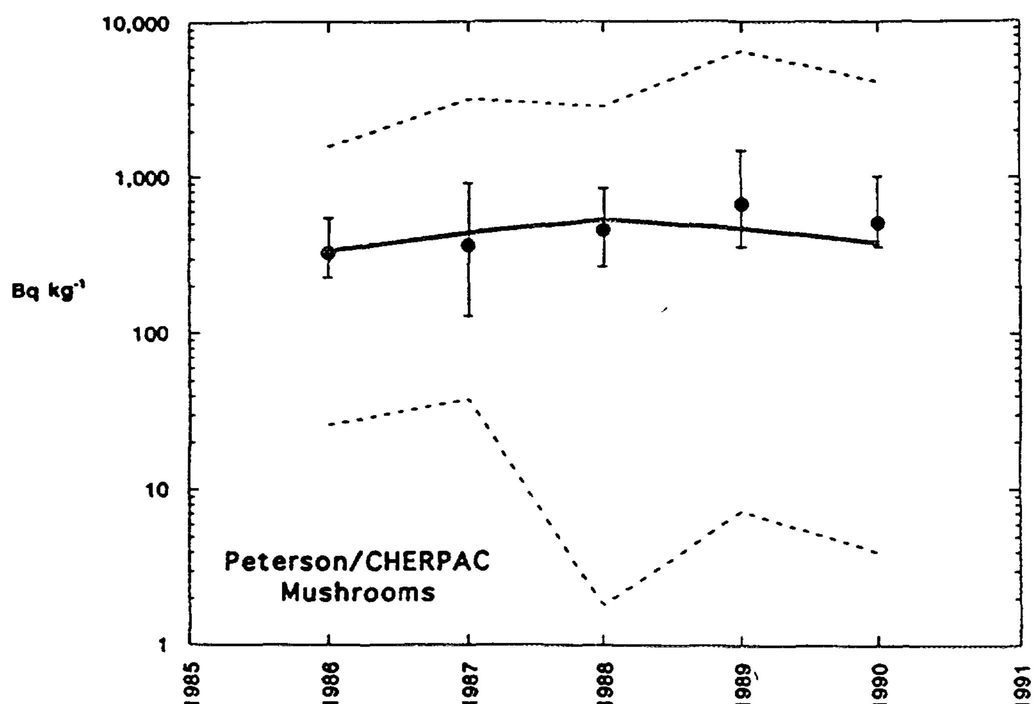


Figure 7. Comparison of observations and predictions for ^{137}Cs concentrations in <u>Boletus</u> and <u>Cantharellus</u> mushrooms; 95% confidence intervals are shown

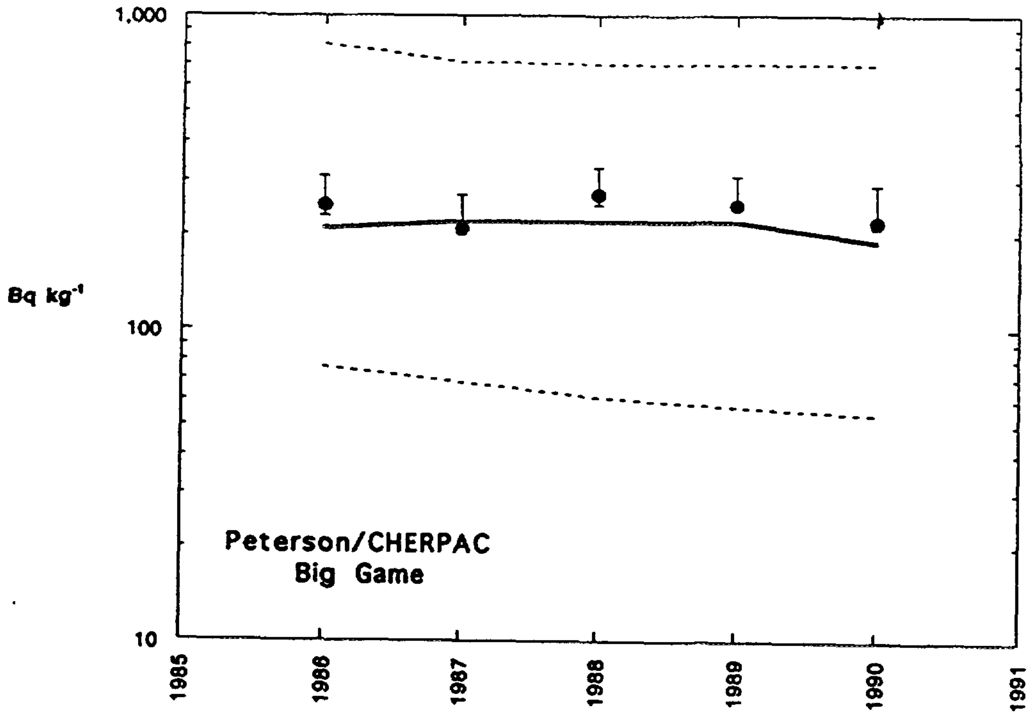


Figure 8. Comparison of observations and predictions for ^{137}Cs concentrations in big game; 95% confidence intervals are shown

3.2.5.4 Small Game

With the exception of 1986 when the prediction falls just outside the 97.5% confidence limit of the observations (Figure 9), all predictions fall within the CI's of the observations. The uncertainty of the predictions ranges from within a factor of 2 and 7 of the mean.

3.2.6 **Other Items of Specific Interest**

3.2.6.1 Animal feed

3.2.6.1.1 Pasture

The match between predictions and observations is quite good and only varies by, at most, a factor of 2 (Figure 10). The CI's of the predictions and observations are the same size, although the observed CI's are skewed on the high side.

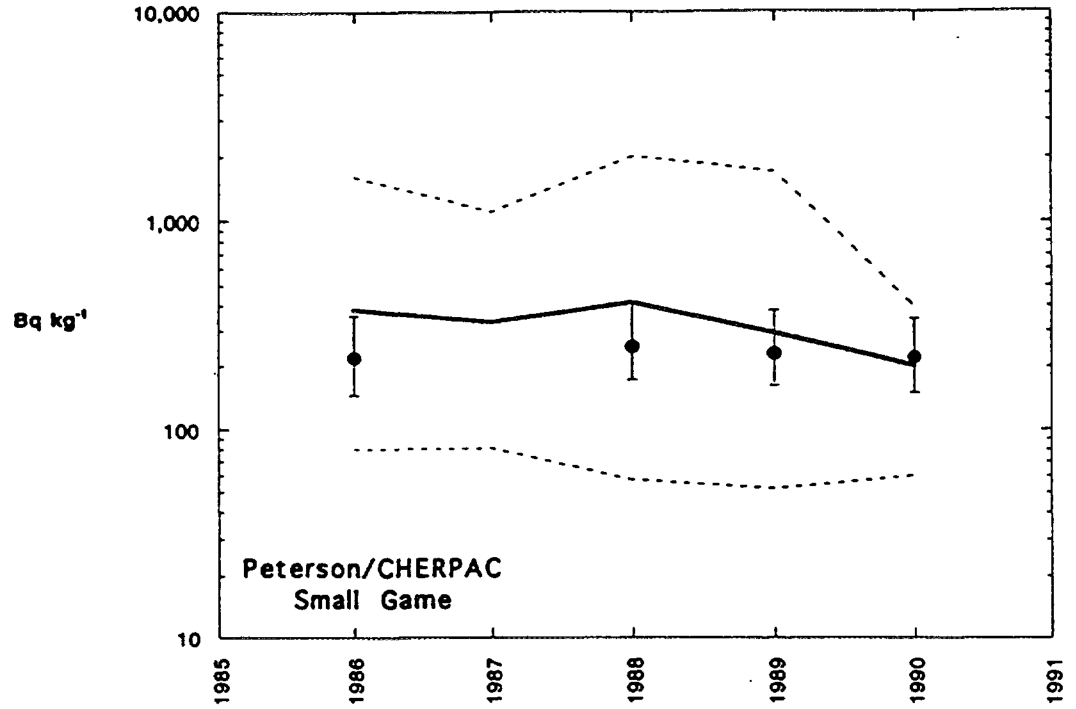


Figure 9. Comparison of observations and predictions for ^{137}Cs concentrations in small game; 95% confidence intervals are shown

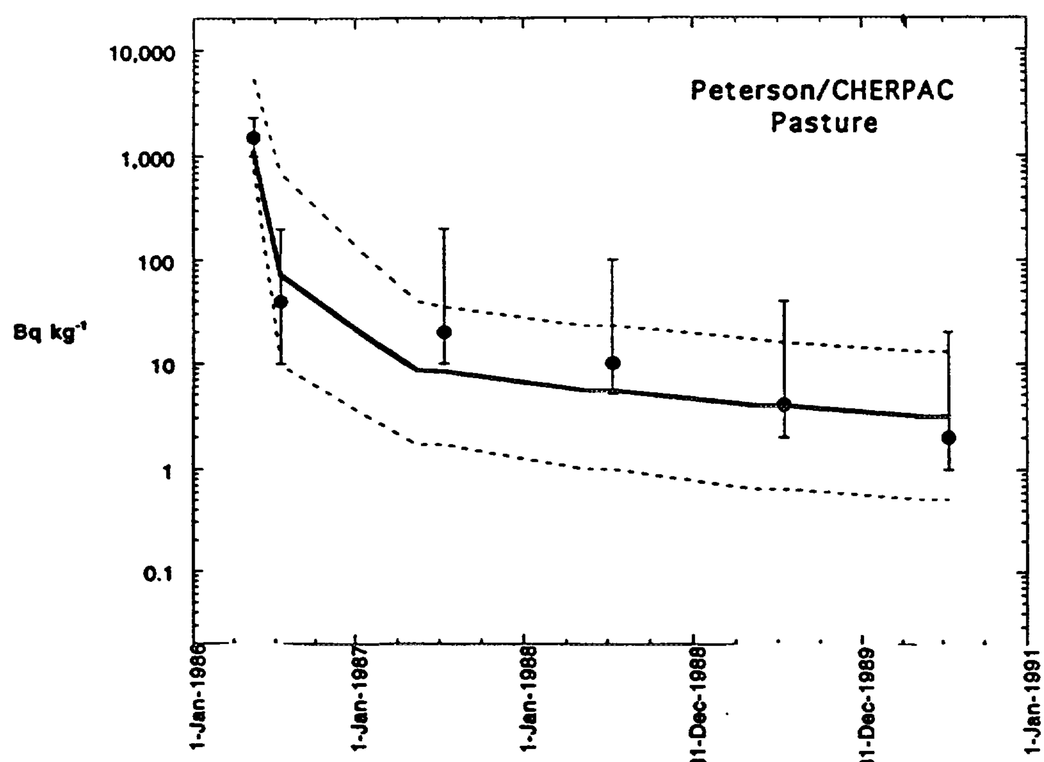


Figure 10. Comparison of observations and predictions for ^{137}Cs concentrations in pasture; 95% confidence intervals are shown

3.2.6.1.2 Barley

The predictions match the observations well during the first three years, but in 1989 the prediction falls below the 2.5% confidence limit of the observations (Figure 11). The CI's of the observations are contained within those on the predictions until 1989.

3.2.6.1.3 Oats

The prediction for 1986 coincides with the observation (Figure 12), but after that, the measured concentrations show an increasing trend while the predictions have a tiny decrease. By 1989, the CI's about the predictions fall below those about the observations, and the prediction is more than a factor of 7 times lower than the observation.

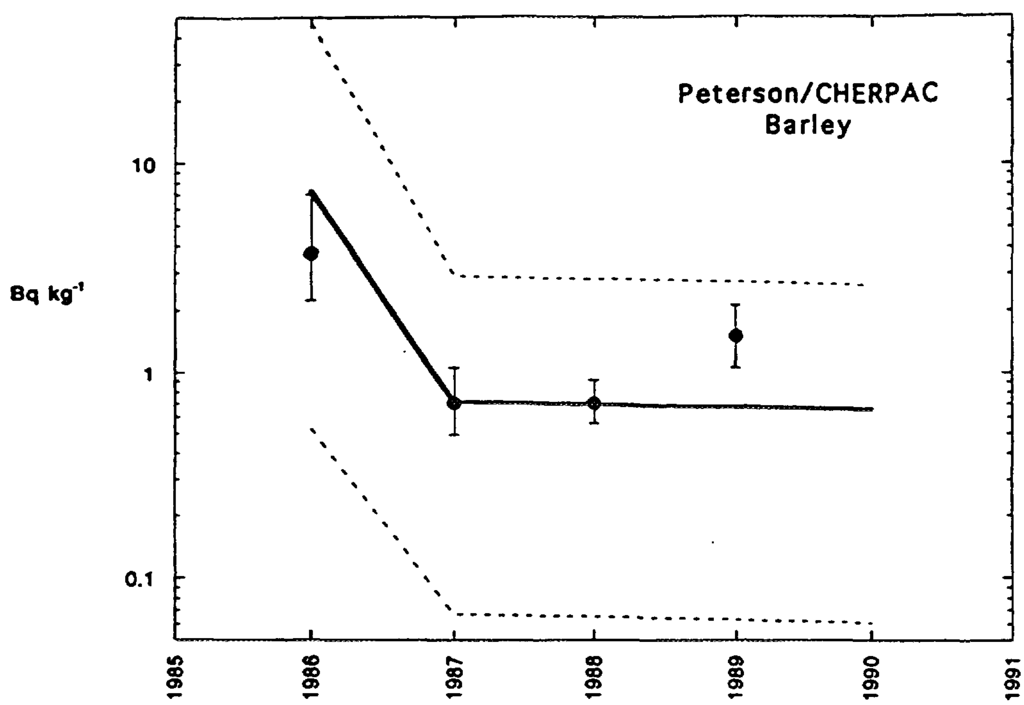


Figure 11. Comparison of observations and predictions for ^{137}Cs concentrations in barley; 95% confidence intervals are shown

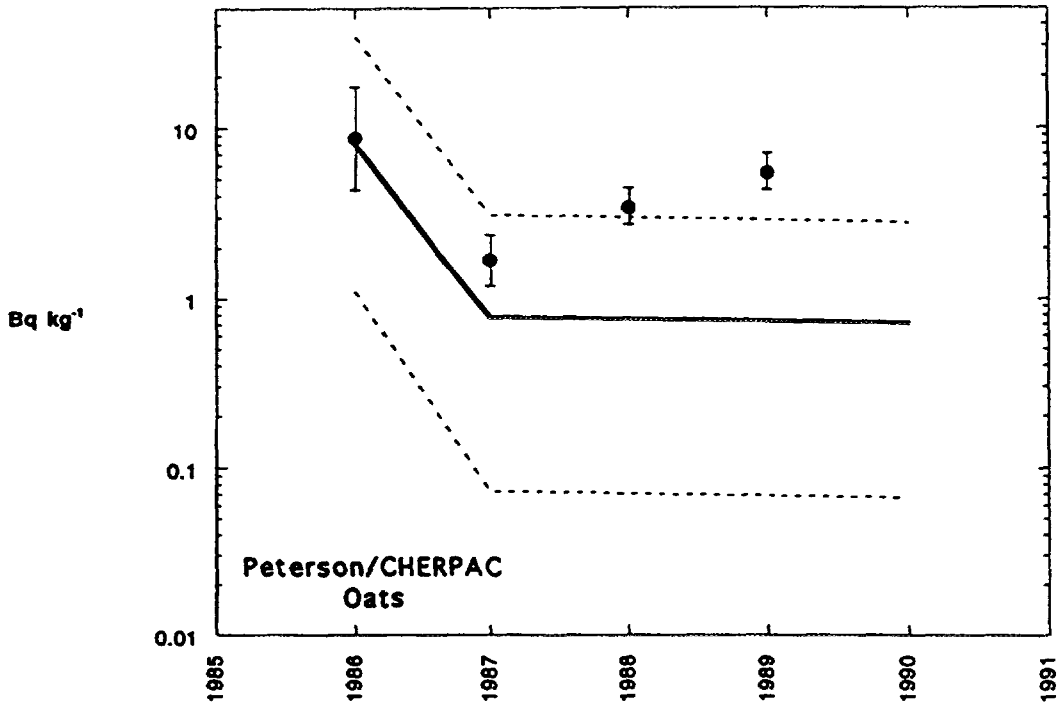


Figure 12. Comparison of observations and predictions for ^{137}Cs concentrations in oats; 95% confidence intervals are shown

3.2.7 Leafy vegetables and grain for human consumption

3.2.7.1 Leafy vegetables

The predictions for leafy vegetables fell just below the 2.5% confidence limit of the observations for 1987, 1988 and 1989 (Figure 13), but for 1986 and 1990 the predictions fall within the CI on the observations. The observations are barely included within the CI on the predictions.

3.2.7.2 Wheat

The predictions for wheat are quite accurate (Figure 14): all fall within the CI of the observations except for 1990, which is overestimated by only a factor of 2. The observations and their CI lie centrally in the CI about the predictions.

3.2.7.3 Rye

The best estimates fall within the CI on the observations for 1986, 1989 and 1990 (Figure 15). For 1987 and 1988 the observations coincide with the 97.5% confidence limit of the predictions.

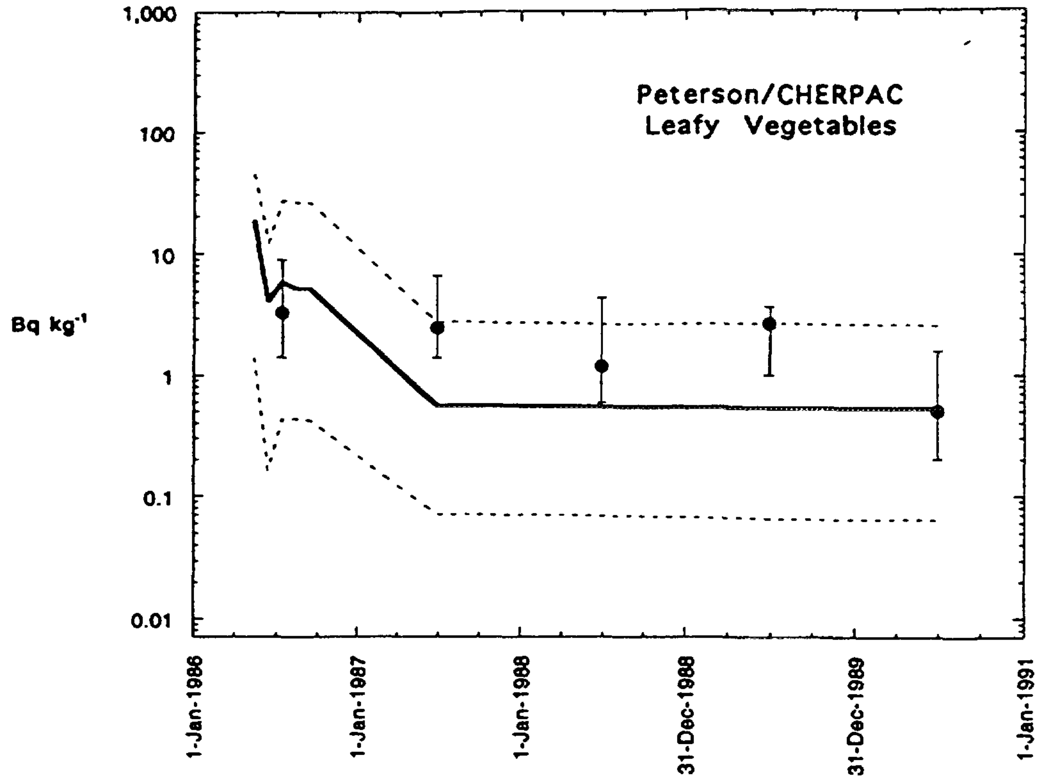


Figure 13. Comparison of observations and predictions for ^{137}Cs concentrations in leafy vegetables; 95% confidence intervals are shown

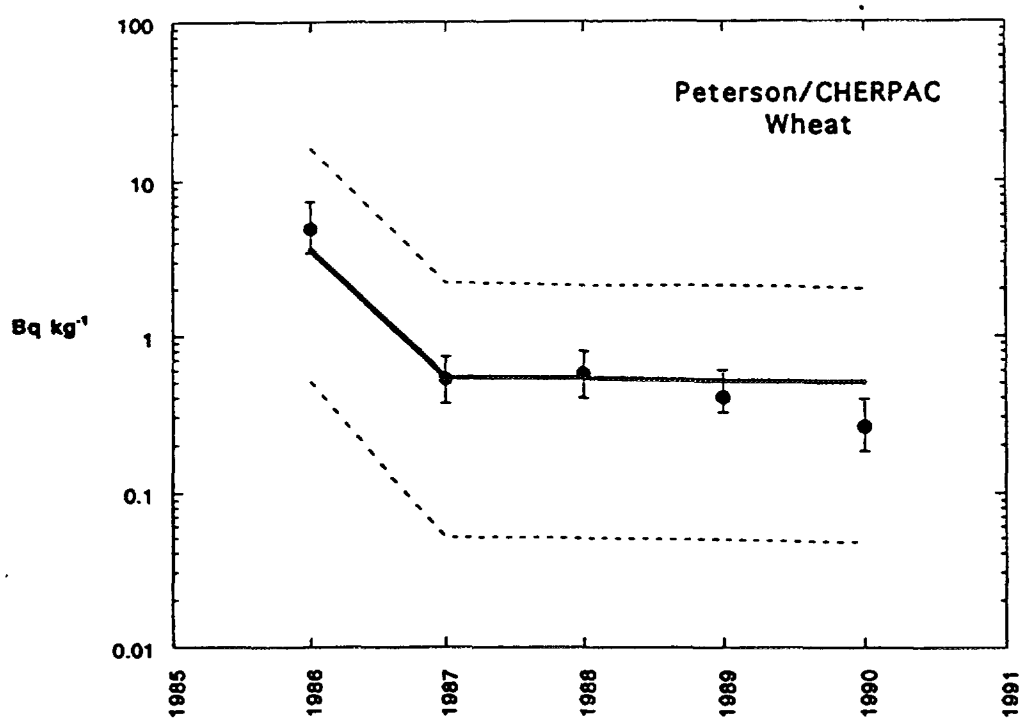


Figure 14. Comparison of observations and predictions for ^{137}Cs concentrations in wheat; 95% confidence intervals are shown

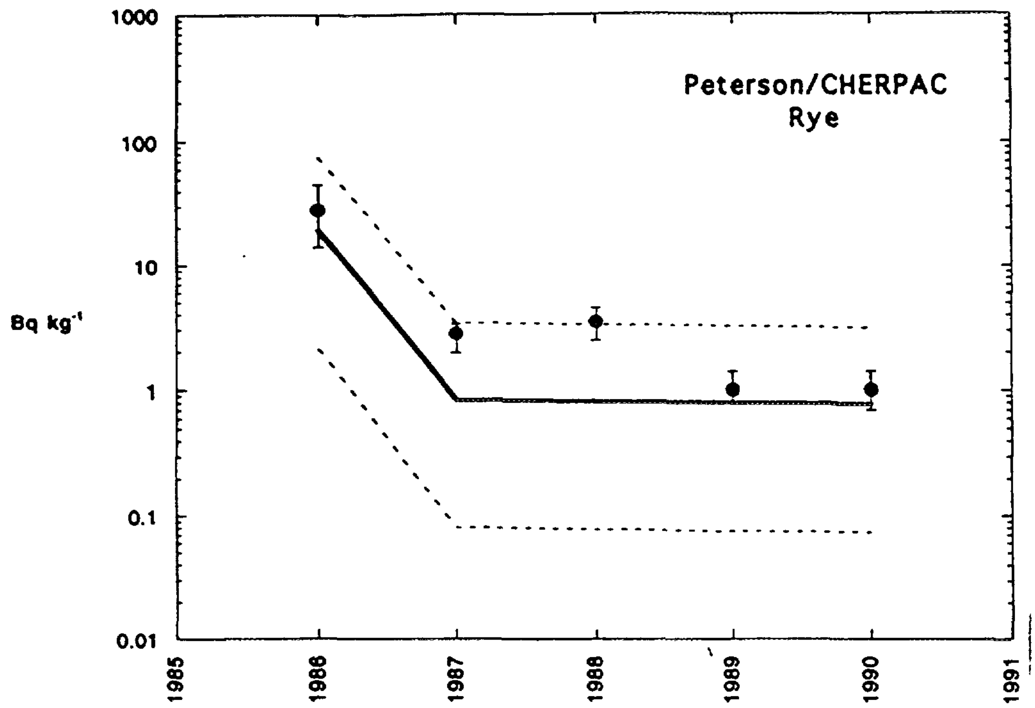


Figure 15. Comparison of observations and predictions for ^{137}Cs concentrations in rye; 95% confidence intervals are shown

3.3 Human intake (man)

Except for the first half-year, where the observations rise and the predictions fall (Figure 16), the dynamics of the predictions parallel the observations but the concentrations are lower, and the observations are contained within the 95% CI on the predictions

3.4 Whole body concentrations

3.4.1 Mean Whole Body Concentrations

The relationship between predictions and observations is the same for man (Figure 17) and woman: the overpredictions for each year are less than a factor of 2 but still fall outside the CI on the observations. For the child, the predictions all fall within the CI on the observations except for 1987, when there is a slight underestimate. The CI on the predictions is not large - less than a factor of three on either side of the best estimate and it includes the observations. These small overpredictions for man, woman and child occur in spite of an underestimation of intake for all years except 1986 June.

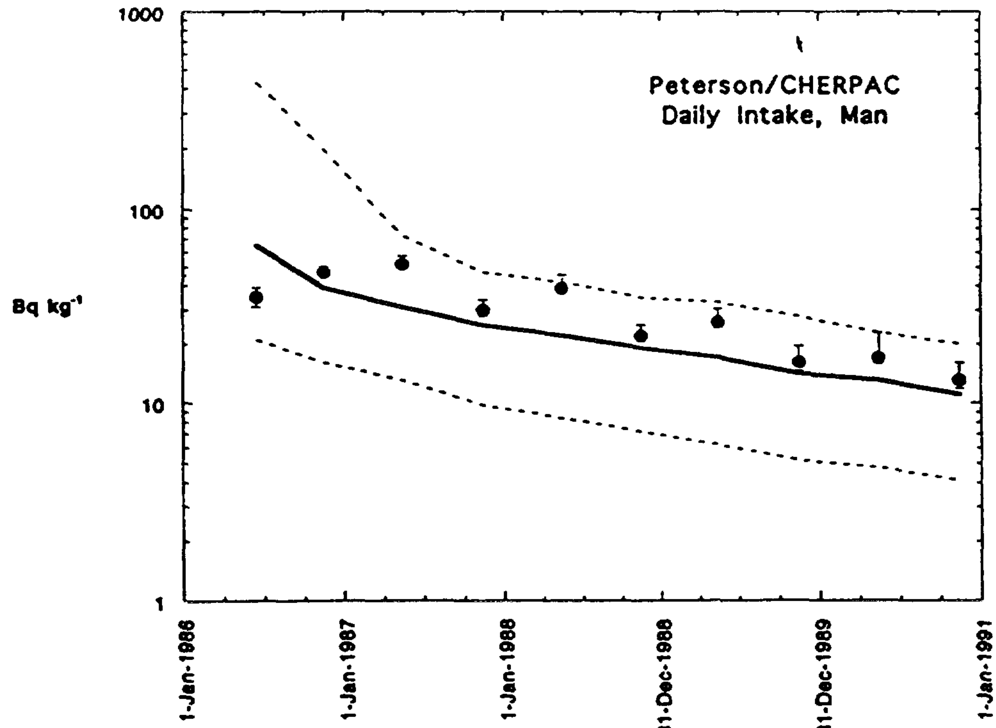


Figure 16. Comparison of observations and predictions for ^{137}Cs amounts in daily intake (man); 95% confidence intervals are shown

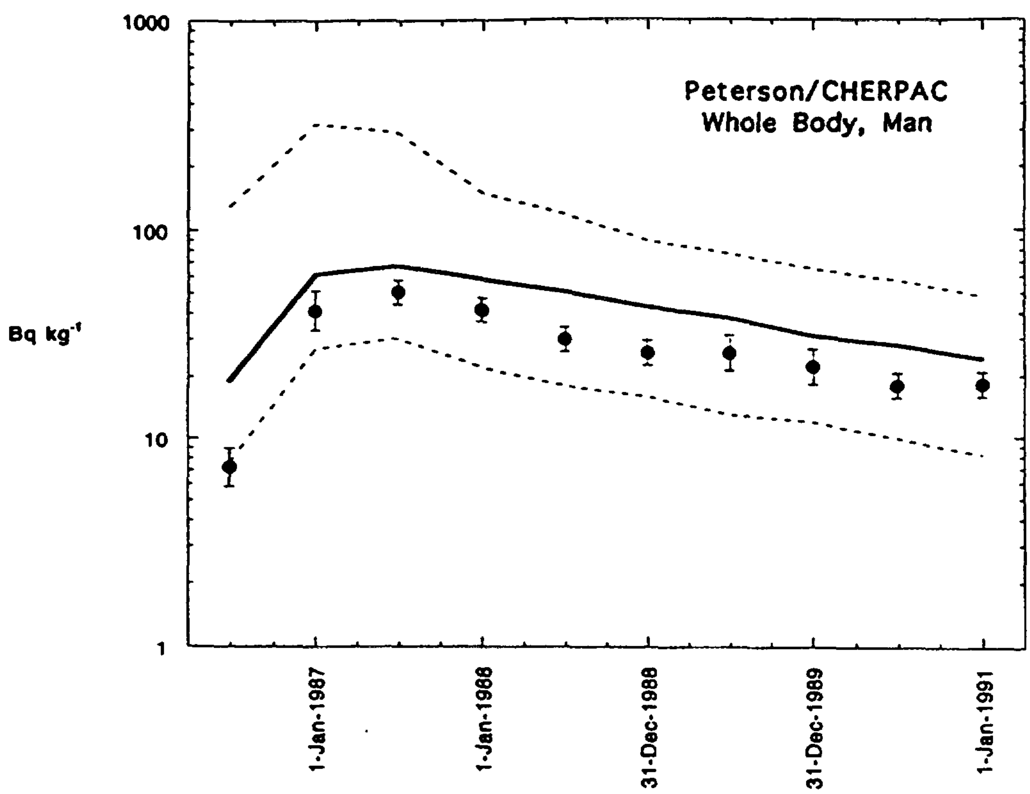


Figure 17. Comparison of observations and predictions for ^{137}Cs concentrations in body burden (man); 95% confidence intervals are shown

3.4.2 Distribution of Whole Body Concentrations

Distributions of whole body concentrations for December 1987 are shown in Figure 18 and those for December 1990 are shown in Figure 19. Although the averages predicted for 1987 are consistently higher than the observations, the observations are nevertheless within the CI which is only a factor of two about the mean. The situation is similar for 1990, except that the observations for the 2.5% fractile are skewed to the high side. In this case, the uncertainty bounds predicted by CHERPAC just barely contain the observations.

3.5 Dose calculations

CHERPAC's best estimate for dose from inhalation (2.2 10^{-4} mSv) was identical to the Finnish estimate. However, CHERPAC's uncertainty was only about one-third that estimated by the data collectors because uncertainty in the applicability of the 2 sets of air measurements was not taken into account.

Dose from external exposure was underestimated by CHERPAC (Figure 20), and the magnitude of the underestimation increases with time. Even for the first year, the 97.5% confidence limit on the predictions is lower than the 2.5% confidence limit on the observations.

4. EXPLANATION OF MAJOR SOURCES OF MISPREDICTION

By and large, CHERPAC's predictions were accurate: many best estimates fell within the confidence intervals on the observations, which were quite small due to the sampling strategy employed. Certainly, in most cases the CI's on the predictions included those of the observations.

Predictions for concentrations in milk and beef were not accurate. Milk and beef were modelled similarly except for different diets and feeding restrictions, and for both the observations lie above the 97.5% confidence limit on the predictions for most or all of 1987-1990. The underprediction (Figures 2 and 3) was, on average, about a factor of 8 for both dairy and beef cattle. This result is quite difficult to explain given that the predictions for pasture are either spot on or high by up to a factor of 3 and that the predictions for barley were good or low by only a factor of 2. Only for oats were the underpredictions serious - up to a

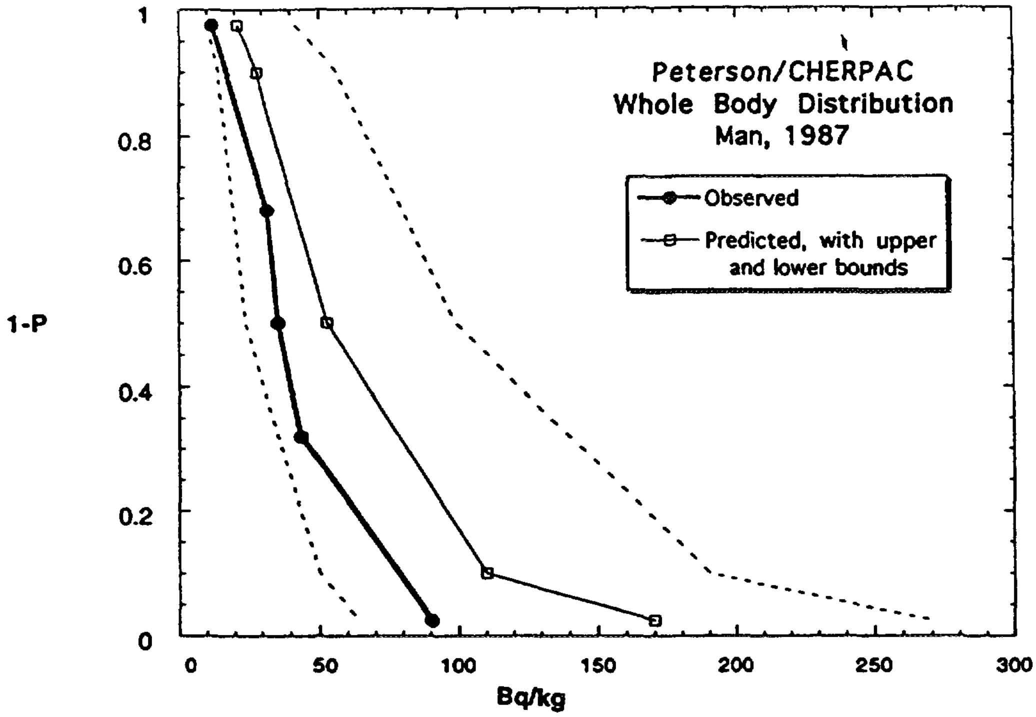


Figure 18. Complementary Cumulative Distribution Function of ^{137}Cs body burden for December 1987; predictions and the 95% confidence interval are shown compared with observations

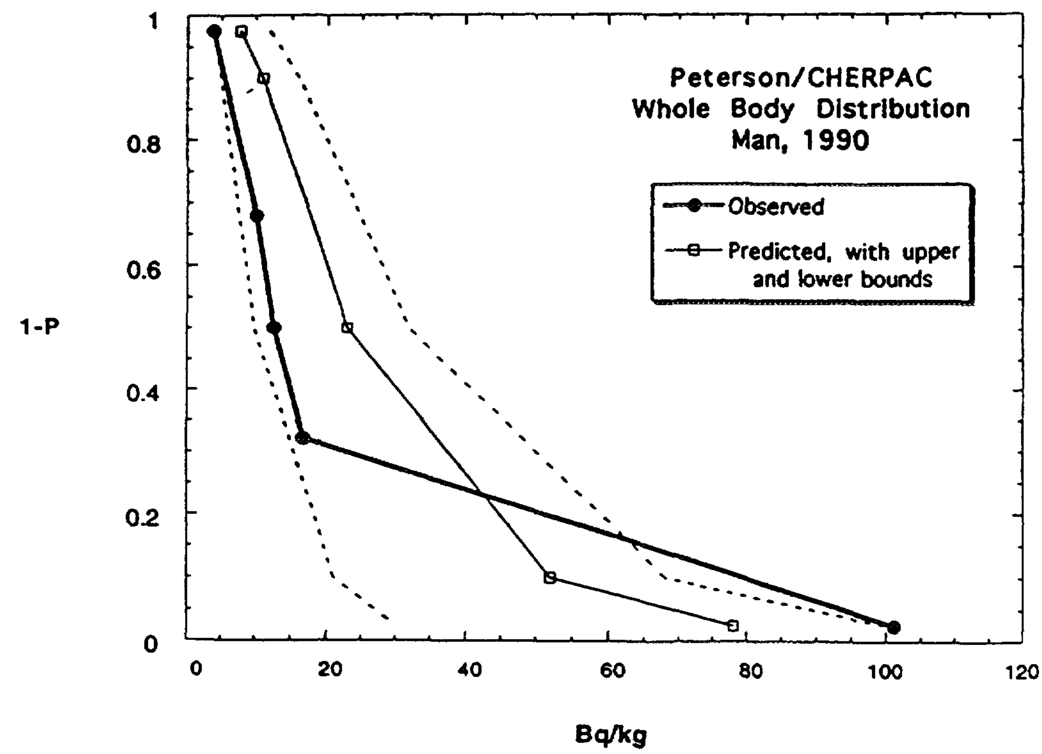


Figure 19. Complementary Cumulative Distribution Function of ^{137}Cs body burden for December 1990; predictions and the 95% confidence interval are shown compared with observations

factor of nearly 8 over time. But the amount of all grain consumed was only about 15% that of pasture by weight, which cannot account for the underpredictions in milk and beef. It was suggested that the pasture data were not representative of the pasture the cows grazed, since the pasture measured grew on different soils in another part of the country from the cattle industry.

The two extremely low values for beef in May and June (Figure 3) are due to the assumption that the animals received no contaminated food until they were fed contaminated hay harvested in July. This was obviously an erroneous assumption. The predicted activity in the meat is due only to what was taken in by inhalation.

Concentrations in pork were also not modelled well (Figure 4). However, even given the observed grain values and the diet supplied, the observed concentrations in pork cannot be predicted. Certainly the amount by which CHERPAC underestimated the two grains cannot account for the size of the underestimation here. The predicted declining concentrations in pork for 1986 May through September are due to initial contamination from inhalation of the plume followed by metabolic loss coupled with the obviously erroneous assumption that the pigs were fed no contaminated grain until the October harvest. Furthermore, the pigs slaughtered during these five months were all one month old or more at the time of the accident and hence were not suckling. The underestimation of pork was not helped by an error in the code that was only detected after the scenario closed: only the pigs born in April 1986 received milk as their diet, while the model assumes that all pigs will receive milk for the first month of life. However, correction increased the predictions at most by 10%. The major decrease in concentration in the fall of 1988 is due to consumption of grain solely contaminated by root uptake; until then grain consumed was at least partially contaminated by direct deposition in 1986 (see Section 2.5.2.6).

The dose due to exposure to deposited cesium (Figure 20) was modelled in a very simple fashion, but in addition, it should have been multiplied by the conversion factor (2.4) to simulate deposition over the entire land area. As it stands, the dose is equivalent to standing on a pasture, with occupancy and shielding factors taken into account.

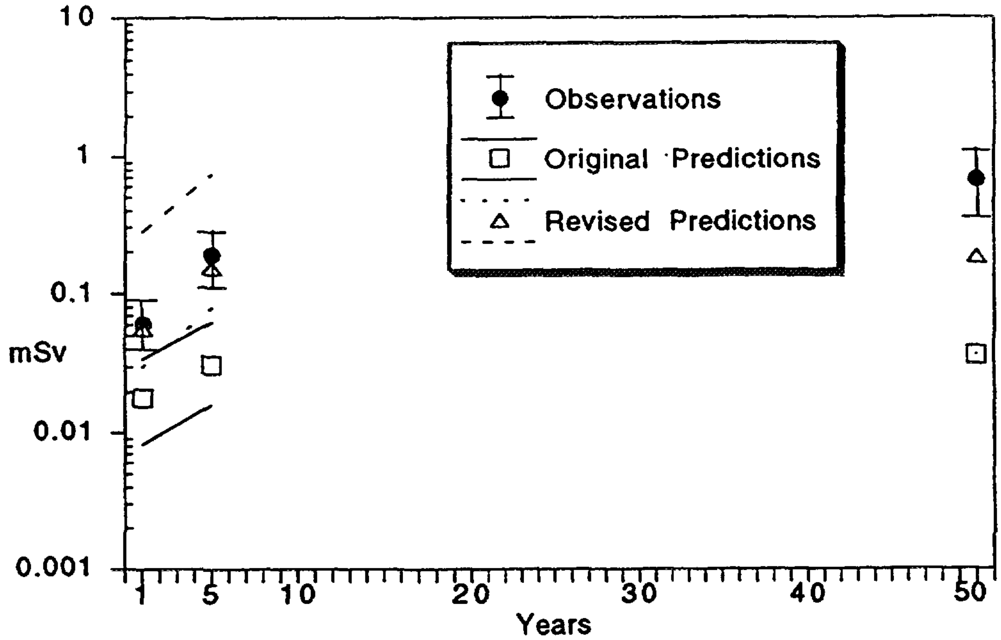


Figure 20. Comparison of Finnish estimates and CHERPAC's predictions for the dose from exposure from deposited ^{137}Cs; 95% confidence intervals are shown except for the 50-year prediction

4.1 Recommendations for Changes to the Model

Based on what has been learned here, the calculation of dose from ground exposure must be corrected. Presently, the migration through the soil is too fast and not enough is left near the surface, so the dose over time is smaller than it should be. Although there were no data in this scenario for fruit contamination, CHERPAC still needs a reasonable model for fruit. Also, the milk and beef models can be improved to resemble actual processes. The soil model must be made more process-oriented.

4.2 Examples of How Changes Improve Calculations

Based on the discussion in Section 4, the concentration ratio (CR) from soil to pasture vegetation was adjusted upwards by a factor of 7.8 - a simple calibration. No other changes were made to the model. The results in concentrations of milk and beef can be seen in Figures 21 and 22. The increased CR resulted in increased predictions, but since the relative size of the increase is greatest at longer times, the early dynamics are not changed significantly. For milk the revised predictions are identical to the observations 50% of the time from mid-1987 on, while for beef there is

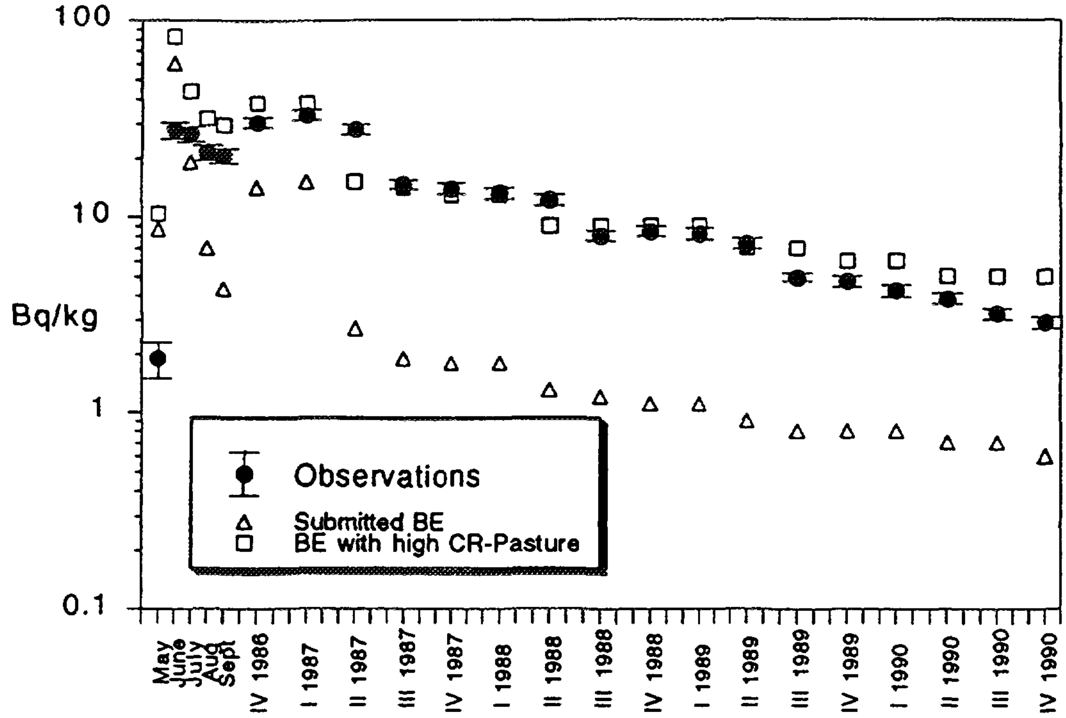


Figure 21. Comparison of observations with 95% confidence intervals with the original submitted best estimate and the revised best estimate, based on an increased soil to plant concentration ratio, for concentrations of ^{137}Cs in milk

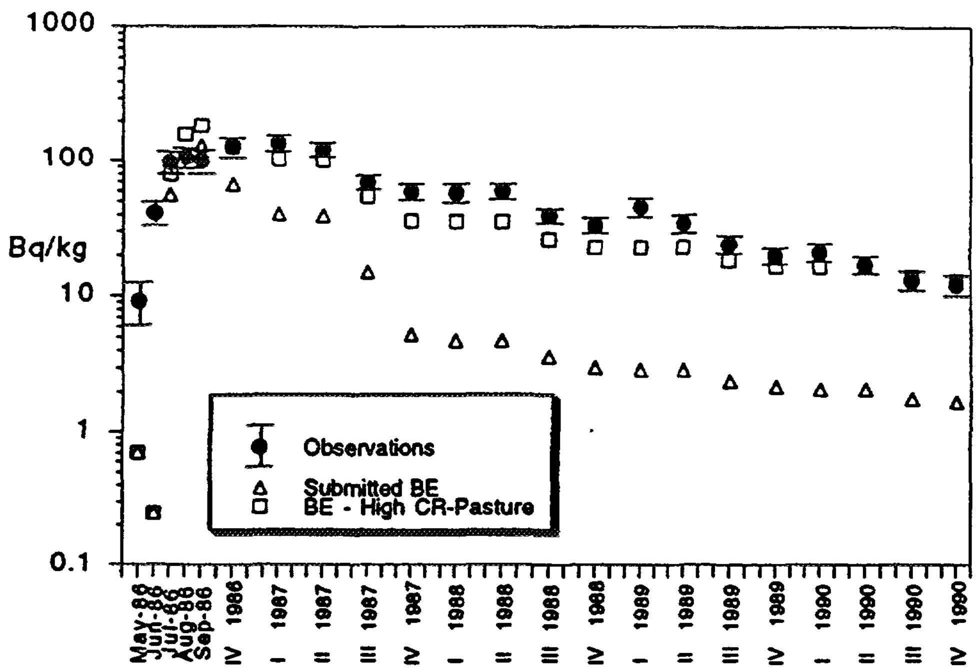


Figure 22. Comparison of observations with 95% confidence intervals with the original submitted best estimate and the revised best estimate, based on an increased soil to plant concentration ratio, for concentrations of ^{137}Cs in beef

still a small underestimation most of the time but the dynamic is followed extremely well. Obviously, this solution is much too simple and corrections need be made to the dynamic modelling of pasture, oats and barley before any defensible changes to parameter values can be made. But it looks as if an especially high CR for pasture may be the answer. This is reasonable at least partially because of the peat content of Finnish soils. An unfortunate fact here is that the revised predictions are falling outside the present confidence intervals on the predictions (compare the uncertainty in Figures 2 and 3). This is because, at the moment, we lack enough data to justify changing the distribution of values of the concentration ratio. However, concentration ratios equally high have been reported by Pietzrak-Flis [16] and Jackson and Smith [17].

With milk corrected, the pork concentration will rise by about 10% since it is assumed that piglets drink milk during their first month. If sow's milk is much higher that cow's milk, the concentration predicted will rise further.

As mentioned, the predictions for body burdens in humans were very good. Unfortunately once the predictions for the other foodstuffs are calibrated to the observations, the body burdens get higher, although they still fall within the predicted confidence intervals. The initial excellent predictions, then, appear to be due to compensatory error.

An error in the CHERPAC code accounted for part of the underprediction of external doses (see Section 4). When external doses were multiplied by the factor of 2.4 to convert pasture deposition to total deposition to land surfaces, the underprediction in the first year lies on the 2.5% confidence limit of the observations, and at year 5, the 97.5% confidence limit on the prediction lies close to the observed. At 50 years the results are still unacceptable. As mentioned, the submodel for external dose is extremely simple, with a single loss rate constant for removal of activity from surface soil. The half-life for this constant used for Scenario S was 365 days, which is obviously too short. It has been doubled to 730 days. This, plus the correction to deposition, results in excellent agreement between doses estimated by STUK and those predicted by CHERPAC for one and five years post-accident (Figure 20). The model still underpredicts at 50 years, but had uncertainty bounds been calculated, they would certainly overlap STUK's estimated uncertainty bounds.

5. SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

Both the successes and the failures here can be traced to the site being Southern Finland. Because we knew the site, we successfully could select transfer parameter values and distributions which would reflect what was known about the area, i.e., that the particle size distribution was larger here than in most places because the first plume was the one to arrive in Finland, that nothing would have been growing or even planted when the plume arrived, and that high concentration ratios were to be expected because of the preponderance of peaty soils. The successful selection of dry deposition velocity and washout ratio meant an accurate prediction of average deposition which agreed with the estimated measured value. The literature on transfer to wild produce is dominated by Nordic data, about a fifth of which is Finnish in our data base. Although the data were in no way calibrated to Finnish conditions, these bulk transfer values (kg wild produce m^{-2}) from the open literature were used along with other similar data to derive the values used in the code. As a result, and because the values in the literature worked, most of our predictions for wild produce were very good. Failures, such as the underestimation of milk and beef, are also due to unique Finnish conditions for which we failed to account adequately even though we were alerted to them. High uncertainty for wild pathways arose from not trusting the data because it was limited. Also, this would seem to be a good area for where good Canadian data are needed, but there are few or none.

Each scenario not only tests the model but tests the user. Not only does the user learn exactly how his model behaves, but he learns which input is most important to his code and what he needs to spend the time on in order to improve the output. The success of CHERPAC in this scenario is based on previous experience with other scenarios and on discussion of the uniqueness of the Finnish situation with colleagues. A code cannot just be run with the best input provided: the results must be analyzed carefully to see if they are what is expected, and if they are not, the whole procedure must be reconsidered.

There is also an element of luck involved, which is most often disclosed by the existence of compensatory errors. Although CHERPAC had none that made more than a minor difference in the results, there was at least one instance in which the predictions appeared to be correct but the justification for them was incorrect. Results for pasture (Figure 10) for 1986 are very close to the observations. This is due, not to deposition on growing plants as was modelled, but rather, apparently, to vegetation growing up through the contaminated remains of the previous year's vegetation. This example emphasizes the importance of not blindly accepting results as successful just because they seem to be correct. In addition, so many things go into the prediction of human body burden that one suspects that each good prediction has been arrived at in a very different way. We thus should not be too satisfied, even with good predictions.

CHERPAC performed quite respectably here. It would be more satisfying if the processes had been better understood for the wild pathways and if the unique Finnish situation (i.e., increased transfer from peaty soils to plant) had been handled better. CHERPAC's level of uncertainty is acceptable, and there is a good probability that, to predict Chernobyl ^{137}Cs, using site specific information, CHERPAC may be considered reliable.

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II.8. ECOMOD

1. ECOMOD - ECOLOGICAL MODEL

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Obninsk, Russian Federation

2. MODEL DESCRIPTION

2.1. Name of model, model developer, model user

Name of model: ECOMOD

Model developers: T.G. Sazykina, I.I. Kryshev

Model user: Institute of Experimental Meteorology, Obninsk, Russia.

2.2. Important model characteristics

2.2.1. Intended purpose of the model in radiation assessment

The main purpose of the model is a more detailed description of radionuclide transfer in food chains, including the dynamics in the early period after accidental release. Detailed modelling of the dynamics of radioactive depositions is beyond the purpose of the model. Standard procedures are used for assessing inhalation and external doses.

There exist two versions of the model:

a) radionuclide transfer in terrestrial food chains;

b) radionuclide transfer in aquatic food chains.

2.2.2. Intended accuracy of the model prediction

It is well known that in case of radioactive contamination of the territory with long-lived biologically active radionuclides (^{90}Sr, ^{137}Cs, etc.), the major portion of exposure dose is received by the population through food chains as a consequence of consumption of contaminated foodstuffs . The important source of uncertainty in predictions of foodstuff contamination is the the uncertainty in coefficients of primary radionuclide transfer from soil to plants. In the absence of the information on climatic and soil conditions of the region under study, the uncertainty of the values of individual "soil-plant" transfer coefficients may be as great as one order of magnitude and over, resulting in 2-5-fold uncertainty in the calculated daily human intake of radionuclides.

The uncertainty of foodstuff contamination estimates in long-term predictions (for 20-50 years) depends on the correctness of predictions of soil decontamination,i.e.decreasing in the amount of plant-available radionuclide in the upper soil layer. Predicting the soil "self-purification" is a separate complicated problem, and its solution is beyond the purpose of the radioecological model.

Long-term predictions performed with radioecological models are based either on experimental data on the dynamics of decontamination of the upper soil layer or on simple assumptions about this process. For S scenario ECOMOD uses simple assumptions about the dynamics of radionuclide migration into deeper soil layers.

2.2.3. Method used for deriving uncertainty estimates

In ECOMOD, the method of "sensitive parameters" is used for deriving uncertainty estimates. Preliminary calculations with the model reveal 1-2 key parameters (for each kind of foodstuffs), to which the model is most sensitive, i.e., variations of these parameters have the most pronounced effect on the model predictions. Then the mean value of each sensitive parameter and a possible range of its values are determined. Using the mean value of the key parameter and its boundary values, the model calculations are performed for the most important foodstuffs.

2.2.4. Past experiences using this model

The "aquatic" version of the model was used to assess the radioecological situation in the cooling pond of the Chernobyl NPP in 1986, as well as in the "cooling pond" of the Leningrad NPP (coastal waters of the Kopora bay, Gulf of Finland). The "terrestrial" version of the model in a simplified form was used for the radiation assessment in the area of the Leningrad NPP.

2.2.5. Modifications made for this scenario

For scenario S a more detailed description of the initial retention of radionuclides by plants was given, taking into account the dynamics of biomass growth. Account was taken of the differences in vegetation periods and biomass growth, depending on the geographical latitude of the area. A non-

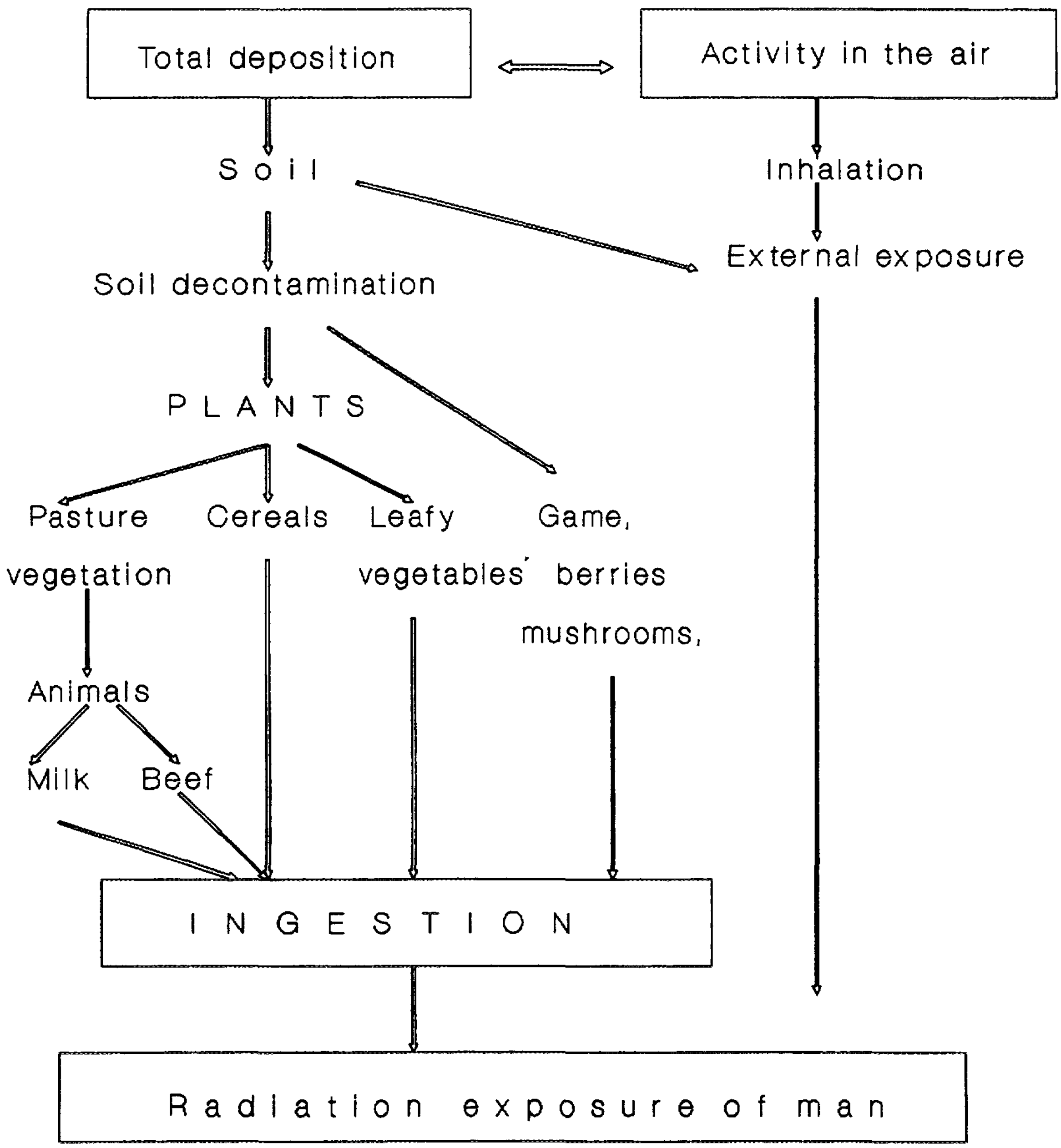

FIG. 1. Flowchart of ECOMOD model.

standard formula was used for the coeffisient of initial retention of radionuclides by plants, depending on their biomass. It is assumed that the model may be especially useful for operational radiation assessment of agricultural lands, contaminated as a result of radiation accidents which may occur in different climatic zones and in different seasons of the year.

2.3. References describing detailed documentation of model

A detailed description of the "terrestrial" version of the model is being prepared for publication.

The "aquatic" version of the model is described in the following publications:

a)Kryshev I.I.,Sazykina T.G. Simulation models of ecosystem's dynamics under unthropogenic impact of thermal and nuclear power plants.-Moscow:Energoatomizdat.-1990.-184 PP.(Monograph,in Russian)

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2.4. Model structure (flowchart indicating transfer processes)

The flowchart of ECOMOD is presented in Fig.1.

2.5. Descriptions of procedures, equations and parameters used in different components of the model

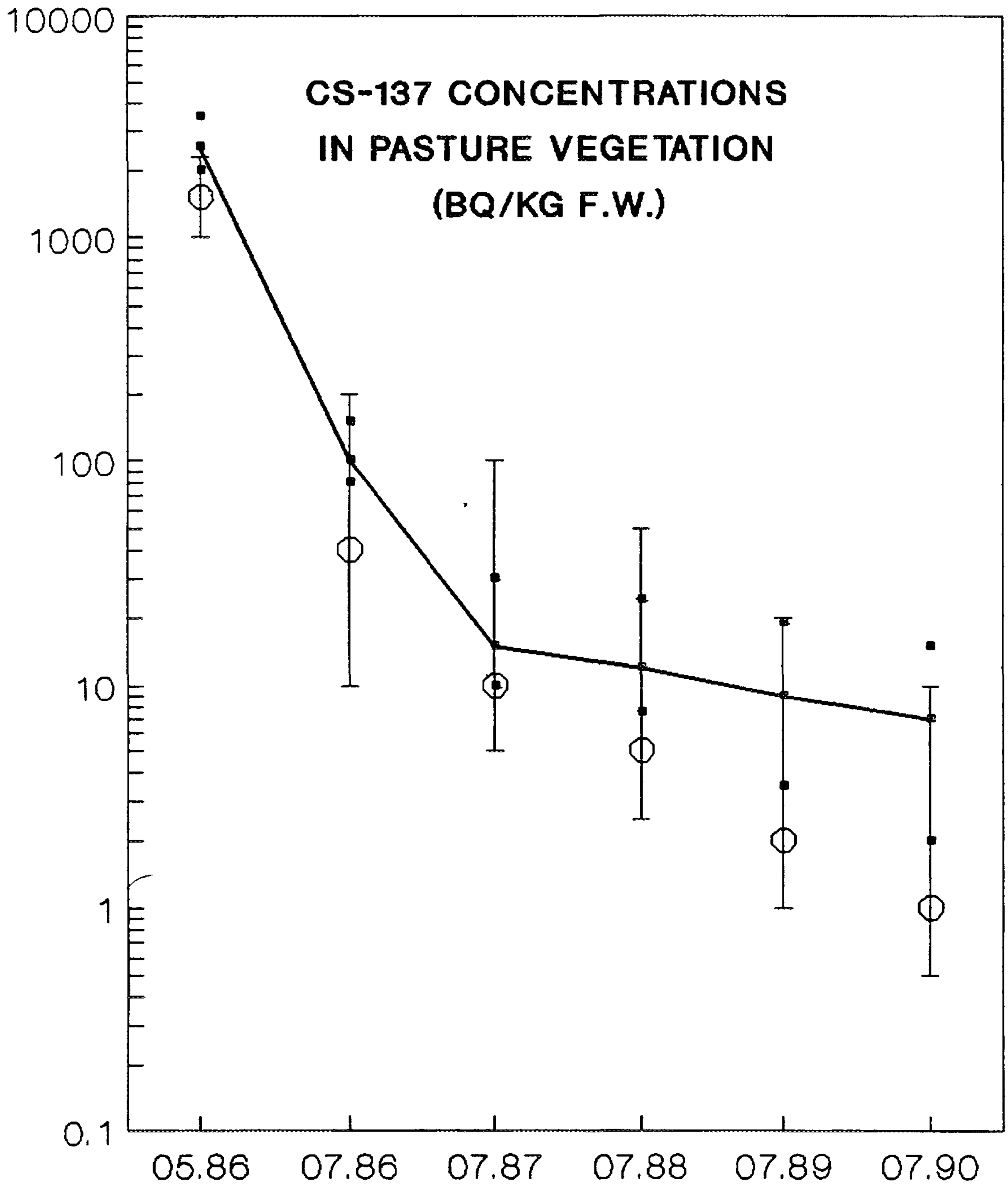
2.5.1. Total deposition

The total ^{137}Cs deposition (Bq/m^2) resulting from the Chernobyl accident was taken as the weighted average value for the entire area under study (from the soil sample measurement data). It was assumed that daily depositions were maximum on the first day (28 April 1986) and exponentially decreased on the subsequent days (up to 15 May 1986). Beginning on 15 May 1986 and to the end of the year, small residual depositions with constant intensity occurred.

2.5.2. Food items contributing to total diet

2.5.2.1. Animal feed - pasture vegetation

Radioactive contamination of grass was assumed to consist of external (surface) and internal contamination, the latter being due to root uptake from soil.



The coefficient (portion) of initial retention of radionuclides by grass, R was taken to be dependent on the grass biomass Y per unit area, in accordance with the following formula:

$$R = \frac{Y}{K + Y} \qquad (1)$$

where Y is the biomass, g/m^2; K is the coefficient of semi-saturation equal to the amount of biomass, at which R=0.5.

The seasonal biomass growth was calculated, using the differental equation:

$$\frac{dY}{dt} = a*SOL(t)*\exp(0.065*TEMP) - \epsilon*Y, \qquad (2)$$

where
SOL(t) is the daily energy of photosynthetically active solar radiation ($Kcal/cm^2*day$) at a given latitude (ϕ=66.6 ^{o}N), t is the time since the beginning of the year (days); exp(0.065*TEMP) reflects the acceleration of grass growth with increasing temperature (according to Arrhenius law); TEMP is the temperature, centigrade degrees; a is the growth coefficient for a given species of vegetation; ϵ is the cofficient of biomass loss under metabolism.

The beginning of grass growth is 1 April, and the time of the first mowing is the middle of June. The value of Y in the beginning of growth was taken to be 10 g/m^2, and during mowing Y=400g/m^2. From these conditions the values of a and ϵ were determined.

The total amount of radionuclide retained by grass (Bq/m^2) is given by the following equation:

$$\frac{dT_S}{dt} = D(t) * R(Y) - \lambda_w T_S - \lambda_r * T_S, \qquad (3)$$

where T_S is the amount of radionuclide retained at the surface of vegetation, Bq/m^2 (per unit area); D(t) is the intensity of depositions, Bq/m^2*day; λ_w is the coefficient of wash-off and blow-off of radionuclide from vegetation; λ_r is the coefficient of radioactive decay.

The surface contamination per unit biomass can be calculated as follows:

$$C_{xs}(t) = \frac{T_s'(t)}{Y(t)} \qquad (4)$$

The internal contamination of vegetation resulting from root uptake of radionuclides can be calculated by the equation:

$$\frac{dC_{in}}{dt} = \frac{\Delta Y}{Y} * (-C_{in} + C_s * B_{vx}) \qquad (5)$$

where C_{in} is the radionuclide concentration in biomass due to root uptake, Bq/kg; C_s is the radionuclide concentration in soil, Bq/kg; B_{vx} is the "soil-plant" transfer factor; $\Delta Y = a * SOL(t) * \exp(0.065 * TEMP)$
is the daily biomass synthesis, see Eq.(2).

The total radioactive contamination of vegetation is:

$$C_{xf}(t) = C_{xs}(t) + C_{xin}(t) \qquad (6)$$

Predictions of pasture contamination in 1987-1990 are strongly dependent on the intensity of soil decontamination. Annual decreasing in the concentration of available ^{137}Cs in soil may range from 10% to 50%.

2.5.2.2. Cereals

Average concentrations of ^{137}Cs in wheat and rye were calculated using the following soil-plant transfer factors: F = 0.02 Bq/kg f.w/(Bq/kg soil) for wheat and F = 0.015 for rye.

2.5.2.3. Milk and meat

The radioactive contamination of cow milk and beef can be given by the equations:

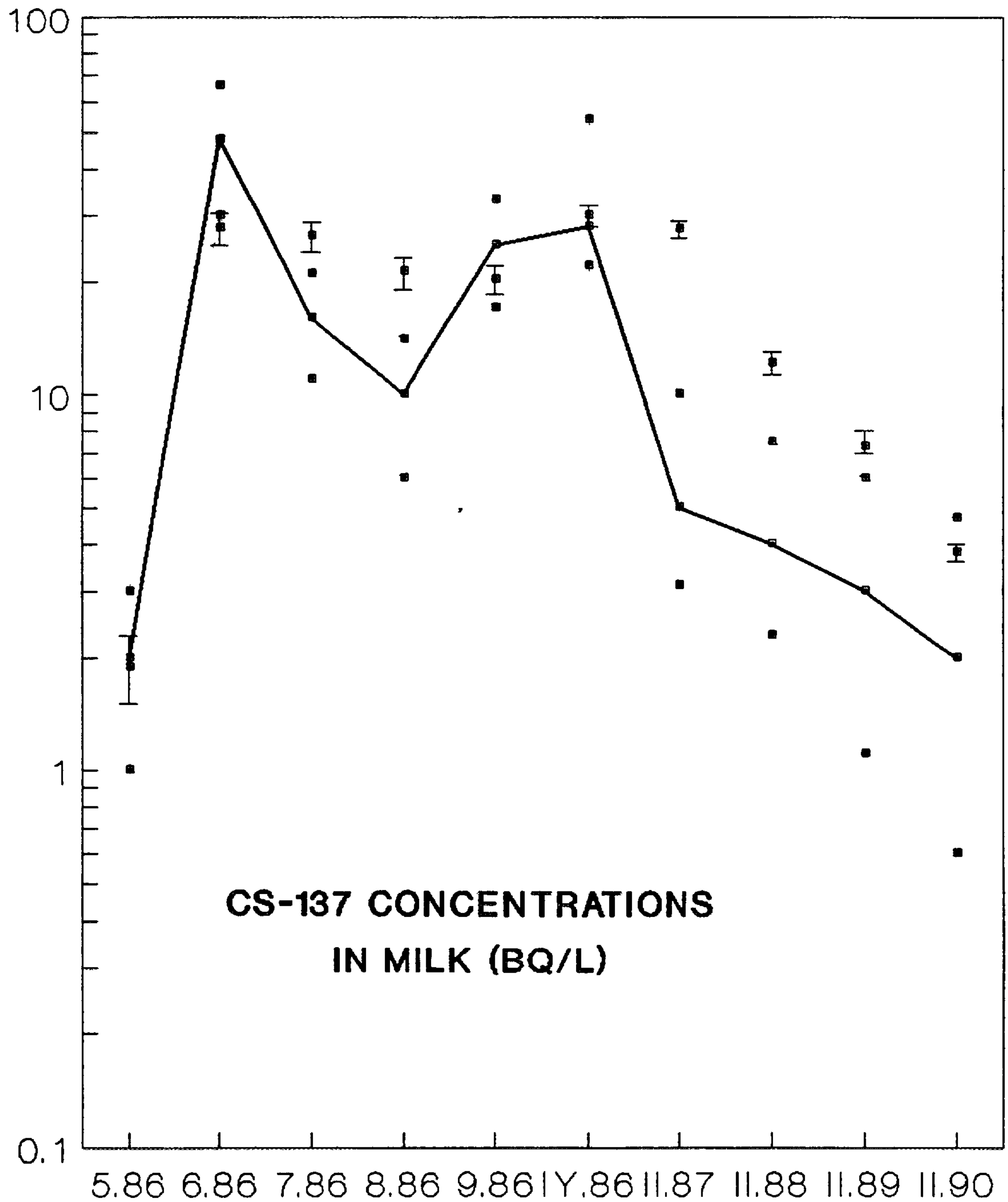
$$\frac{dC_b}{dt} = \frac{F_b * k * I_c(t)}{m_c} - \lambda_b * C_b \qquad (7)$$

$$\frac{dC_m}{dt} = \frac{F_m * k * I_c(t)}{m_m} - \lambda_m * C_m + \lambda_{mb} * C_b \qquad (8)$$

where C_b and C_m are the radionuclide concentrations in beef and milk, respectively, Bq/kg; $I_c(t)$ is the daily consumption of radionuclide by a cow; k is the coefficient of feed bioassimilation by a cow (k=0.2); F_b and F_m are the beef and milk partition coefficients of radionuclide ($F_b + F_m = 1$); m_c is the mass of a cow, kg; m_m is the daily milk production by a cow, kg/day; λ_b is the beef self-purification constant; λ_{bm} is the coefficient of radioactivity removal from beef through milk.For S scenario: F_m =0.4;m_m =10;λ_m =1; λ_{mb} =0.003

The daily radionuclide consumption by a cow in the outdoor period was calculated by the following formula:

$$I_c = C_{xf} * m_v + C_s * m_{si} \qquad (9)$$



where m_v is the daily consumption of grass, kg/day; m_{si} is the mass of soil swallowed in grazing (m_{si}=0.3 kg/d). For the indoor period, I_c was calculated on the basis of hay and silage rations.

The radioactive contamination of pork was calculated by the equation similar to Eq.(7).

2.5.2.4. Leafy vegetables

The dynamics of radioactive contamination of leafy vegetables (lettuce) was simulated by the same method as that of pasture vegetation (see Eq.1-4). The yield was taken to be 2 kg f.w./m^2. The vegetation period was from 1 May to 10 June. The soil-lettuce transfer coefficient was 0.004 Bq/kg f. w./(Bq/kg d.w.soil).

2.5.2.5. Wild, edible mushrooms and berries

For calculations with the scenario S we used the values of transfer factors known for the region of the Leningrad NPP located in similar climatic conditions (see Table 1).

Table 1

Coefficients of ^{137}Cs transfer to wild mushrooms and berries used in calculations with the scenario S (Bq/kg f.w./(Bq/m^2 soil))

Products	Years 1986	1987	1988	1989	1990	1991	1992
Mushrooms	0.12	0.032	0.07	0.027	0.022	0.019	0.002
Berries (Bilberry	0.009	0.008	0.004	0.01	0.01	0.01	0.009

2.5.2.6. Game

Estimates of game contamination with ^{137}Cs were made on the basis of experimental data on game in Sweden. The highest contamination of game meat with ^{137}Cs was detected two years after the Chernobyl accident. The maximum value of transfer factor was 0.0185 m^2/kg for big game and about 1.5 times higher for small game.

2.5.2.7. Freshwater fish

The radioactive contamination of fish was assessed using the accumulation factors in fish with respect to water.

For preliminary calculations we used the values of the factors known for the lakes in the region of the Leningrad NPP. These values turned out to be too low and gave underestimated model predictions. The values of the accumulation factors known for the lakes in Sweden (see Table 2) fit well and are in good agreement with the observed data in the scenario S.

Table 2

The factors of ^{137}Cs accumulation by freshwater (lake) fish used for calculations with the scenario S (refined values)

Fish	Years				
	1986	1987	1988	1989	1990
Predatory species	12250	34000	24000	23000	24000
Non-predatory species	4750	10000	6000	7000	6000
Intermediate species	7900	11250	7300	7700	6700

2.5.3. Human intake

The radionuclide intake with foodstuffs was calculated with the following formula:

$$C_{tot} = \Sigma x_i * m_i * t$$

where C_{tot} is the total radionuclide intake with food for the time t, Bq; x_i is the radionuclide concentration in a food product of the i-th kind, Bq/kg; m_i is the daily consumption ration of the food product of the i-th kind, kg/day; t is the time, days.

For the scenario S the values of radionuclide intake with food were calculated separately for men, women and children, taking into account the differences in their rations.

2.5.4. Dose calculations

2.5.4.1. External

The exposure dose from a cloud was calculated with the following formula:

$$D_c = E_c * C * t$$

where $E_c = 9.3 * 10^{-11}$ Sv*m^3/hr*Bq; C is the concentration of ^{137}Cs in the near-surface air, Bq/m^3; t is the time of the cloud passage, hrs. The maximum time of exposure could be 15 days and the minimum one 3 days.

The external exposure dose from soil was calculated with the following formula:

$$D_\gamma(t) = K * E_\gamma * C_s$$

where C_s is the density of soil contamination with ^{137}Cs, KBq/m^2; $E_\gamma = 1.3 * 10^{-12}$ Sv*m^2*hr^{-1}*Bq^{-1}; K is the factor of the radiation intensity reduction resulting from the radionuclide migration deep into the soil and shielding by buildings.

We used the following values of the factor K:

1986: K=0.24 for urban population and K = 0.46 for rural population;

1987-1990: K = 0.15 for urban population and K=0.27 for rural population.

2.5.5.2. Ingestion

The dose from ingestion of ^{137}Cs with foodstuffs was calculated with the following formula:

$$D_{ig}(t) = E_{ig} * C_{tot}(t)$$

where $E_{ig} = 1.4 * 10^{-8}$ Sv/Bq; C_{tot} is the human intake of ^{137}Cs for the period t.

2.5.5.3. Inhalation

The internal exposure dose from inhalation of radionuclide was calculated by the following formula:

$$D_{ih} = E_{ih} * C_t$$

where $E_{ih} = 8.6 * 10^{-9}$ Sv/Bq; C_t is the amount of radionuclide entered the organism through inhalation for the time t:

$$C_t = m * \int x(t) * dt$$

where x(t) is the radionuclide concentration in the air, Bq/m^3; m is the daily volume of the inhaled air, m^3/day; t is the time, days.

For adults m = 22 m^3/day; for children over 10, m = 15 m^3/day; for children under 1, m = 3.8 m^3/day.

4.EXPLANATION OF MAJOR SOURCES OF MISPREDICTION

4.1.Recommendations for changes to the model

The major part of mispredictions was connected with the lack of knowledge of real dynamics of soil contamination in the investigated region. For example, the observed data for pasture vegetation show 50% decrease in grass contamination every year,but in the same region data for wheat and rye give us only 20% decrease in radioactive contamination every year. Data on milk contamination which are strongly connected with grass contamination show again 20% decrease every year. Using of different assumptions about the dynamics of soil decontamination leads us to the uncertainty in milk contamination more than one order of magnitude.

4.2. Examples of how changes improved calculations

Figure show the dynamics of milk contamination with ^{137}Cs calculated with the assumption that annual decrease in soil and grass contamination is about 50%. As a result of this assumption the milk contamination for 1988-1990 is strongly underestimated. Figures show the revised dynamics of grass and milk contamination with ^{137}Cs calculated with the assumpion that annual decrease in soil contamination is 20%. The revised version is in good agreement with observed data for milk but grass contamination is now slightly underestimated.

5. SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

Calculations with Scenario S provide one a valuable experience in model prediction of accidental radioactive contamination of agricultural and natural food chains.

In most cases results obtained with ECOMOD model were in sufficiently good agreement with observed data and differed from them not more than half of order. The dynamics of foodstuff contamination during the first year after the accident was accurately described by sets of differential equations.

The "soil - plant" transfer factors seem to be "key" parameters responsible for the main part of uncertainty in model predictions of foodstuff contamination. The "water-fish" transfer factors play the same role for lake ecosystems. Values of these parameters may be very specific for certain area and differ from values known for nearest territories.

It is difficult to make long-term prognosis of foodstuff contamination without data on the real dynamics of soil and water decontamination. It would be very helpful to provide modellers with this information in the Input Data of the Scenario.

II.9. DETRA

1. MODEL DESCRIPTION AND EVALUATION OF MODEL PERFORMANCE

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2 MODEL DESCRIPTION

2.1 Name of model, model developer, model user

The numerical calculations have been performed employing the computer code DETRA [3] (*Doses via Environmental Transfer of Radionuclides*). The DETRA code has been originally developed by Dr. Ilkka Savolainen and Dr. Riitta Korhonen from VTT. The present user of the code is Vesa Suolanen.

The DETRA code employs a dynamic compartment approach. Except for the fish model [4], the conceptual models i.e. the compartment models to simulate the transfer of cesium via different pathways of Test Scenario S have been created by the user. Some dose calculations were performed by additional analytical equations.

2.2 Important model characteristics

2.2.1 Intended purpose of the model in radiation assessment

The computer code DETRA is a generic tool for environmental transfer analyses of radioactive or stable substances. The code has been applied for various purposes, mainly problems related to the biospheric transfer of radionuclides both in safety analyses of disposal of nuclear wastes and in consideration of foodchain exposure pathways in the analyses of off-site consequences of reactor accidents. For each specific application an individually tailored conceptual model can be developed. The biospheric transfer analyses performed by the code are typically carried out for terrestrial, aquatic and food chain applications.

2.2.2 Intended accuracy of the model prediction

The intended accuracy of the model predictions depends on the specific application, but in the type of analyses discussed in this report the intended accuracy is roughly within a factor of about 10, based on the estimation of uncertainty related to the conceptual models and to the input parameters.

2.2.3 Method used for deriving uncertainty estimates

The uncertainty estimates were derived based on simplified Monte Carlo type analyses for the most important parameters. Basically the model at present employs a deterministic approach.

2.2.4 Past experiences using this model

The total set of the conceptual sub-models applied in the context of this exercise was used for the first time. Past experiences of the sub-models have, however, shown in many cases harmonic temporal behaviour with the observed values available. Considerable experience has been gained in modelling pasture and aquatic environment while the metabolic models of domestic animals have been created recently.

I TEST SCENARIO S

The Multiple Pathways Assessment (MPA) Working Group aims to test models that predict doses to actual population groups living in contaminated environments. Therefore, the models may have to be capable of predicting doses arising from pathways related to different environments. Ingestion pathways related to terrestrial and aquatic environments, inhalation of contaminated air either directly or after resuspension, as well as external exposure from contaminated surfaces or from the radioactive discharge plume are included in the model predictions.

After the Chernobyl accident, suitable data sets for testing these models exist in several countries. The observed data provide the modellers an opportunity for testing their ability to predict the temporal behaviour of cesium concentrations in foodstuffs and in the bodies of human populations. The exercises in the MPA working group are being carried out as so-called 'blind-tests', i.e. the modellers receive a scenario description and are provided with the observation data only after their predictions have been submitted to the Secretariat.

Test Scenario S uses data from Finland [1]. The deposition area considered in Test Scenario S is presented in Fig. 1. The area of S includes fully the area of the highest deposition intensity measured in Finland after the Chernobyl accident. Fig. 2 presents the relative position of population areas (POP1, POP2, ..., POP9) and air sampling stations (AIR1, AIR2) given in the scenario description [1]. Furthermore, the relative positions of agricultural areas (AGR1, AGR2, ... , AGR17) and fish catchment areas (FISH1, FISH2, ..., FISH6) are presented in Figs. 3 and 4 [1].

The modelling tasks, predictions, and comparison of observed data vs predictions of Test Scenario S are presented in the following text of this report.

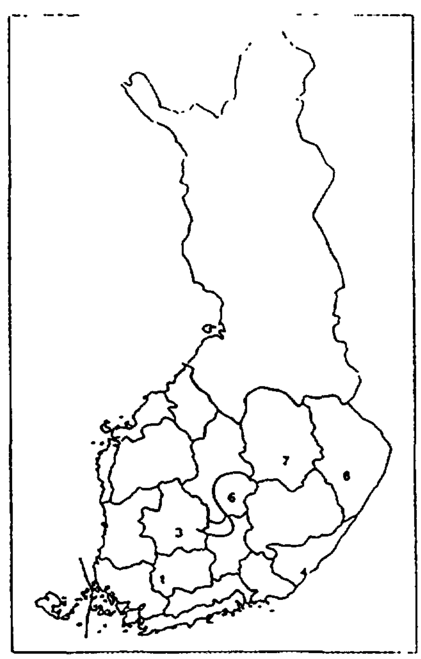


Fig. 1. Deposition area of Test Scenario S.

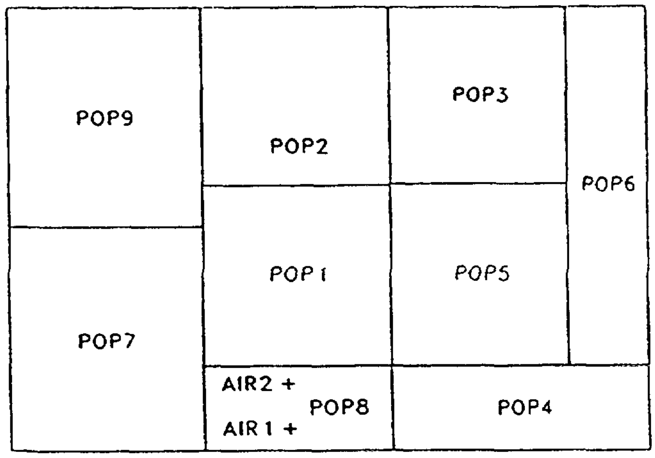


Fig. 2. Relative position of population areas (POP) and air sampling stations (AIR) [1].

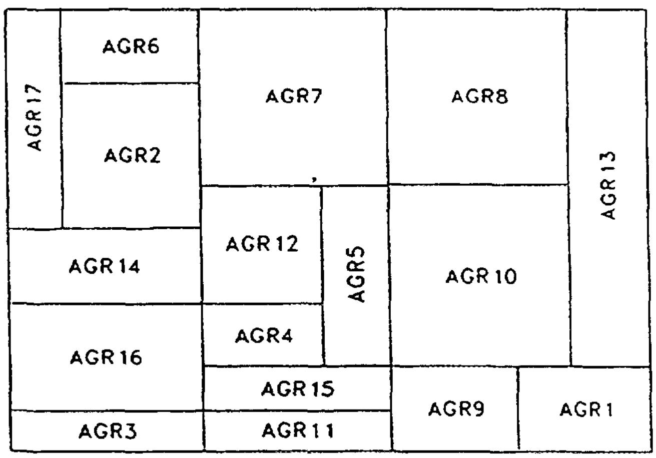


Fig. 3. Relative position of agricultural areas (AGR) [1].

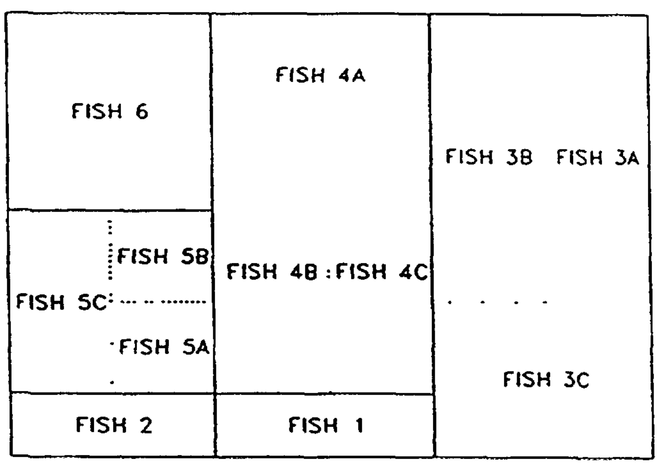


Fig. 4. Relative position of fish catchment areas (FISH) [1].

2.4 Model structure

Fig. 5. presents the structure of the compartment model used for pasture, grain and related pathways. The lines between each compartment describe the transfer of radionuclides from one compartment to another. A precondition for a reliable prediction of the contamination of milk, beef and pork is a successful modelling of the contamination of pasture and grain products. Simplified metabolic models for cows and pigs are used to estimate the accumulation of cesium in organisms of those animals.

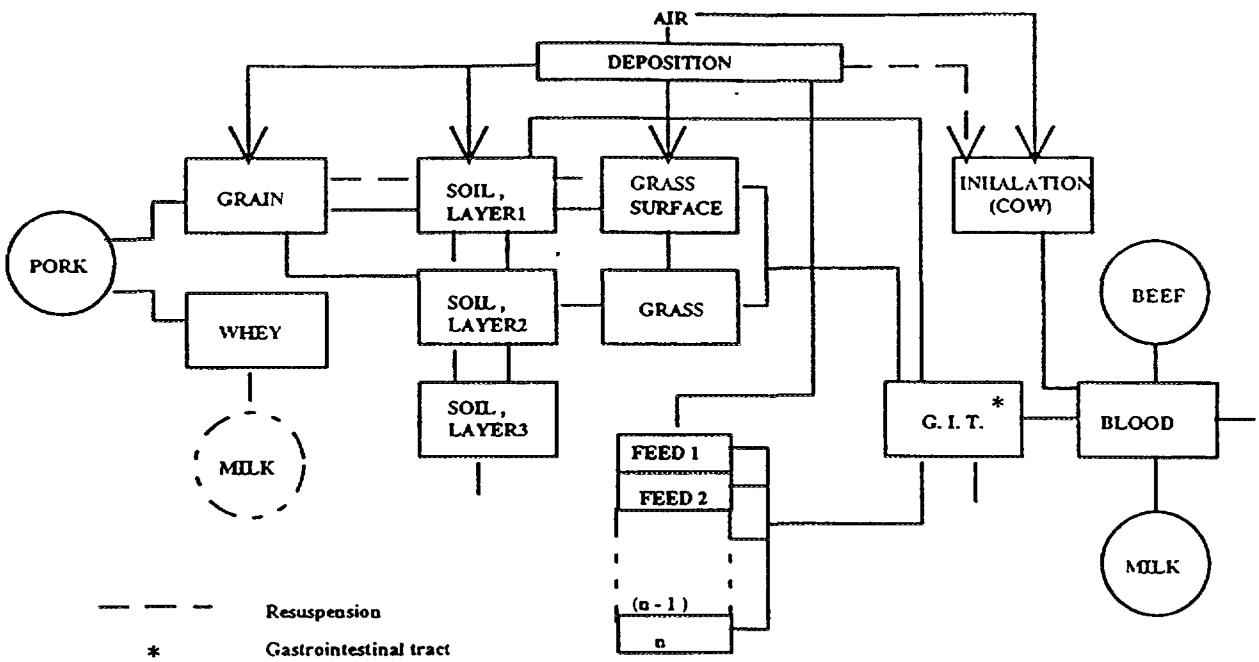


Fig. 5. The compartment model used for modelling pasture and related pathways.

Based on the description of scenario S, the beef cattle do not usually graze. Therefore, the consumption of soil particles of pasture was not considered in case of beef cattle. Additionally, the feed consumption rate for beef cattle is assumed to be one third of that for milk cattle [1].

The feed for pigs is assumed to consist mainly of mixed grain and a minor fraction (0.05) of the byproduct of milk, whey. The specific activity of cesium nuclides in whey is, however, higher by a factor of about 9.5 than for milk [5]. The activity inflow to pig organism might therefore be even higher via the consumption of contaminated whey than via the consumption of contaminated mixed grain.

Many uncertainty factors affect concentrations in animal products in the long term, such as contaminated soil particles which are sorbed on feed, changes in the solubility of elements, various agricultural practices, etc. The effect of these factors can approximately be considered e.g. with indirect methods such as assuming an additional, gradually decreasing fraction of contaminated material in the feed system of animals for some years after deposition.

The model used is based on sequential modelling approach by accounting multiple season sequences after deposition. The calculation procedure is based on realistic agricultural practices, i.e. modelling systematically the sequences of grazing periods and housed periods. The selective concentration values at the end of each grazing period are used as initial concentration values for the further calculation of the housed period and vice versa. According to the scenario description, the grazing period was assumed to start on the 10th of May and end on the 20th of September when the housed period starts.

2.5 Descriptions of procedures, equations and parameters used in different components of the model

2.5.1 Total deposition

The total deposition was calculated based on the measured deposition values of the sub-areas of Scenario S which were given in the scenario description [1]. By using the given deposition values and surface areas of the sub-areas, the mean total deposition value for the whole area of S is obtained as follows:

$$\bar{d}_S = \frac{1}{A_S} \cdot \sum d_i \cdot A_i$$

where

$\bar{d}_S$	is the mean total deposition over the area S, [Bq/m^2]
d_i	is the mean deposition of sub-area i, [Bq/m^2]
A_S	is the area of S, [m^2]
A_i	is the area of i, [m^2].

According to the scenario description, there were only a few measurement stations for collecting data for air concentrations. Because the area S is relatively large, it was decided to use the measured deposition values which are likely to give a more comprehensive and reliable picture of the deposition profile for the area S than an approach based on the use of air concentration. The calculated mean deposition value, based on measured values of sub-areas of area S, was assumed to be realistic for the purpose of further predictions of Scenario S. Reliable deposition values were also regarded as important considering prediction of the ingestion doses which were one of the main tasks of Scenario S. As a result, the mean deposition value, integrated over the whole area of Scenario S, was estimated to be 19.3 kBq/m^2.

The presented predicted concentration values of foodstuffs of Scenario S are weighted by deposition and by production values.

2.5.2 Foodstuffs contributing to total diet

2.5.2.1 Milk

The conceptual model employed is condensed in Fig. 5 above. The parameters and data are presented in Table I. Airborne ^{137}Cs was assumed to be deposited on grass, soil (and also on other crops such as grain, etc.). The time of the year in which the deposition of the Chernobyl release in the area S took place was late spring, end of April. At that time of the year and considering the milk model it was assumed that a fraction of 30 per cent of the deposited material was intercepted on the grass surface [6] and the rest of the material was assumed to have been deposited on soil surface. The interception factor between grass and deposited nuclides is directly proportional to the grass intensity on pasture [kg_{grass}/m^2], i.e. generally the leaf area of crops. The effective half-life of cesium on grass surface was assumed to be 25 days [7]. The loss rate of cesium from grass surface is affected by the intensities of rain and wind.

General method for prediction of the contamination level on the surface of grass or other leafy vegetation is given by:

$$A_{s,j}(t)=A_{s,j}(t_o)\cdot e^{-(\lambda_w+\lambda)\cdot t}$$

$$\lambda_w=\frac{ln2}{T_{½,w}}$$

$$\lambda=\frac{ln2}{T_{½}}$$

where

$A_{s,j}(t_o)$	is the initial surface activity on crop j, [Bq/m^2]
$A_{s,j}(t)$	is the temporal surface activity on crop j, [Bq/m^2]
λ_w	is the weathering loss-rate, [1/d]
λ	is the radioactive decay rate, [1/d]
$T_{1/2,w}$	is the weathering half-life, [d]
$T_{1/2}$	is the radioactive half-life, [d].

The model used accounts for the foliar uptake, but it was assumed to have only a minor effect when considering the transfer of cesium in the pasture system. The root uptake becomes relatively more important in the longterm. The resuspension of contaminated soil particles and their deposition on grass are modelled as well (see Fig. 5), although resuspension has in general only a minor effect on grass and milk contamination levels. In the case of Scenario S, the main contribution to the contamination of milk comes, however, from the effects of direct deposition.

The modelling approach of the milk model used is based on multiple season sequences. During the calculation, the grazing period and the housed period of cows are assumed to alternate in constant periods. Therefore, at the beginning of each calculation sequence, initialization of the concentrations in each relevant compartment is performed in the model.

The grazing period was assumed to start on 10th May and to end on 20th September, when the housed period of cows correspondingly starts [1]. Additionally, a grazing restriction up to the end of May was applied at the beginning of the calculation of Test Scenario S. Because the deposition occured at the end of April there was a period of one month during which the contamination level of grass decreased from the maximum value. By the time the cows were allowed to go on the pasture contamination level had therefore passed the maximum value. The real temporal behaviour of the contamination level of pasture was used in the calculation.

The assumed harvesting times of hay were 15th June, 15th July and the 15th of August, when the feed for the housed period was gathered. It was also assumed that for each harvesting time the yield is equal. The mean concentration value of feed can then be estimated based on the contamination levels of those three harvests.

In the longterm, many uncertainty factors such as contaminated soil in feed, changes in the solubility of elements, and matters related to agricultural practices affect the contamination level of milk and other domestic animal products. In order to account for these uncertainty factors and to apply a conservative modelling approach, it was assumed that the loss of contaminated material from the considered system will be delayed to some extent. Fig. 6 presents the assumed decrease in the amount of originally contaminated material in the feed of cows during the housed period after the deposition. The values employed for the fraction of contaminated material in feed in the years following the accident are based on a qualitative judgement and not on direct empirical observations.

Fraction of contaminated material in feed

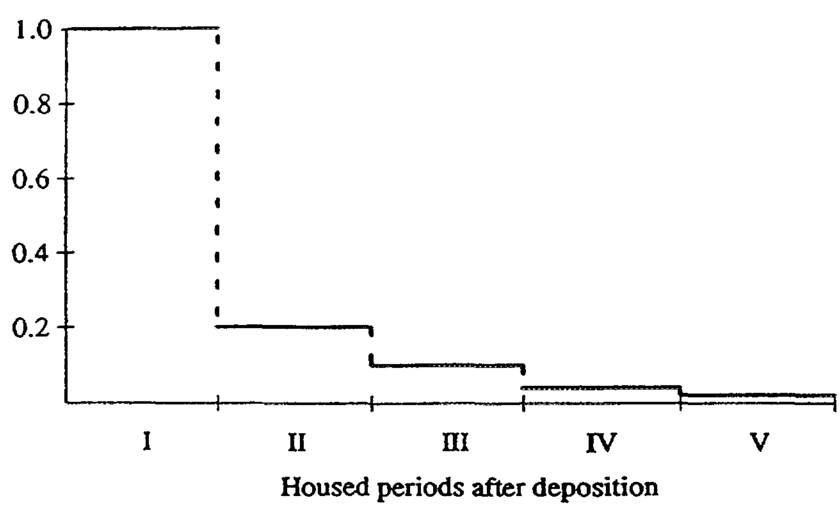


Fig. 6. The assumed amount of originally contaminated material in feed of cows during the housed periods after the deposition.

Besides being radiologically a very important foodstuff in itself, milk contributes to contamination levels in other foodstuffs such as pork. This is due to the fact that whey, a byproduct of milk, is used as feed for pigs. This question will be discussed in more detail in the context of pork. Additionally, the temporal behaviour of the contamination of beef is qualitatively closely related to the contamination of milk. The essential differences between milk and beef consist of different infiltration factors and metabolic time constants related to those foodstuffs.

Table I Data used in the pasture and milk models.

	Reference[1)]	General data of the model	Data for ^{137}Cs nuclide
PASTURE MODEL			
- grass intensity on pasture, $[kg_{d.w.}/m^2]$	[8]	0.45	
- grass interception factor for deposition	[6]		0.30
- initial fraction of soil sorbed on the grass surface[2)], [per cent of dry weight of grass]	[9]	4 ($T_{1/2}$ = 1 a)	
- radioactive half-life of nuclide, [a]			30
- effective half-life of cesium on grass surface, [d]	[7]		25
- soil to grass concentration factor, $[Bq/kg_{f.w.}]/[Bq/kg_{soil}]$	[10]		$2 \cdot 10^{-2}$
- absorption factor from grass surface into grass, $[d^{-1}]$	[11]		$2 \cdot 10^{-3}$
- soil layer[3)] 1: [cm]		0 -> 1	
- soil layer[3)] 2: [cm]		1 -> 5	
- soil layer[3)] 3: [cm]		5 -> 10	
- density of soil[3)], $[kg/m^3_{soil}]$		1650	
· water, $[kg_w/m^3_{soil}]$		300	
· solid matter, $[kg_s/m^3_{soil}]$		1350	
- distribution coefficient K_d, [liter/kg]	[12]		$1 \cdot 10^3$
- average rain intensity, [mm/d]	[13]	1.8	
- evaporation, [per cent of rain intensity]	[13]	45	
HOUSED PERIOD MODEL			
- assumed harvesting times in feed production:		15th June 15th July 15th August	
MILK CATTLE DATA			
- grass consumed by cow, $[kg_{f.w.}/d]$	[1]	50	
- soil consumed by cow during grazing, $[kg_s/d]$	[9]	2	
- average milk production of cow, [liter/cow/year]	[1]	4900	

1) Reference which is used directly or from which the data used in this study is derived.

2) The half-life for fraction of soil contamination on grass surface is assumed to be one year [14]. The used value for half-life is based on observed temporal behaviour of resuspension after deposition in the Nordic environment.

3) The data used is based on previous experience of environmental modelling and on review of literature.

2.5.2.2 Beef

The calculation method applied to predict the activity content in beef is presented above in Fig. 5. The additional data used are presented in Table II, other necessary data used to calculate the contamination level of beef were presented earlier in Table I. The calculation method for beef is very similar to the calculation method for the milk component. The reason for that is the similarity of the metabolism of the animal in the two cases. There are significant differences, however, in the metabolic infiltration factors and in the time constants needed to reach the steady state between the source term (i.e. the activity intake) and the contamination of the considered foodstuff. The time constant related to the contamination of beef is much larger than the time constant for milk. The biological half-life used for cesium in beef is 40 days [15]. Qualitatively the temporal behaviour of concentrations of cesium in beef and milk is of similar form, but the concentration curve of beef has a smoother tendency than the concentration curve of milk. The reasons for this were discussed above.

The consumption rate for feed beef cattle is lower than that for cows, because of the lower requirements of nutriments for beef cattle. The mean consumption rate used for grass for beef cattle is 17 $kg_{f.w.}/d$.

Table II *Data used in the beef model.*

	Reference[1)]	General data of the model	Data for ^{137}Cs nuclide
BEEF CATTLE DATA			
- grass eaten by beef cattle, [$kg_{f.w.}/d$]	[1]	17	
- biological half-life $T_{1/2b}$ in beef, [d]	[15]		40

1) Reference which is used directly or from which the data used in this study is derived.

2.5.2.3 Pork

The calculation method applied to predict the activity concentration in pork is presented above in Fig. 5. Some cereals data related to the pork model are presented in Table VIII, the other data of the pork model are presented in Table III.

The pig feed consists mainly of mixed grain feed [1], about 90 per cent, and the rest is assumed to be supplementary feed such as whey. Because the cesium activity concentration in dried whey is about 9.5 times higher than cesium concentration in dried milk [5], whey forms a very significant activity flux into the pig organism. Occasionally, activity flux via whey might be even higher than via intake of grain feeds.

A prerequisite for a successful prediction of the contamination level in pork is a sufficient accuracy of predictions of the contamination levels of grain and milk products which are used as pig feed. The modelling approach of grain is to a large extent of the same type as in the case of grass, although the interception properties and the derived interception factors of grass and grain differ.

The biological half-life of cesium in pork is assumed to be 18 days [15].

Table III *Data used in the pork model[1)].*

	Reference[2)]	General data of the model	Data for ^{137}Cs nuclide
DATA RELATED TO PIGS			
- mixed grain feed eaten by pigs, [kg/d]	[5]	1.5	
- whey eaten by pigs, [kg/d]	[5]	0.15	
- ingestion transfer factor, [d/kg]	[15]		$2.6 \cdot 10^{-1}$
- biological half-life $T_{1/2b}$ in pork, [d]	[15]		18

1) See also Table VIII, the cereals model.
2) Reference which is used directly or from which the data used in this study is derived.

2.5.2.4 Game

The activity concentration in game meat is proportional to the activity concentration in the forest soil. The concentration of cesium in game has been estimated by applying the following equations:

For summer and autumn ($t_o \leq t \leq t_1$):

$$C_{game}(t) = C_s(t) \cdot c_v \cdot J_v \cdot f_g \cdot (1 - e^{-\frac{\ln 2}{T_{½,b}} \cdot (t - t_o)})$$

For winter ($t_1 < t < t_o$):

$$C_{game}(t) = C_{game}(t_1) \cdot e^{-\frac{\ln 2}{T_{½,b}} \cdot (t - t_1)}$$

where

C_{game}	is the concentration of cesium in game meat, [Bq/kg]
C_s	is the concentration in forest soil, [Bq/kg$_{f.w.}$]
c_v	is the forest soil to forest vegetation concentration factor
J_v	is the consumption rate of vegetation by the game animal, [kg/d]
f_g	is the ingestion transfer factor of the game animal, [d/kg]
$T_{1/2,b}$	is the biological half-life of cesium in game, [d]
t_o	is the time point of 1 May
t_1	is the time point of 31 December.

According to analyses performed by the soil model, the cesium activity concentration in forest soil decreases slowly. In the case of ^{137}Cs the decrease rate of the activity level in forest soil is about five per cent per year. Thus the decrease of the activity concentration in game meat will also be relatively slow. The diet of game is different according to the season. During the winter the diet of game includes probably less contaminated material which tends to decrease the cesium concentration in game.

The data used in the game model are presented in Table IV.

Table IV *The data used in the game model.*

	General data of the model	Data for ^{137}Cs nuclide and consumption rates:	
		Big game	*Small game*
GAME			
- ingestion transfer factor[1], [d/kg]		$4 \cdot 10^{-2}$	$9 \cdot 10^{-2}$
- biological half-life[1], [d]		40	30
- eff. soil to forest vegetation transfer factor[2], $[Bq/kg_{f.w.}]/[Bq/kg_{forest\ soil}]$	0.5		
- consumption rates of vegetation[1], $[kg_{f.w}/d]$		9	2

1) See explanation 3) under Table I.
2) Includes all kinds of vegetation, such the contaminated organic material in the top layer of forest soil, mushrooms, etc.

2.5.2.5 Wild berries

The activity concentration in wild berries, such as blueberry and lingonberry, is proportional to the activity concentration in forest soil. Therefore, the prediction of the cesium concentrations in wild berries was based on dynamic calculation of the surface activity concentration in forest soil (up to 1.5 centimeters depth in soil) after the deposition. Subsequently, the concentration factor method was applied to calculate the concentrations in berries at harvesting times based on forest soil concentrations. The activity concentration in soil was calculated with a compartment model, as shown above in Fig. 5, to simulate the vertical migration of cesium nuclides in the forest soil. The data used are presented in Table V. The soil to berries transfer factor represents a mean value applied for various types of berries.

Table V *Data used in the wild berries model.*

	General data of the model	Data for ^{137}Cs nuclide
WILD BERRIES		
- soil to berries transfer factor[1], $[Bq/kg_{f.w.,berry}]/[Bq/kg_{forest\ soil}]$		0.1
- harvesting time	31st August	

1) See explanation 3) under Table I.

2.5.2.6 Mushrooms

As in the case of wild berries, the activity concentration in mushrooms is also proportional to the activity concentration in the forest soil. The mushrooms grow out of a so-called mycelium which spreads out widely in the soil. The mycelium increases the transfer of radionuclides from the soil to the mushrooms, because the contact surface area for infiltration is remarkably larger. Also, in the case of Scenario S, the mushrooms had to penetrate the contaminated soil surface and thereby interact with soil particles. It is easy to see that the contaminated soil particles will, to some extent, be sorbed on the surface of the mushrooms. Considering the circumstances mentioned above, it was concluded to increase the concentration effect and concentration factors compared to wild berries. Otherwise, the modelling approach for mushrooms is of the same type as for wild berries. The data used are presented in Table VI.

Table VI *Data used in the mushrooms model.*

	General data of the model	Data for ^{137}Cs nuclide
MUSHROOMS		
- soil to mushrooms transfer factor[1)], $[Bq/kg_{f.w.,mushroom}]/[Bq/kg_{forest\ soil}]$		0.5
- harvesting time	15th October	

1) See explanation 3) under Table I and the text above.

2.5.2.7 Leafy vegetables

According to the information given in Scenario S description, most of the leafy vegetables are grown in greenhouses. Therefore, the average deposition value of area S has to be reduced in order to obtain a realistic value of deposition on leafy vegetables in greenhouses. The reduction of the activity content of air in greenhouses is caused by infiltration from the atmosphere into the greenhouses. The phenomena which accounted for the contamination of leafy vegetables were deposition and resuspension during the first summer and autumn seasons, and only resuspension thereafter.

After the assumed deposition on leafy vegetables, the loss of radionuclides from the surface of leafy vegetables is traditionally calculated by applying a given half-life. The data used for leafy vegetables are presented in Table VII.

2.5.2.8 Cereals

The conceptual calculation method used is presented in Fig. 5 above. The essential data in the prediction of the contamination level of cereals is the initial interception factor between cereals and the deposited radionuclides on the one hand, and the effective loss rate of nuclides from the surface of cereals in the later phase on the other. Table VIII presents the used data.

After ploughing, the soil contamination level is recalculated, based on the concentration profile of the soil before ploughing.

Table VII Data used in the leafy vegetables model.

	Reference[1)]	General data of the model	Data for ^{137}Cs nuclide
LEAFY VEGETABLES			
- yield, [$kg_{f.w.}/m^2$]	[8]	1	
- soil contamination on surface of leafy vegetables, [per cent of dry weight of vegetable]	[9]	0.01	
- effective half-life of cesium on surface of leafy vegetable, [d]	[7]		30
- infiltration factor for greenhouses[2)]			0.05
- interception factor[3)]			0.3

1) Reference which is used directly or from which the data used in this study is derived.
2) Educated guess based on the sealing properties of greenhouses.
3) Effective interception factor applied in the case of greenhouses is: interception factor · infiltration factor = 0.3 · 0.05 = 0.02

Table VIII The data used in the cereals model.

	Reference[1)]	General data of the model	Data for ^{137}Cs nuclide
CEREALS			
- yield, [$kg_{d.w.}/m^2$]	[8]	0.4	
- interception factor (grain):	[16]		0.05 (rye[2)]) 0.005 (others)
- initial fraction of soil on surface of cereals, [per cent of dry weight of grain]	[9]	0.01	
- effective weathering half-life, [d]	[7]		32
- harvesting time:			15th August
- soil to cereals transfer factor, [$Bq/kg_{f.w}$]/[Bq/kg_{soil}]	[10]		$1 \cdot 10^{-2}$

1) Reference which is used directly or from which the data used in this study is derived.
2) The interception factor of rye accounts for the additional contamination effect of soil particles which were assumed to be sorbed on winter rye when rye penetrated the contaminated soil layer in the spring. Cesium was assumed to be transfered into cereals by translocation and by root uptake.

2.5.2.9 Fish

The method of predicting the contamination of freshwater fish in area S is based on the utilization of three selected lake size classes, three selected environmental sorption classes and on the dynamic fish model for non-predatory, intermediate and predatory fish types. The compartment structure of the fish model is presented in Fig. 7 below. Detailed information on this type of a dynamic fish model is given in ref. [4].

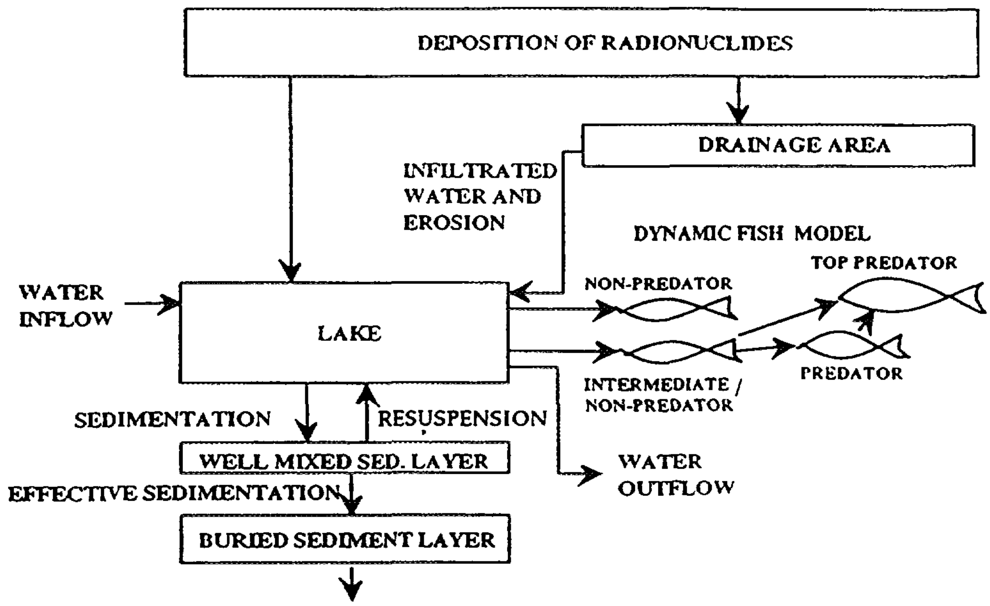


Fig. 7. The compartment model used for fish and related pathways.

The characteristics of different selected sizes of lakes are presented in Table IX. The selection of lake size classes is based on information given in the scenario description [1]. The dilution property of a lake, i.e. lake volume multiplied by the water exchange rate, is an essential factor when predicting not only the contamination of lake water but also the contamination of various fish types. Additionally, the sorption properties related to the considered aquatic environment affect the concentration of radionuclides in fish.

The deposition area of S was divided into six fishing areas which have different areal occurrence probabilities of lake sizes. The occurrence probabilities of different selected lake sizes and mean areal deposition values in different fishing areas are presented in Table X. The selection of occurrence probabilities of lakes sizes is based on a rough investigation of areal maps available of the area S.

In the first phase of the calculation procedure, the mean concentration values of different fish types (non-predatory, intermediate and predatory) of sub-areas (FISH1, FISH2, ..., FISH6) [1] were determinated as a function of time. In the second phase, the results of the sub-areas were integrated to obtain the mean fish concentrations of the whole area S.

Table IX The characteristics of the used lake types.

Lake surface area, [km^2]	Effective drainage area, [km^2]	Mean depth of lake, [m]	Suspended sediment load of lake and sedim. rate [kg_s/m^3] or ($kg_s/m^2/a$)	Water exchange rate, [1/a]	Sorption distribution coefficient, [Bq/kg_s]/[$Bq/liter_w$] class 1[1)]	class 2[2)]	class 3[3)]
1	2	2.5	$1.5 \cdot 10^{-3}$ (0.5)	2	$1.1 \cdot 10^3$	$1 \cdot 10^3$	$9 \cdot 10^2$
100	300	5	$1 \cdot 10^{-3}$ (0.2)	1	$1.1 \cdot 10^3$	$1 \cdot 10^3$	$9 \cdot 10^2$
1000	1000	7	$1 \cdot 10^{-3}$ (0.2)	1	$1.1 \cdot 10^3$	$1 \cdot 10^3$	$9 \cdot 10^2$

1) Fishing areas [1]: FISH1, FISH2, FISH5, FISH6
2) Fishing areas [1]: FISH4
3) Fishing areas [1]: FISH3

Table X The occurrence probabilities of different lake sizes of area S and the mean deposition rates in fishing areas FISH1 to FISH6.

Fishing area	Occurrence probabilities, Lake area, [km^2] 1	100	1000	Mean deposition of ^{137}Cs [1], [kBq/m^2]
FISH1	0.6	0.4	0	14.0
FISH2	0.6	0.4	0	12.2
FISH3	0.1	0.5	0.4	6.7
FISH4	0.02	0.08	0.9	30.7
FISH5	0.3	0.5	0.2	31.8
FISH6	0.5	0.5	0	15.3

2.5.3 Human intake

The human intake is given as follows:

$$U_{f,HB}(t) = J_f \cdot C_f(t)$$

where

$U_{f,HB}(t)$	is the intake rate of activity of human, [Bq/d]
J_f	is the consumption rate of foodstuff, [kg/d]
$C_f(t)$	is the concentration in foodstuff, [Bq/kg].

The typical consumption rates of foodstuffs of the population living in area S, were given in the scenario description [1]. Because of the relatively high deposition values it was felt reasonable to give some recommendations of the consumption rates of some important foodstuffs, such as freshwater fish, by the authorities responsible for radiation safety in area S. Additionally, when predicting the ingestion doses of area S, it was assumed that people will voluntarily reduce temporarily the consumption rates of some foodstuffs. The typical consumption rates and the assumed reduction of consumption rates after deposition are presented in Table XI. The calculation results of area S are based on reduced consumption rates. A reduction of cesium concentrations by decontamination is applied for cereals, vegetables and mushrooms. The decontamination methods generally used for leafy vegetables and mushrooms are washing and boiling. In the case of cereals, the husks can be removed from the grains.

2.5.4 Whole body concentrations

2.5.4.1 Mean whole body concentrations

The prediction of the body burden of human is based on the utilization of the biological half-lives which are known for cesium in the body and on single compartment approximation for the human body. The data used are presented in Table XII. The biological half-lives presented in Table XII are shorter than those proposed by the ICRP. The data for biological half-lives used in this study reflect the studies of whole body contamination measurements performed in Finland [17,18]. The intake rates [Bq/d] described above were used as source-term in the body model. The body masses used for child and female in this study are probably overestimated.

2.5.4.2 Distribution of whole body concentrations (man)

The uncertainty in the input data was studied with the model by performing several computer runs for the considered scenario. At the beginning of each run, a new set of input data was casted from the input data distributions. The cumulative and complementary cumulative probability distribution function (CCDF) was satisfactorily reached after about 30 computer runs. Furthermore, the uncertainty bounds corresponding to 0.95 probabilities were determined for the distributions of the whole body concentrations.

Analyses performed earlier indicated that the uncertainty in predictions for body burdens are contributed mostly by just a few important dose pathways, such as milk. The parameter values of the input data distribution of the milk pathway are presented in Table XIII.

Table XI *The consumption rates of foodstuffs [1].*

Food-stuff	Type of human	Mean consumption rate, [g/d]	Estimated reduction of consumption rates, [per cent of mean consumption rate]				
			1986	1987	1988	1989	1990
MILK[1]	male	940	30	20	10	0	0
	female	636	30	25	15	5	0
	child (10 yr)	766	20	15	10	0	0
BEEF	male	64	10	0	0	0	0
	female	49	10	0	0	0	0
	child	39	5	0	0	0	0
PORK	male	88	10	0	0	0	0
	female	54	10	0	0	0	0
	child	37	5	0	0	0	0
FISH	male	15	35	25	20	5	0
	female	10	35	25	20	5	0
	child	5	30	20	15	0	0
SMALL GAME	male	0.4	25	10	5	0	0
	female	0.3	25	10	5	0	0
	child	0.2	25	10	5	0	0
BIG GAME	male	3.8	25	10	5	0	0
	female	3.1	25	10	5	0	0
	child	2.1	25	10	5	0	0
RYE[2]	male	58	0	0	0	0	0
	female	42	0	0	0	0	0
	child	32	0	0	0	0	0
WHEAT[2]	male	135	0	0	0	0	0
	female	109	0	0	0	0	0
	child	115	0	0	0	0	0
OAT[2]	male	38	0	0	0	0	0
	female	28	0	0	0	0	0
	child	32	0	0	0	0	0
VEGETABLES[2]	male	35	5	0	0	0	0
	female	45	5	0	0	0	0
	child	96	5	0	0	0	0
WILD BERRIES	male	9	30	15	0	0	0
	female	9	30	15	0	0	0
	child	9	30	15	0	0	0
MUSHROOMS[2]	male	3.6	35	20	10	0	0
	female	3.6	35	20	10	0	0
	child	2.5	35	20	10	0	0

1) Includes the consumption of cheese.
2) Reduction factor by decontamination: 0.1 for cereals and 0.3 for vegetables and mushrooms.

Table XII Data used in the body model.

	Child 10 year	Female	Male
BODY MODEL			
- biological half-life $T_{1/2b}$ for cesium, [d]	50	85	90
- body mass, [kg]	45	65	75

Table XIII The input data applied in uncertainty analyses of milk pathway.

Parameter	μ	min	max
- interception factor	0.3	0.1	0.9
- effective half-life from grass surface, [d]	25	8.3	75
- distribution coefficient in soil, K_d, [liter/kg]	1000	300	10000

2.5.5 Dose calculations

2.5.5.1 External

The prediction approach of external dose from ground is similar to Gale's formula [19]. The mean external dose from contaminated *ground* is given as follows:

$$H_{ext,g}(t)=(\alpha_{t,s}\cdot(f_{MS}\cdot s_{s,MS}+f_{SF}\cdot s_{s,SF})+(1-\alpha_{t,s})\cdot s_{s,out})\cdot d_g\cdot DF\cdot\int(\xi\cdot e^{-(\mu_1+\lambda)\cdot t}+(1-\xi)\cdot e^{-(\mu_2+\lambda)\cdot t})dt$$

where

$H_{ext,g}(t)$	is the individual dose from external exposure from ground, [Sv]
$\alpha_{t,s}$	is the fraction of time spent inside
f_{MS}	is the fraction of population living in multi-storey buildings
f_{SF}	is the fraction of population living in single-family houses
$s_{s,MS}$	is the location factor of multi-storey buildings
$s_{s,SF}$	is the location factor of single-family houses
$s_{s,out}$	is the location factor outside
d_g	is the total deposition on ground, [Bq/m^2]
DF	is the dose conversion factor, [Sv/a]/[Bq/m^2]
ξ	is the fraction of the fast migration component
μ_1	is the removal rate constant of the fast migration, [1/a]
μ_2	is the removal rate constant of the long-term migration, [1/a]
λ	is the radioactive decay rate, [1/a].

The mean external dose from *plume* is given as follows:

$$H_{ext,c}(t)=\frac{\zeta_{POP8}+\zeta_{OTHER}\cdot 0.02^{*}}{\zeta_{ALL}}\cdot(\alpha_{t,s}\cdot(f_{MS}\cdot s_{s,MS}+f_{SF}\cdot s_{s,SF})+(1-\alpha_{t,s})\cdot s_{s,out})\cdot g_{\gamma}\cdot\int C_{a,POP8}(t)dt$$

where

$H_{ext,c}(t)$	is the dose from external exposure from plume, [Sv]
g_{γ}	is the external dose conversion factor, [Sv/h]/[Bq/m^3]
ζ_{POP8}	is the population of sub-area POP8
ζ_{OTHER}	is the total population of other sub-areas than POP8
ζ_{ALL}	is the population of the whole area S
$C_{a,POP8}(t)$	is the cesium concentration in air of POP8, [Bq/m^3].

* Measurements of total activity in air from ten stations of another monitoring network showed significantly lower concentrations outside the subarea POP8 and the southern half of POP7 than at stations AIR1 and AIR2. During 27.4.–1.5.1986, the total activities in air at stations in the subareas *did not exceed 2%* of those measured at AIR2 [1].

The data for external dose calculations are presented in Table XIV.

Table XIV Data used in the external dose models.

	Reference	General data of the model	Data for ^{137}Cs nuclide
EXTERNAL DOSE FROM GROUND			
- fraction of time spent inside		0.95	
- fraction of population living in multi-storey buildings		0.5	
- fraction of population living in single-family houses		0.5	
- location factor[1)] of multi-storey buildings	[21]		0.05
- location factor of single-family houses	[21]		0.5
- dose conversion factor[2)], [Sv/a]/[Bq/m^2]	[1]		$1.1 \cdot 10^{-8}$
- fraction of the fast migration component	[20]		0.63
- removal rate constant of the fast migration, [1/a]	[20]		1.13
- removal rate constant of the long-term migration, [1/a]	[20]		0.0075
EXTERNAL DOSE FROM PLUME			
- dose conversion factor, [Sv/a]/[Bq/m^3]	[1]		$8.1 \cdot 10^{-7}$
- shielding factor of multi-storey buildings	[21]		0.2
- shielding factor of single-family houses	[21]		0.5

1) Location factor accounts for the modification of the reference dose rate at different locations [21].

2) Includes shielding caused by roughness of terrain.

The variation of location factors is large, depending on the types of buildings and also on the living habits of the population exposed to external radiation. Recent research work [21] concerning location factors in the Nordic countries proposes the following variation of location factors applicable for Finland for external exposure from ground: 0.01–0.05 for multi-storey buildings, 0.04–1 for single-family houses. The proposed shielding factors in the case of external exposure from plume are: 0.016–0.33 for multi-storey buildings, 0.27–0.52 for single-family houses. The recent studies, carried out in Finland, support also the values of location and shielding factors presented above.

2.5.5.2 Ingestion

The individual ingestion dose is given as:

$$H_{ing,HB}(t) = d_i \cdot J_f \cdot \int C_f(t)dt$$

where

$H_{ing,HB}(t)$	is the individual ingestion dose, [Sv]
$C_f(t)$	is the concentration in a foodstuff, [Bq/kg]
J_f	is the consumption rate of a foodstuff, [kg/a]
d_i	is the ingestion dose conversion factor, [Sv/Bq].

The total ingestion dose will be obtained by summing up the dose contributions from all the considered foodstuffs. The consumption rates of foodstuffs and ingestion dose conversion factor ($1.4 \cdot 10^{-8}$ Sv/Bq) of ^{137}Cs were given in the scenario description [1]. However, as discussed earlier in chapter 2.5.3, the consumption rates of some foodstuffs by humans were reduced to some extent during the first two to three years after deposition.

2.5.5.3 Inhalation

The mean inhalation dose arising from *resuspended material* in air is given as follows:

$$H_{a,r}(t) = \alpha_{t,out} \cdot J_I \cdot \vartheta \cdot d_I \cdot \int C_s(t)dt$$

where

$H_{a,r}(t)$	is the mean inhalation dose from resuspension to individual, [Sv]
$\alpha_{t,out}$	is the fraction of time spent outside
J_I	is the inhalation rate, [m_a^3/h]
ϑ	is the soil concentration in air, [kg/m_a^3]
d_I	is the inhalation dose conversion factor, [Sv/Bq]
$C_s(t)$	is the activity concentration in soil, [Bq/kg].

The temporal behaviour of the activity concentration of cesium in soil $C_s(t)$ is predicted based on the compartment model approach as presented in Fig. 5 above. Taking into account the soil concentration in air ϑ (see Table XV) and the calculated activity concentration in soil, the initial resuspension factor was derived to be about $7 \cdot 10^{-8}$ 1/m. This resuspension value is relevant looking at the observed resuspension values for the Nordic environment as presented in ref. [14]. In the longterm, the decrease of the resuspension factor is proportional to the decrease of activity concentration in the top soil layer.

The mean inhalation dose arising from the original radioactive *plume* is given as follows:

$$H_{a,c}(t) = \frac{\zeta_{POP8} + \zeta_{OTHER} \cdot 0.02^{*}}{\zeta_{ALL}} \cdot d_I \cdot J_I \cdot \int C_{a,POP8}(t)dt$$

where

$H_{a,c}(t)$	is the mean inhalation dose from plume to individual, [Sv]
ζ_{POP8}	is the population of sub-area 8
ζ_{OTHER}	is the total population of other sub-areas than 8
ζ_{ALL}	is the population of the whole area S
d_I	is the inhalation dose conversion factor, [Sv/Bq]
J_I	is the inhalation rate, [m^3/h]
$C_{a,POP8}(t)$	is the cesium concentration in the air of POP8, [Bq/m^3].
*	See explanation on previous page 21.

The data used in prediction of inhalation doses are presented in Table XV.

Table XV *Data used in the inhalation model.*

	Reference	General data of the model	Data for ^{137}Cs nuclide
INHALATION			
- fraction of time spent outside[1)]		0.1	
- inhalation rate[1)], [m^3/h]		0.8	
- soil content in air[1),2)], [kg/m^3]			$1 \cdot 10^{-6}$
- inhalation dose conversion factor, [Sv/Bq]	[1]		$8.6 \cdot 10^{-9}$

1) See explanation 3) under Table I.
2) The activity concentration of resuspended material in air is calculated from a homogenized soil layer up to 0.5 cm from the soil surface.

2.6 Identification of important processes and parameters

For the terrestrial pathways, the weathering effects on the surface of e.g. grass affect significantly the cesium activity contents of several foodstuffs. The migration rate of cesium in surface soil affects also long-term concentrations in wild berries, mushrooms and game. According to measurements, the cesium concentration in forest soil has reduced slowly. The calculations performed support the observed behaviour.

Looking at the aquatic environment, the dilution properties of various lakes affect the concentration of lake water as well as the concentrations in fish. The strong dynamic behaviour of the trophic chain of different fish types causes a long lasting contamination effect in the aquatic environment after deposition.

3 COMPARISON OF OBSERVED DATA AND MODEL PREDICTIONS

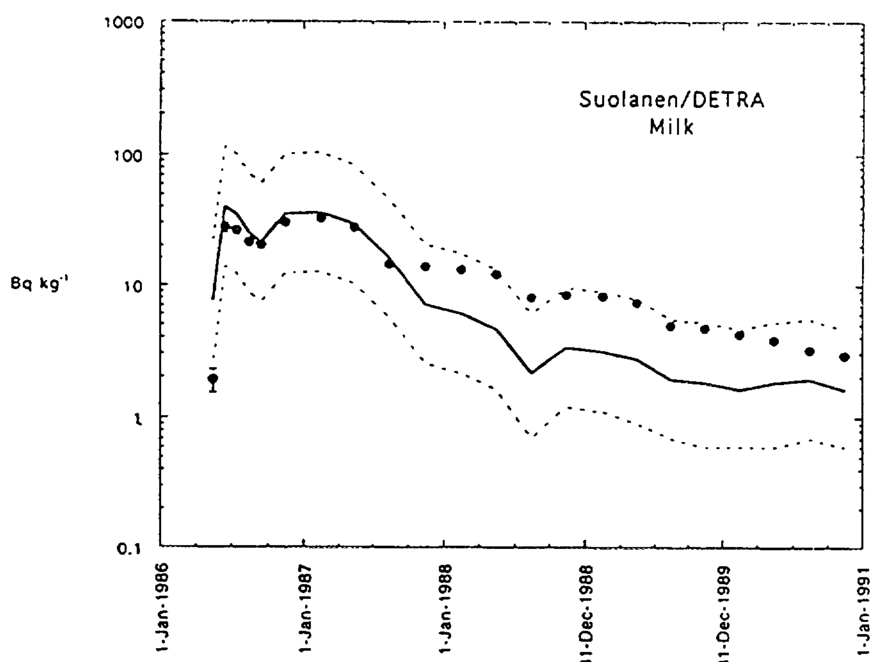
3.1 Total deposition

The predicted mean total deposition 19.3 kBq/m^2 over the whole area S was consistent with the observed value. Correspondingly, the predicted total inventory $3.4 \cdot 10^{15}$ Bq, calculated from the deposition value, was almost identical with the given inventory value $3.5 \cdot 10^{15}$ Bq [1].

3.2 Foodstuffs contributing to total diet

3.2.1 Milk

The observed values of Scenario S of the VAMP research programme were prepared for IAEA by the Finnish Centre for Radiation and Nuclear Safety and they are presented in publication [1]. Fig. 8 presents the temporal behaviour of observed and predicted concentrations of ^{137}Cs in milk. For the first year after the deposition, the model predicts well the activity content in milk. Thereafter, the uncertainty bounds of the predicted values cover the observed values although there is a tendency of underestimation of the concentration level in the longterm.



● = observed value [1]
--- = predicted 95 % confidence interval (lower bound and upper bound)
— = predicted mean value

Fig. 8. Observed and predicted concentrations of ^{137}Cs in milk.

3.2.2 Beef

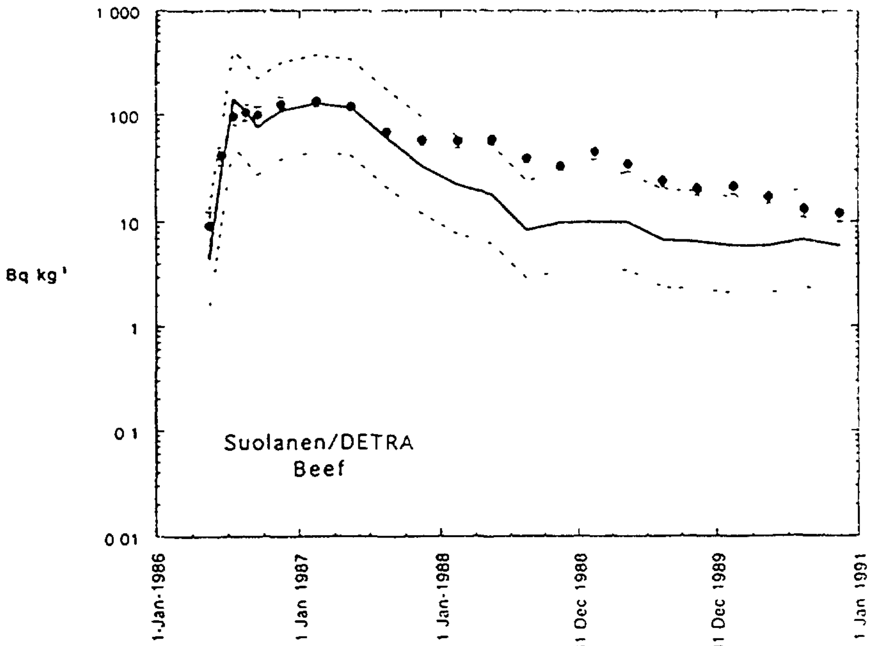


Fig. 9. Observed and predicted concentrations of ^{137}Cs in beef.

3.2.3 Pork

Considering the long-term concentrations in pork, the model clearly underestimates the contamination level. The reasons for underestimation will be discussed later in chapter 4.2.

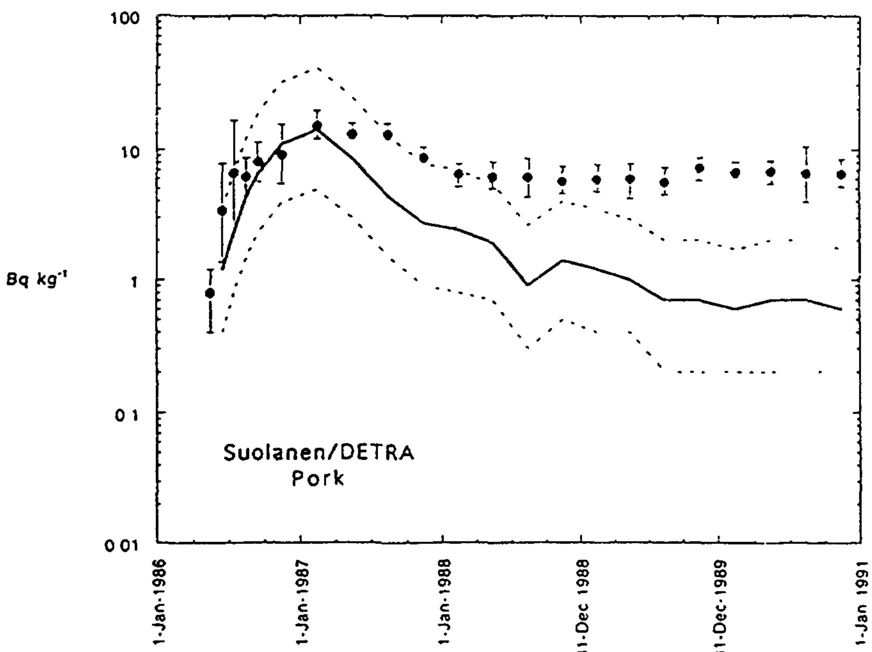


Fig. 10. Observed and predicted concentrations of ^{137}Cs in pork.

3.2.4 Game

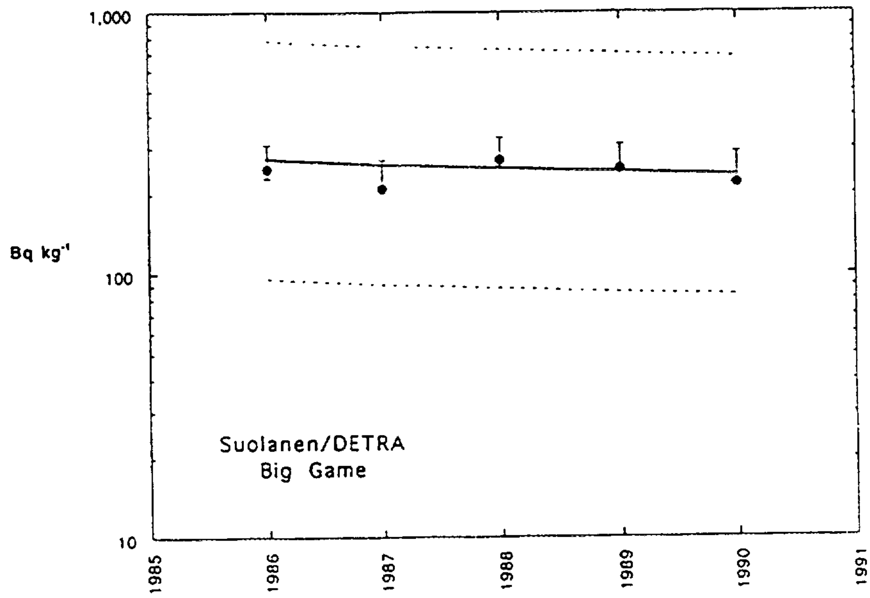


Fig. 11. *Observed and predicted concentrations of ^{137}Cs in big game.*

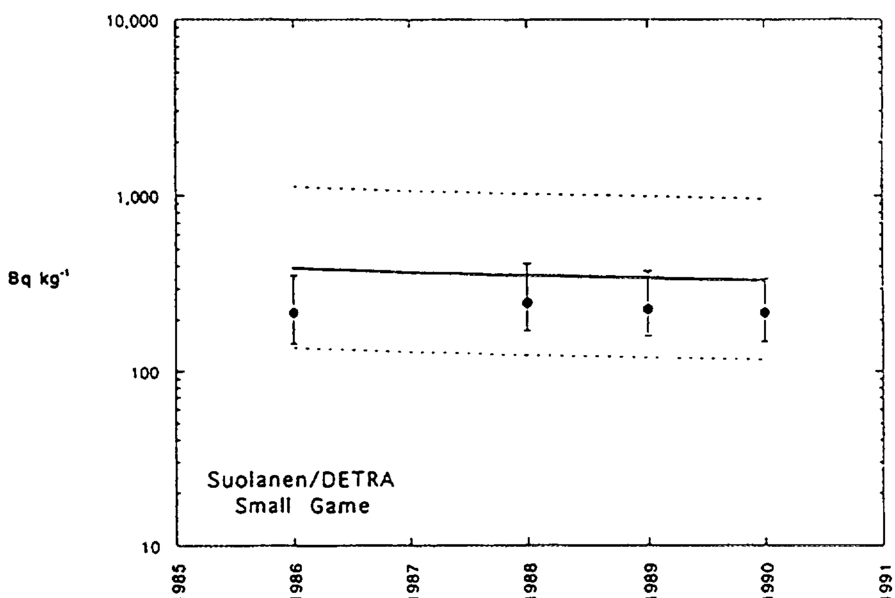


Fig. 12. *Observed and predicted concentrations of ^{137}Cs in small game.*

3.2.5 Wild berries

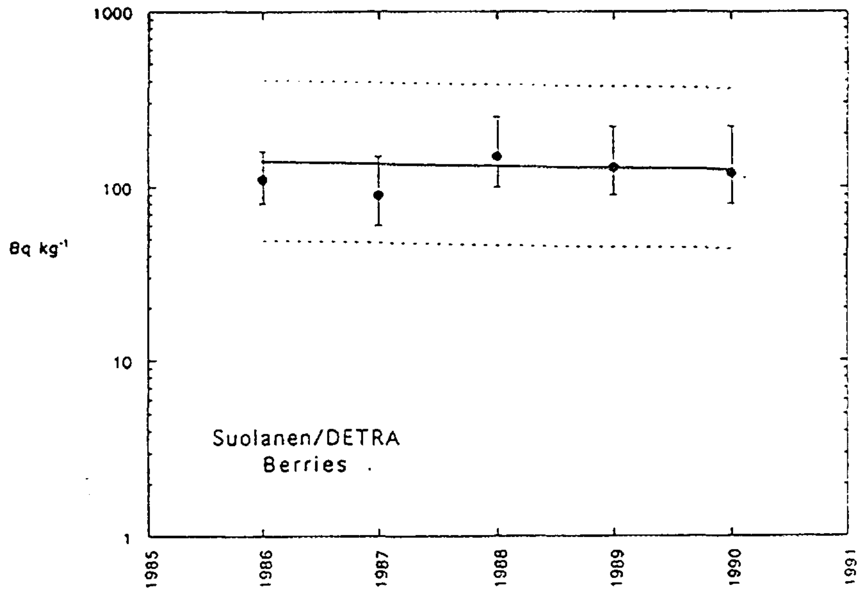


Fig. 13. Observed and predicted concentrations of ^{137}Cs in wild berries.

3.2.6 Mushrooms

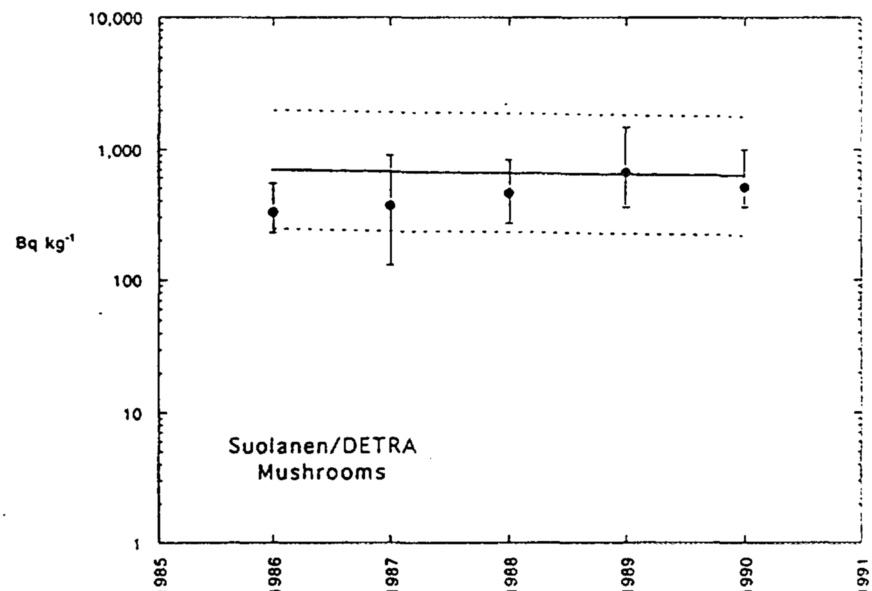


Fig. 14. Observed and predicted concentrations of ^{137}Cs in mushrooms.

3.2.7 Leafy vegetables

Fig. 15. presents the observed vs predicted concentrations of ^{137}Cs in leafy vegetables. The deposition from the Chernobyl nuclear accident is unevenly distributed over the area of Test Scenario S. The intensity of greenhouses in area S is also unevenly distributed. Additionally, deposition in area S was mainly of the wet type. The facts mentioned above affect the accuracy of predictions especially in the case of vegetables produced in the greenhouses.

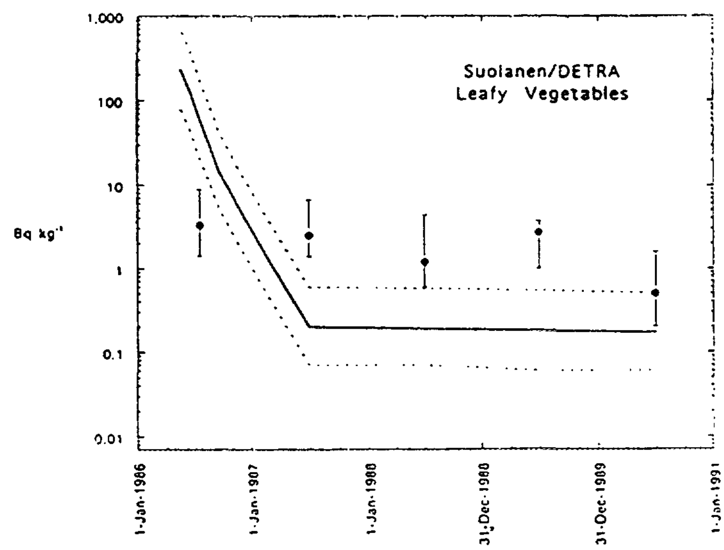


Fig. 15. Observed and predicted concentrations of ^{137}Cs in leafy vegetables.

3.2.8 Cereals

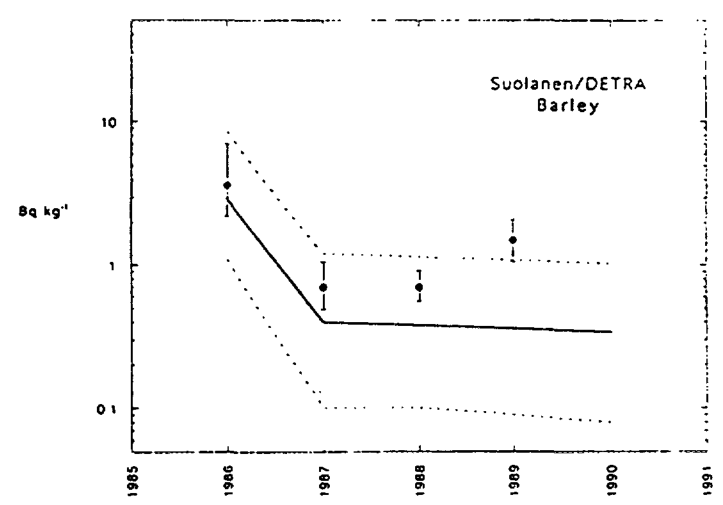


Fig. 16. Observed and predicted concentrations of ^{137}Cs in barley.

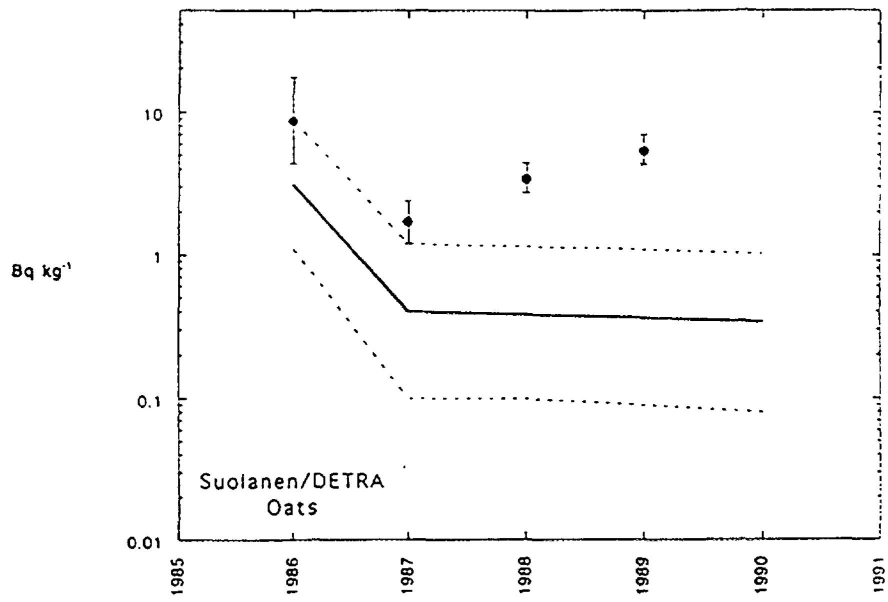


Fig. 17. Observed and predicted concentrations of ^{137}Cs in oats.

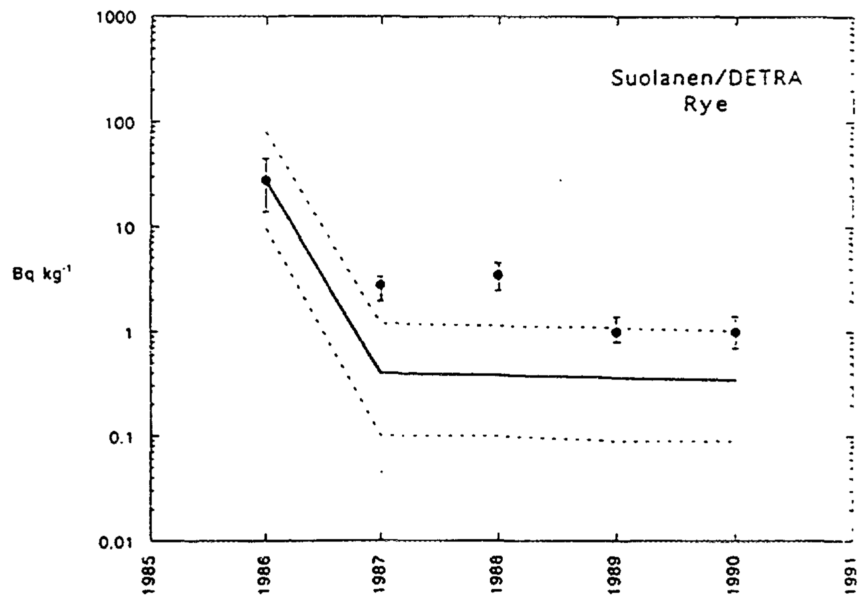


Fig. 18. Observed and predicted concentrations of ^{137}Cs in rye.

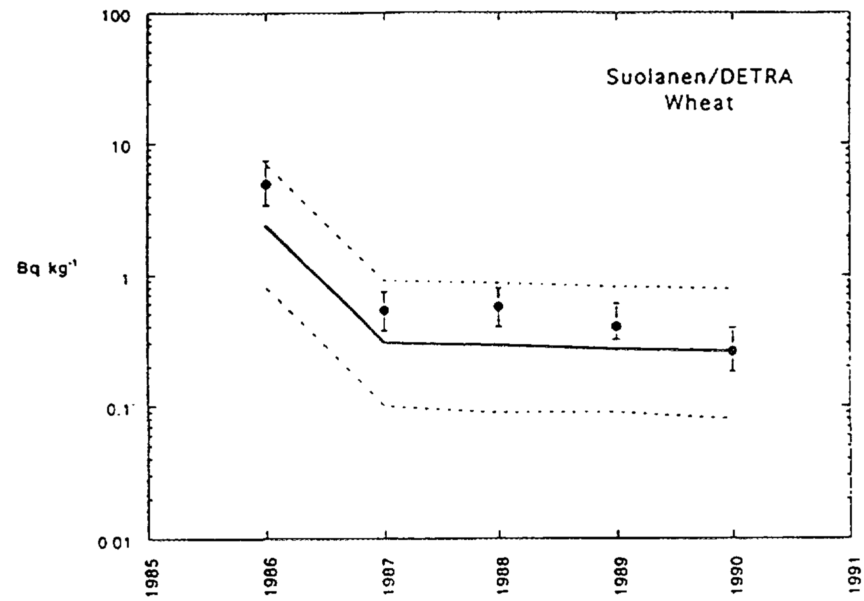


Fig. 19. *Observed and predicted concentrations of ^{137}Cs in wheat.*

3.2.9 Fish

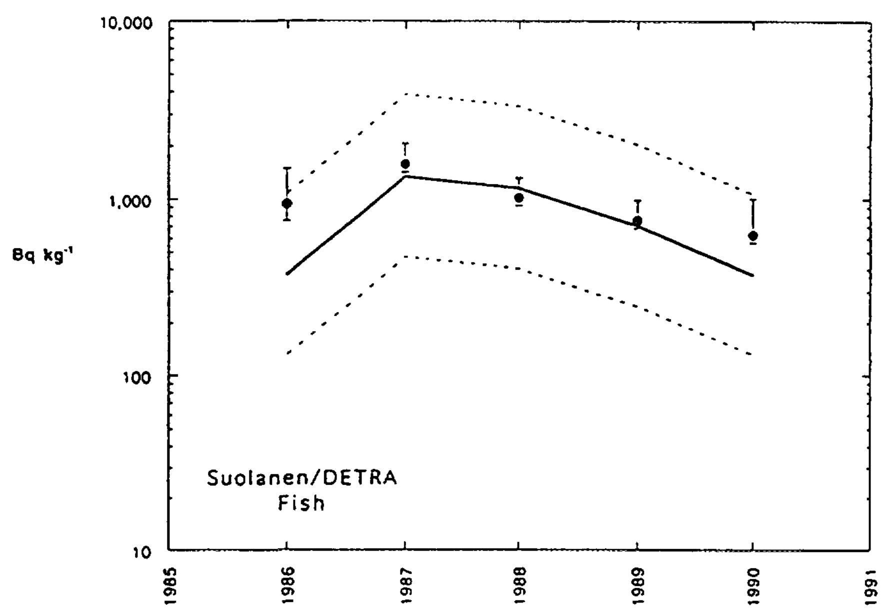


Fig. 20. *Observed and predicted concentrations of ^{137}Cs in fish.*

3.3 Human intake

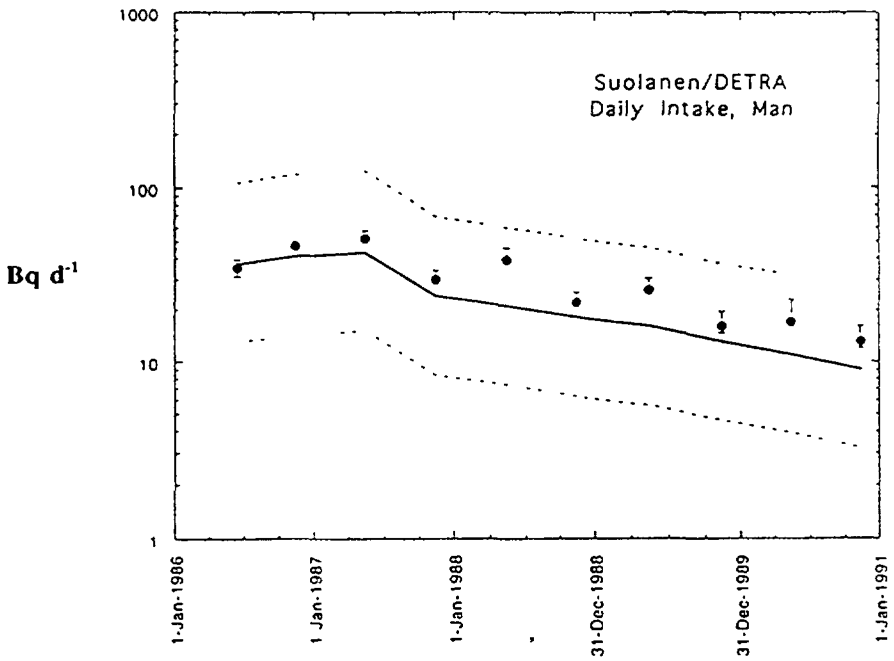


Fig. 21. Daily intake of ^{137}Cs*, man.*

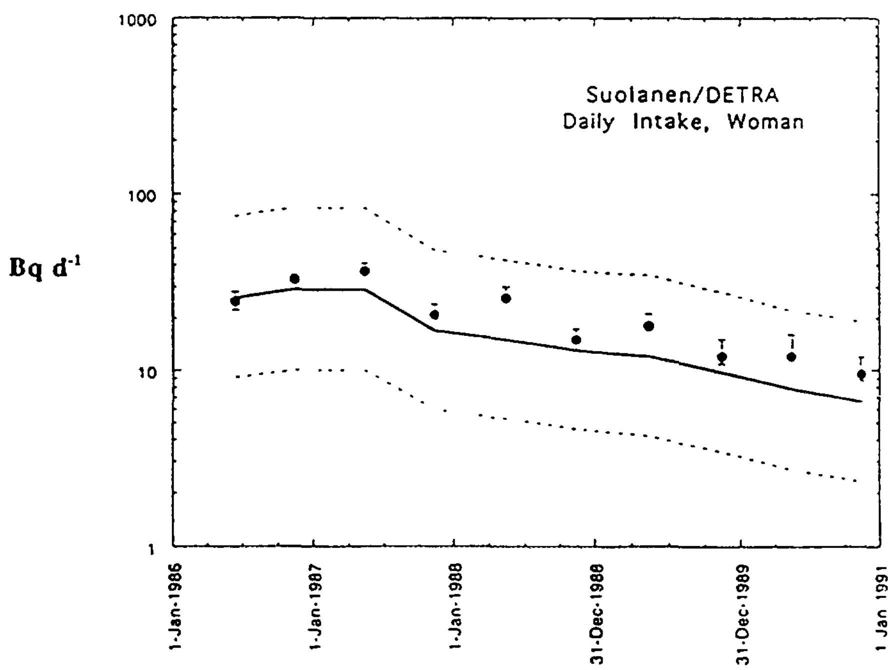


Fig. 22. ***Daily intake of*** ^{137}Cs***, woman.***

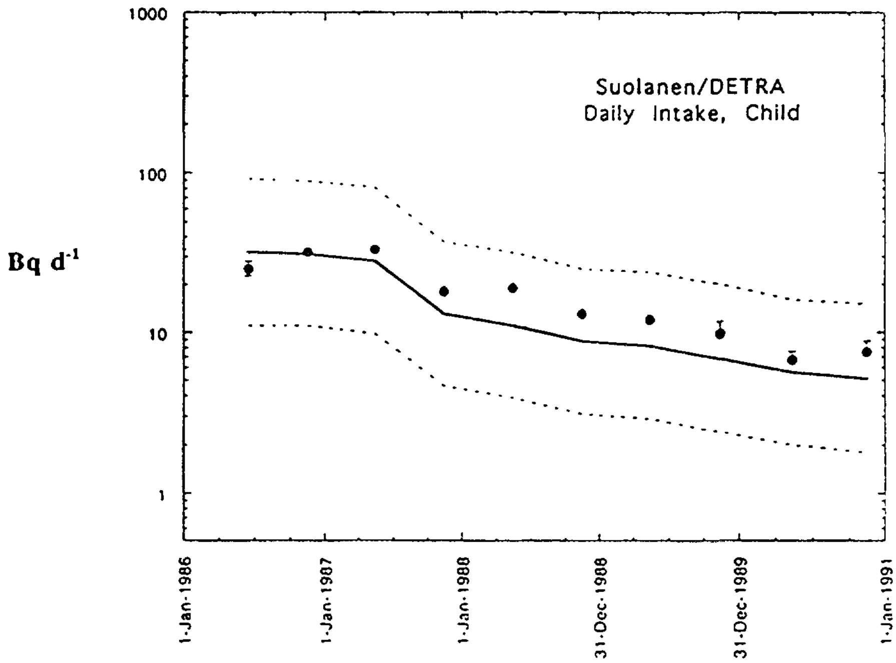


Fig. 23. *Daily intake of ^{137}Cs, child.*

3.4 Whole body concentrations

3.4.1 Mean whole body concentration

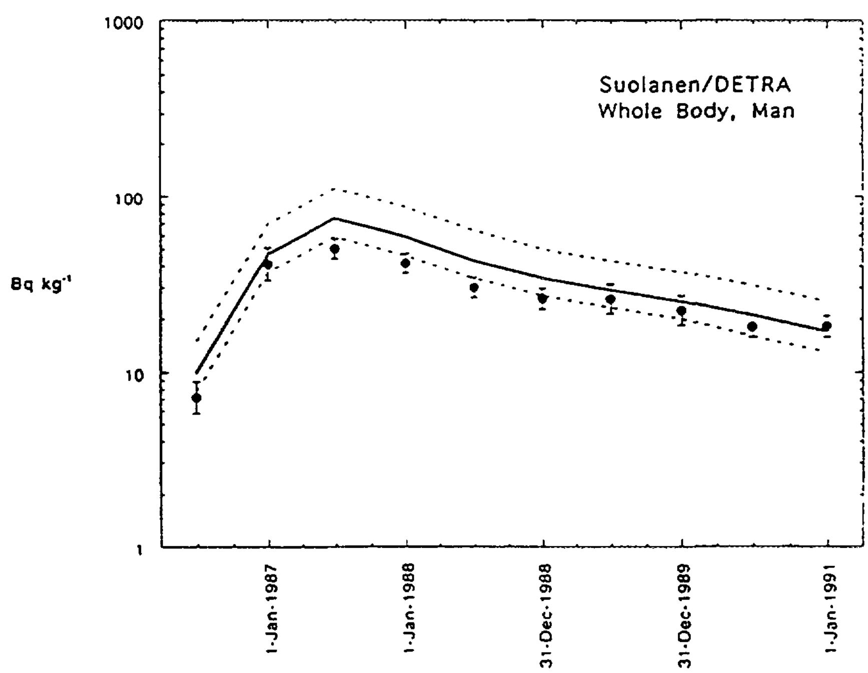


Fig. 24. *Whole body concentration of ^{137}Cs, man.*

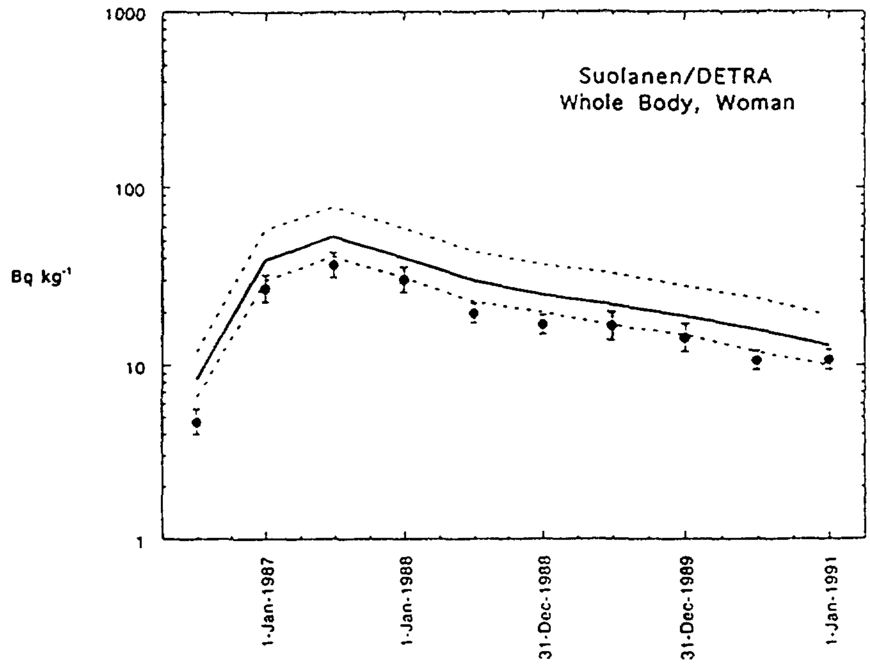


Fig. 25. *Whole body concentration of ^{137}Cs, woman.*

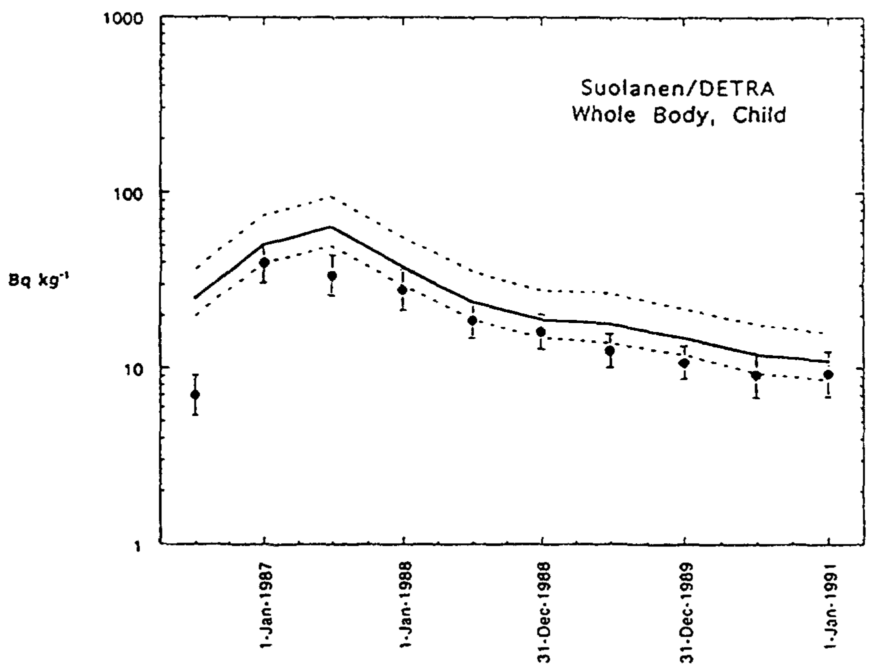
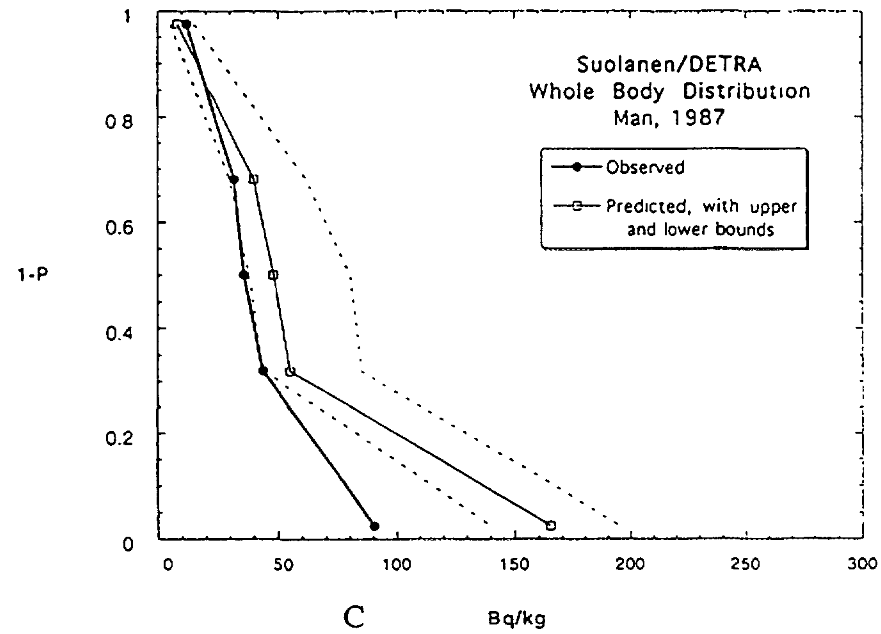


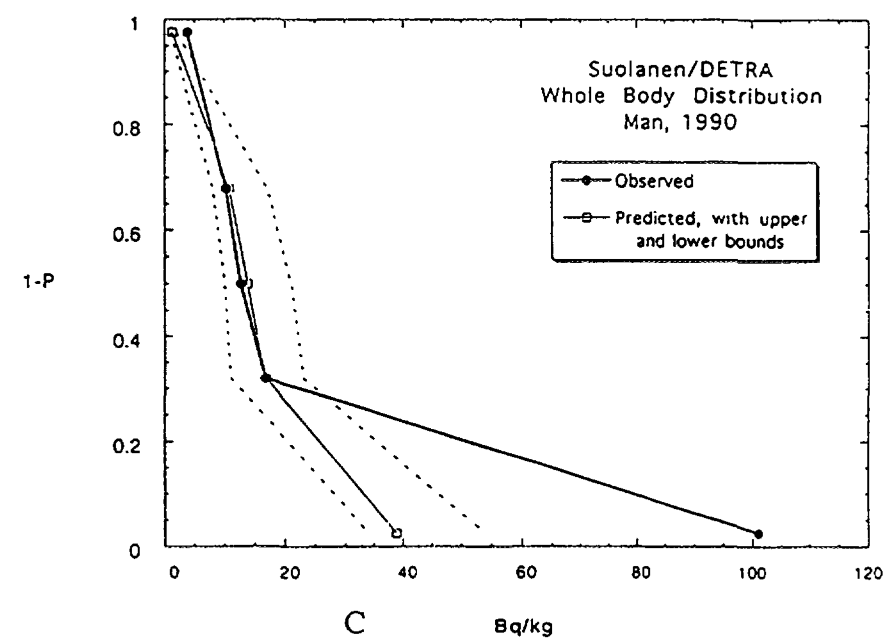
Fig. 26. *Whole body concentration of ^{137}Cs, child.*

3.4.2 Distribution of whole body concentrations



1-P = P(conc. ≥ C)

Fig. 27. *Whole body distribution of concentration of ^{137}Cs, man, 1987.*



1-P = P(conc. ≥ C)

Fig. 28. *Whole body distribution of concentration of ^{137}Cs, man, 1990.*

3.5 Dose calculations

3.5.1 External

Fig. 29 presents the estimated values [1] and predicted values for a lifetime external dose of ground exposure based on different models. External dose from plume exposure is presented in Fig. 30.

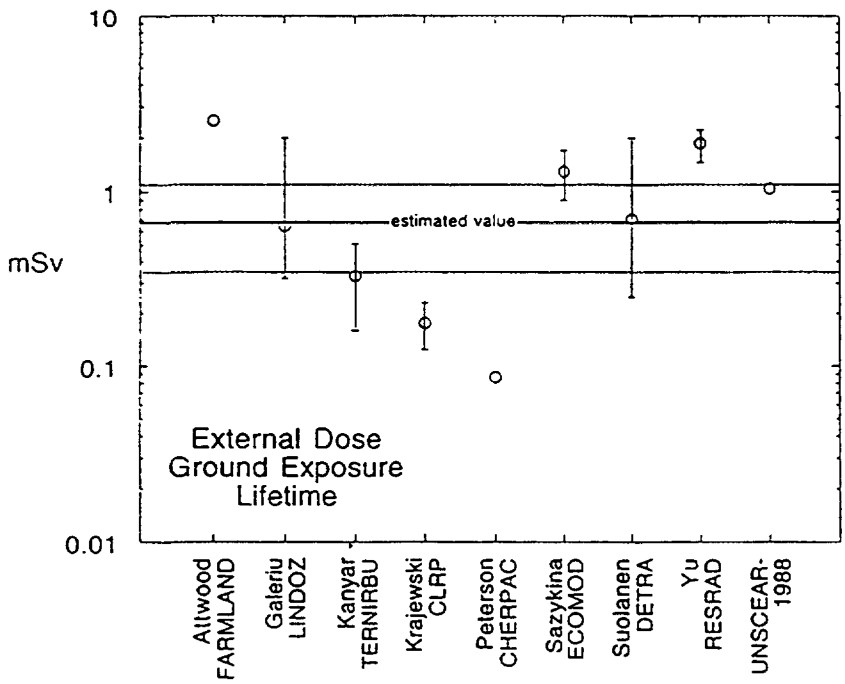


Fig. 29. External dose of ^{137}Cs from ground exposure, estimated and predicted values.

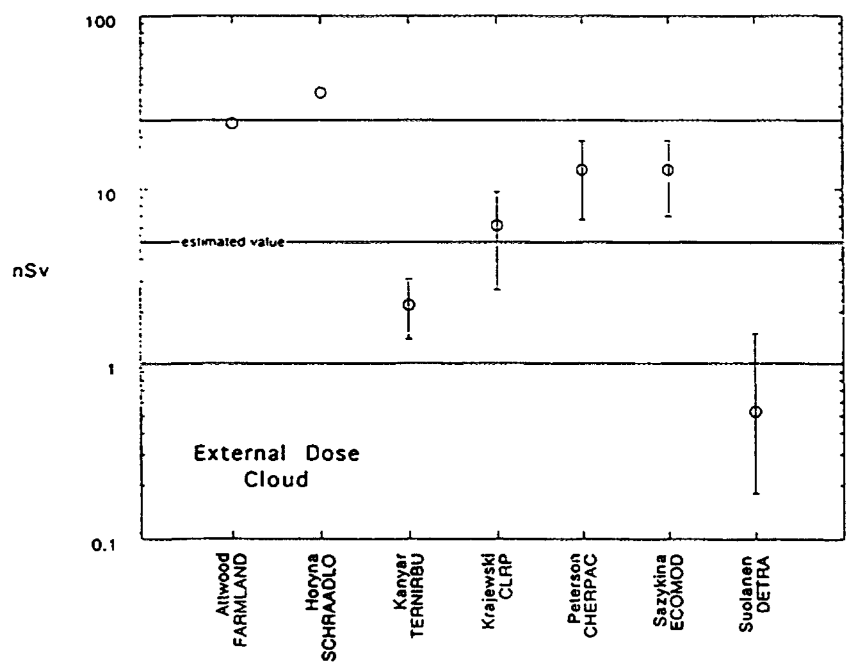


Fig. 30. External dose of ^{137}Cs from plume exposure, estimated and predicted values.

3.5.2 Ingestion

Fig. 31 presents the estimated [1] and predicted lifetime doses from ingestion of contaminated foodstuffs. All models conclude that freshwater fish has the highest contribution to ingestion dose of Scenario S in the long-term consideration.

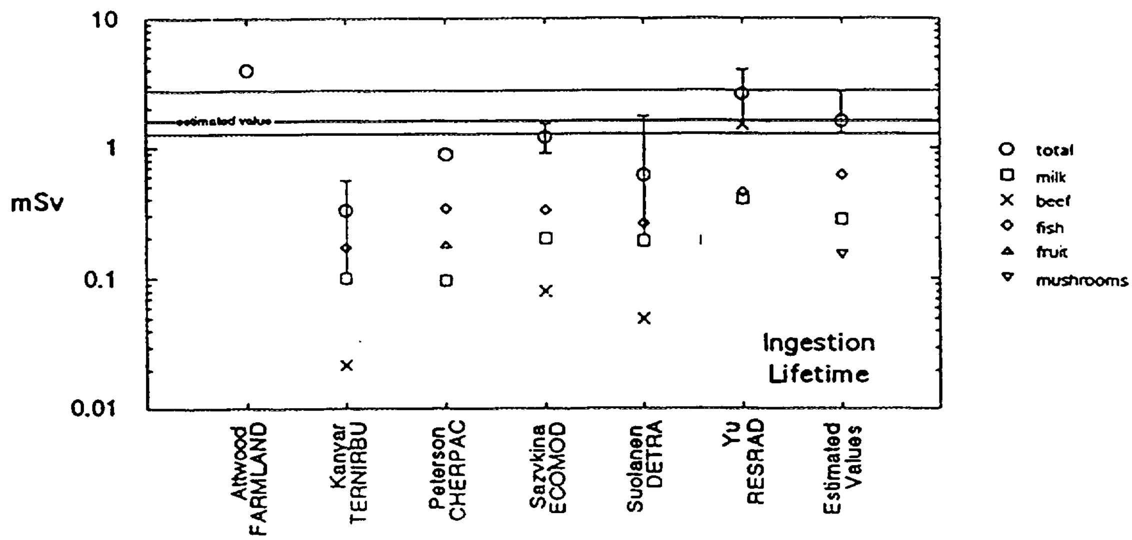


Fig. 31. *Ingestion lifetime doses of ^{137}Cs.*

3.5.3 Inhalation

Inhalation makes a minor contribution to the total dose arising from the deposition of Scenario S. Figures 32 and 33 present the predicted inhalation doses from resuspension and from plume.

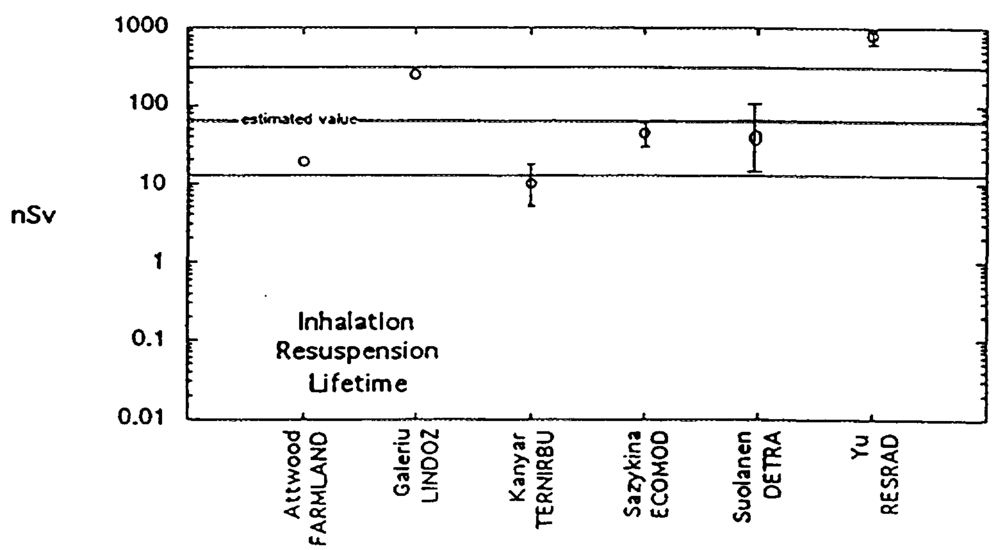


Fig. 32. *Inhalation lifetime doses of ^{137}Cs from resuspension.*

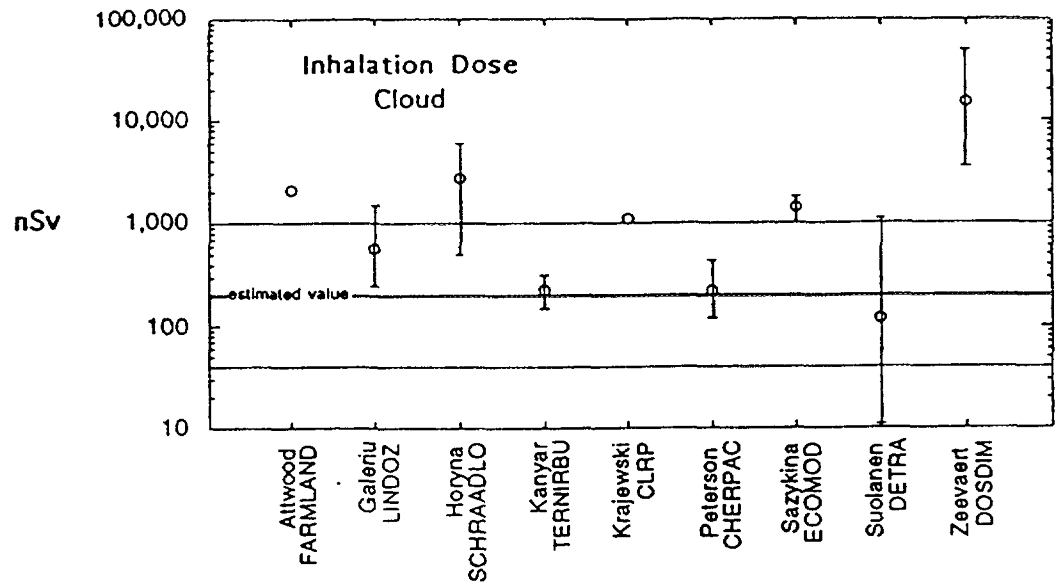


Fig. 33. *Inhalation dose of ^{137}Cs from plume.*

Total doses, predicted by various models, are presented in Fig. 34[1)].

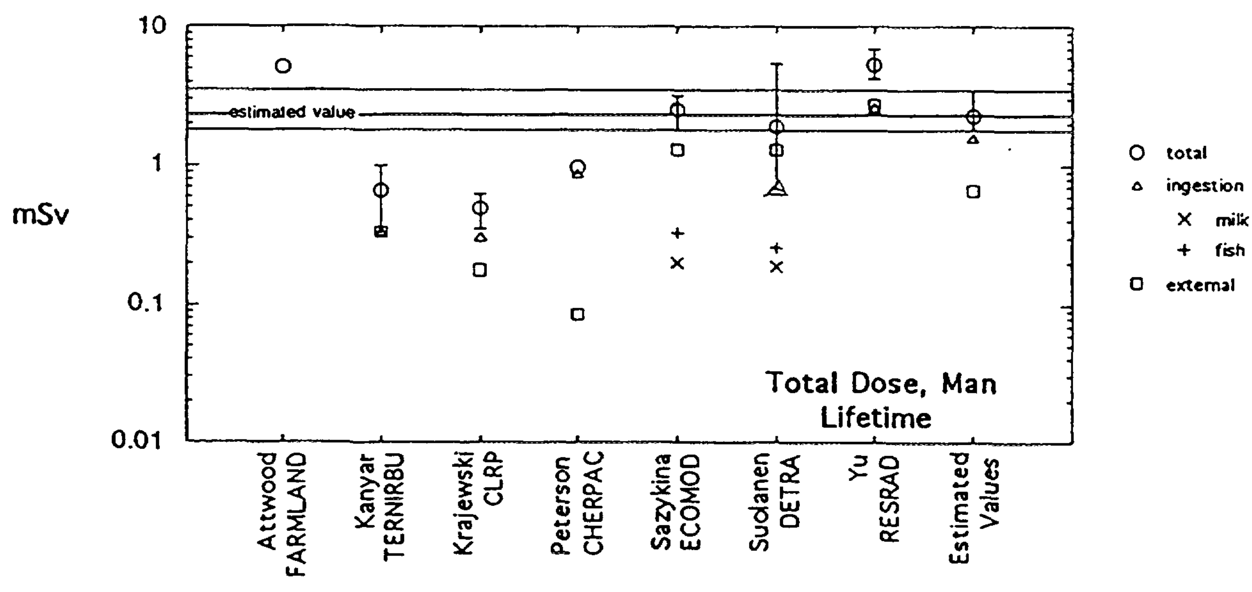


Fig. 34[1)]. *Total lifetime doses of ^{137}Cs over the entire region S.*

1) The results of DETRA presented in the figure are based on a preliminary analysis which employed more conservative values for the location and the shielding factors than those presented in Table XIV above. In the final published version of this report the figure will be replaced accordingly.

4 EXPLANATION OF MAJOR SOURCES OF MISPREDICTION

4.1 Recommendations for changes to the model

Effects of uncertainty factors on the predictions of Scenario S seemed to occur in the long-term considerations. Possible reasons for this include heterogeneity related to the agricultural practices of different farms, such as the production of feeds, and changes in the solubility of radionuclides in the longterm. The conceptual models applied as the bases of calculations simplify and homogenize the real agricultural practices to some extent.

To improve the model, more detailed analyses of the importance of various phenomena in different dose pathways should be carried out. As a result, the main activity flows related to contamination of foodstuffs could possibly be clarified even better than it is known at present.

4.2 Examples of how changes improved calculation

The model used to predict the contamination of pork underestimated the long-term cesium concentrations in pork. After careful investigation of the reasons for such underestimation it seemed evident that the reason might be the underestimation of the concentration in mixed grain. In the case of Scenario S, the activity content of cereals started to increase some years after the deposition. If this increase in the activity content of mixed grain is accounted for, a more consistent behaviour with the observed values can be obtained, as illustrated in Fig. 35. In the longterm, some of the difference between the observed and predicted values for concentration in pork is probably caused by an underestimation of the consumption rate of cereal feed for pigs.

[Bq/kg]

PORK = observed for pork [1]
PRED1 = predicted for pork
PRED2 = improved prediction for pork
FEED = observed for cereal feed for pigs [1]
MILK = observed for milk [1]; whey is used as feed for pigs

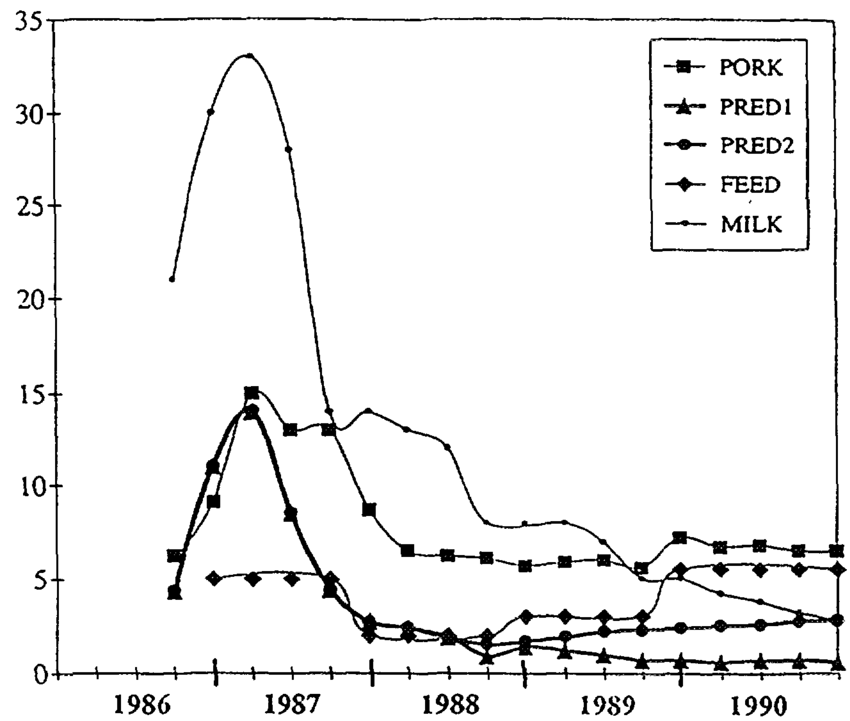


Fig. 35. Example of the effect of model development on the pork pathway.

5 SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

Based on the experiences of predictions performed for Scenario S, successful modelling of milk pathway is essential considering the exposure from terrestrical pathways. Activity concentration in milk byproduct, whey, also affect the activity concentration in pork, and the model of milk pathway is also closely related to the model of beef. The modelling of activity contents in soil and pasture also has similarities compared to modelling the activity content in the forest environment.

Looking at the aquatic environment, freshwater fish have proved important and, according to the analyses performed, it was the most important foodstuff considering the total individual ingestion dose in the longterm.

According to the observations, the ingestion dose contributes most to the estimated total life-time dose for the population living in the area of Scenario S.

The parameters applied in the models of this study are in most cases relevant, especially considering the features of the Finnish environment. The parameters of some pathways are derived based on the practices in national agriculture. In case a deposition should occur in the northern part of Finland, there are some important arctic dose pathways which were not included in this study because the deposition of the Chernobyl accident and the area of Scenario S concerned only the southern and middle parts of Finland.

The models and off-site parameters employed in this study are also in most cases applicable to unexpected severe accidents in either of the Finnish nuclear power plants, the Olkiluoto NPP or the Loviisa NPP. Factors which will essentially change the input data applied in this study include seasonality, production data of foodstuffs and dilution properties of inland freshwater recipients. Seasonality directly affects the interception of grass and other vegetation. Production rates of domestic animal products, feeds and dilution factors of lakes affect the level of concentrations obtained in foodstuffs after a deposition. In any case, rough dose estimates, as derived from the results of this study are applicable in case a radioactive deposition should happen at some other time of the year than in the case of Test Scenario S.

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[11] Watkins BM. Interception, retention, absorption and translocation of radionuclides by vegetation following application in irrigation waters. NSS/R221, 1990.

[12] Handbook of parameter values for the prediction of radionuclide transfer in temperate environments (draft), IAEA, 1993.

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II.10. RESRAD

1. RESRAD MODEL DESCRIPTION AND EVALUATION OF MODEL PERFORMANCE

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Argonne National Laboratory,
Argonne, Illinois, United States of America

2. MODEL DESCRIPTION

2.1 MODEL NAME AND USER

Name of Model: RESRAD
Model Developer: Charley Yu et al.
Model User: Emmanuel K. Gnanapragasam and Charley Yu

2.2 IMPORTANT MODEL CHARACTERISTICS

RESRAD is a computer code developed at Argonne National Laboratory (ANL) for the U.S. Department of Energy (DOE) to calculate site-specific residual radioactive material guidelines and radiation dose/risk to an exposed individual (worker or resident) at a radioactively contaminated site.

RESRAD uses a pathway analysis method in which the relation between radionuclide concentrations in soil and the dose to a member of a critical population group is expressed as a pathway sum, which is the sum of products of "pathway factors." Pathway factors correspond to pathway segments, which connect compartments in the environment. Radionuclides can be transported, or radiation transmitted, between these compartments. Nine potential exposure pathways are analyzed: (1) direct exposure to external radiation from contaminated soil material; (2) internal radiation from inhalation of contaminated dust; (3) internal radiation from inhalation of radon; (4) internal radiation from ingestion of plant foods grown in the contaminated soil and irrigated with water drawn from well or pond; (5) internal radiation from ingestion of meat from livestock fed with fodder grown in the contaminated soil and water drawn from a well or pond; (6) internal radiation from ingestion of milk from livestock fed with fodder grown in the contaminated soil and water drawn from a well or pond; (7) internal radiation from direct ingestion of contaminated soil; (8) internal radiation from ingestion of aquatic foods (fish) from a pond; and (9) internal radiation from drinking water from a well or pond. Figure 1 illustrates the nine pathways considered in the RESRAD code.

[17] Häsänen, E., Rahola, T., The biological half-life of ^{137}Cs and ^{24}Na in man. Annals of Clinical Research 3, 1971.

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To analyze Scenario S, a Monte Carlo routine with Latin hypercube sampling (LHS) technique was used to generate input data sets for RESRAD runs. This routine has now been incorporated into RESRAD as a preprocessor for uncertainty analysis.

The RESRAD code runs on an IBM or IBM-compatible personal computer, or Personal System/2, with a DOS 3.1 or equivalent operating system, a hard disk drive of 3 megabytes storage space, and 550 kilobytes of memory. Use of a math coprocessor or a mouse is optional, but highly recommended. The program is designed with various user-friendly features, including internal help files for information on input and output data. A mouse can be used to show default values. A user-friendly menu system simplifies management of the RESRAD operations and files. Users can access the data input screens, run the RESRAD calculations, and view the output from the menu system. The menu system also provides options for suppressing one or more of the nine exposure pathways calculated by RESRAD.

RESRAD provides both tabular and graphic output. The tabular output presents detailed calculational results, including doses and risk from various pathways, concentration in various media, maximum doses and minimum soil guidelines, and many intermediate calculational results. The graphic output displays calculational results for doses and concentrations and any sensitivity analyses that have been requested.

2.3 DOCUMENTATION

Many supplemental documents have been prepared for the RESRAD code. These include *Manual for Implementing Residual Radioactive Material Guidelines*; *Data Collection Handbook for Establishing Residual Radioactive Material Guidelines*; *A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code;* and *RESRAD Parameter Sensitivity Analysis*. These documents clarify the RESRAD code so that it can be properly applied to solve real problems. Complete citations for these documents are as follows:

1. Yu, C., A.J. Zielen, J.-J. Cheng, Y.C. Yuan, L.G. Jones, D.J. LePoire, Y.Y. Wang, C.O. Loureiro, E. Gnanapragasam, E. Faillace, A. Wallo III, W.A. Williams, and J.H. Peterson, Jr, *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0*, ANL/EAD/LD-2, Working Draft, Argonne National Laboratory, Argonne, Ill. (Sept. 1993).

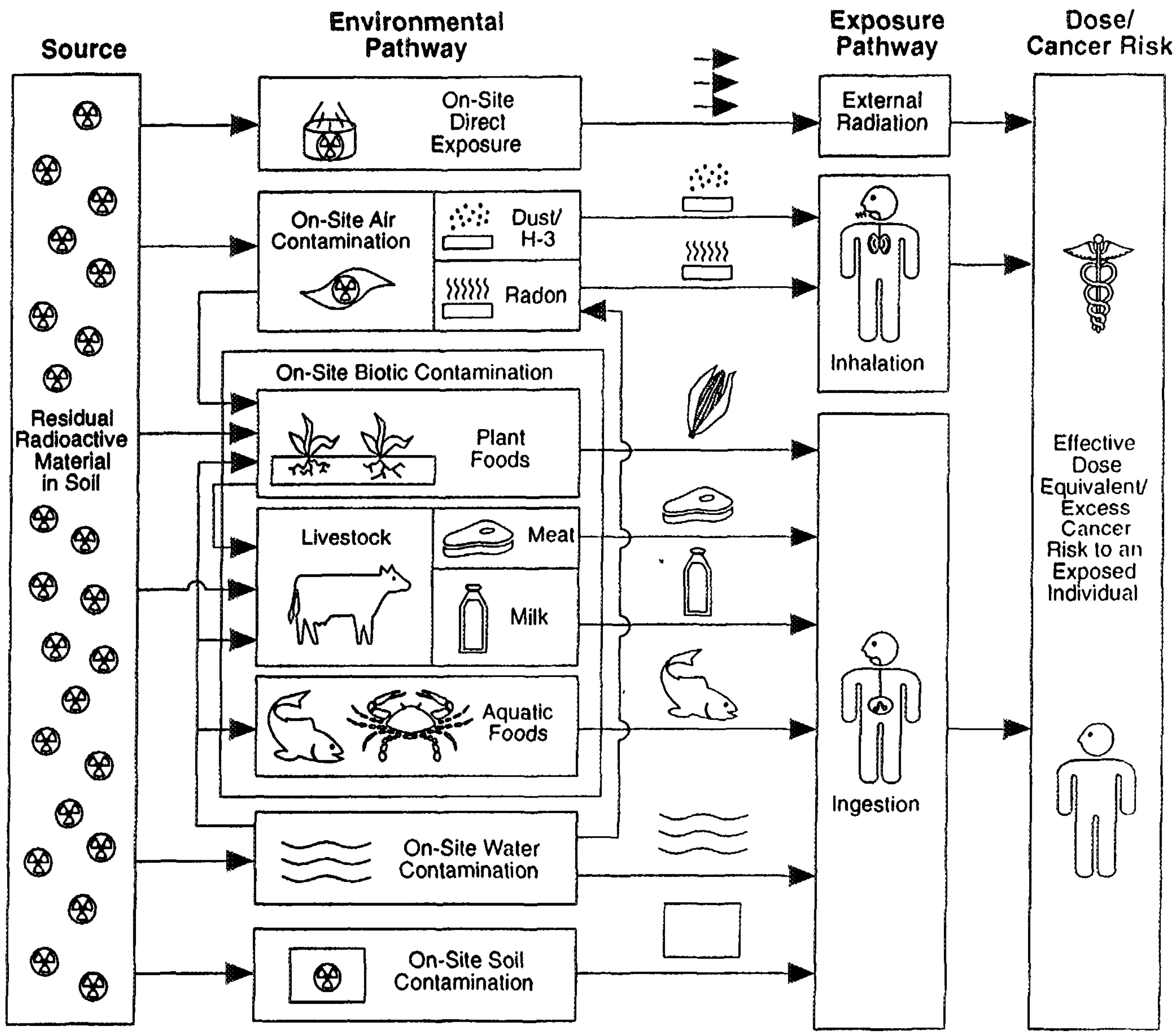

FIGURE 1 Pathways Considered in RESRAD Code

2. Gilbert, T.L., C. Yu, Y.C. Yuan, A.J. Zielen, M.J. Jusko, and A. Wallo, *A Manual for Implementing Residual Radioactive Material Guidelines*, ANL/ES-160, DOE/CH/8901, Argonne National Laboratory, Argonne, Ill. (June 1989).

3. Yu, C., C.O. Loureiro, J.-J. Cheng, L.G. Jones, Y.Y. Wang, Y.P. Chia, and E. Faillace, *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*, ANL/EAIS-8, Argonne National Laboratory, Argonne, Ill. (April 1993).

4. Wang, Y.Y., B.M. Biwer, and C. Yu, *A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code*, ANL/EAIS/TM-103, Argonne National Laboratory, Argonne, Ill. (Aug. 1993).

5. Cheng, J.-J., C. Yu, and A.J. Zielen, *RESRAD Parameter Sensitivity Analysis*, ANL/EAIS-3, Argonne National Laboratory, Argonne, Ill. (Aug. 1991).

2.4 MODIFICATIONS TO RESRAD FOR SCENARIO S

RESRAD computes the concentrations of the nuclides in a surface water body by considering the transport of the nuclides through the unsaturated and saturated zones. However, in Scenario S the surface water was contaminated by direct fallout on the surface of the water course and from contaminated runoff. Given the large extent of the study area and the large subsurface transport distances, groundwater-derived contamination of the surface water sources would not be significant over the time span of the study (50 years). Hence the code (RESRAD version 4.7) was modified by removing the groundwater transport pathway and by including the measured surface water concentrations for the first four years as input. The surface water concentration was assumed to decline solely due to radioactive decay beyond the fourth year after deposition. The code was also modified to compute and output the concentrations of the contaminants in different media.

2.5 SIMULATING THE SCENARIO ON RESRAD

2.5.1 Estimation of Endpoints

Because the version of RESRAD used in this study limited the number of vegetables, animal feed, and meat to two, one, and one, respectively, in a single run of the code, all the required end points could not be obtained from a single series of simulations. In all, 10 series of simulations were required — one each for the ^{137}Cs content of leafy vegetables, cereals (wheat and rye), wild berries, oats, barley, and pasture; one to estimate the nuclide content in fish and in pork; and one each to determine the intake and dose for a man, woman, and child. The results of the three runs for oats, barley, and pasture were used to determine the ^{137}Cs content in beef and milk.

2.5.2 Estimation of Confidence Interval

The probabilistic RESRAD code was still under development when these simulations were performed. Hence, the deterministic code was run repeatedly to generate a distribution of predictions in order to obtain the 95% confidence interval. Considering that 10 series of runs were required to obtain all the endpoints, the number of runs within each series was limited to 25. A Latin hypercube sampling (LHS) scheme was used to obtain 25 representative values of each of the inputs selected for the statistical study. The LHS routine has now been incorporated into RESRAD version 5.2.

2.5.3 Inputs Selected for Statistical Study

Because the simulations for the statistical analysis had to be run manually, only those parameters that were highly uncertain were varied in each series. The soil-to-plant transfer factors for barley, oats, rye, wheat, peas and beans, potatoes, spinach, fruit, root vegetables, and fodder; the water-to-flesh bioaccumulation factor for fish; and the intake-to-edible portion transfer factors for beef, pork, milk, poultry, and eggs were selected for the statistical study, since the value applicable to the region of study was not known a priori. The distribution of these factors and the values characterizing the distributions were obtained from the *IAEA 9th Draft Working Document, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments* (IAEA 1992). The input concentrations of ^{137}Cs in soil and in the surface water body for the first four years after the passage of the radioactive Chernobyl plume were also allowed to vary in the statistical runs. The distributions of the concentrations were assumed to be normal. The standard deviation of the soil concentration was stated to be 10% of the mean in the scenario description. The mean and standard deviation of the surface-water concentrations were obtained from the values given for the 12 drainage (fish) regions in the study.

2.5.4 RESRAD Inputs

The information given in the scenario description had to be manipulated to yield the inputs required by RESRAD. Preparation of the data is discussed in the following sections.

2.5.4.1 Thickness of Contaminated Zone

The vertical distribution of ^{137}Cs in uncultivated soils was given in the scenario description. Analysis of that data resulted in a distribution of depths within which 95% of the radiocesium was present. This distribution (Table 1) could have been sampled and included in the statistical analysis. The depth of contamination only affected the external radiation dose in this scenario because of the values chosen for mixing depth and root depth and the methodology used to compute the radionuclide content in the contaminated zone. Hence, a single value of 10 cm was selected for the depth of the contaminated zone.

2.5.4.2 ^{137}Cs Content of Contaminated Zone

The areal deposition of ^{137}Cs in different parts of the test region was given in the scenario description. This information yielded an average areal deposition rate of 20 kBq m^{-2} over land and water surfaces. Together with the value of contaminated zone thickness chosen above and an assumed density of 1.6 g cm^{-3}, this translated to a ^{137}Cs content of

TABLE 1 Distribution of Depth within Which 95% of the ^{137}Cs in the Surface Soil Is Contained

Depth (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Number of sites[a]	0	1	5	16	8	4	4	10	2	3	3	0	0	2	1

[a] Indicates number of sites at which 95% of the ^{137}Cs is within this depth.

3.4 pCi g^{-1}. The scenario description stated that the error in the areal deposition rates of the different parts of the test region was characterized by a standard deviation equal to 10% of the mean. The ^{137}Cs in soil (pCi g^{-1}) was assumed to be normally distributed, with a mean of 3.4 pCi g^{-1} and a standard deviation of 0.34 pCi g^{-1} for the statistical study.

2.5.4.3 ^{137}Cs Content of Surface Water

The radiocesium concentrations of each surface water body at different times of the year were averaged to obtain a mean annual content. The mean annual content of different surface water bodies for each year were analyzed to obtain the mean and standard deviation of ^{137}Cs content for each year. Since the volumes of the surface water bodies were not known, they were weighted equally. The distribution of the surface water ^{137}Cs content was assumed to be normal for the statistical study. Table 2 gives the mean and standard deviation of the ^{137}Cs in the surface water courses for each of the four years.

2.5.4.4 Evapotranspiration Coefficient

The scenario description states that "a typical value for evaporation for a lake in the south is 500 mm a^{-1} and in the north 350–450 mm a^{-1}. Runoff from drainage areas FISH3, FISH4, and FISH5 to the watercourses typically is about 5–7 L s^{-1} km^{-2}. About two-thirds of the precipitation evaporates." Therefore, an evapotranspiration coefficient of 0.667 was selected.

2.5.4.5 Precipitation Rate

The annual precipitation varies between 450 and 750 mm; an average value of 0.6 m a^{-1} was used in the simulations.

2.5.4.6 Irrigation Rate

An irrigation rate of 0.08 m a^{-1} was used because the rainfall deficiency in the subregions ranged from 60 to 80 and 80 to 100 mm.

2.5.4.7 Runoff Coefficient

The average runoff rate of 6 L s^{-1} km^{-2} and the mean precipitation of 0.6 m a^{-1} were combined to obtain a runoff coefficient of 0.32.

2.5.4.8 Soil-Water Distribution Coefficient of ^{137}Cs

The RESRAD default value of 1,000 cm^3 g^{-1} was used for the soil-water distribution coefficient of ^{137}Cs. Under the conditions chosen to represent this scenario, a nonreactive solute will travel down approximately 1 m a^{-1}. A distribution coefficient of 100 cm^3 g^{-1} would have slowed the downward movement of ^{137}Cs to approximately 2 mm a^{-1}.

TABLE 2 ^{137}Cs Concentration (pCi L^{-1}) in Surface Water Bodies, 1986-1989

Year	Mean	Std. Dev.
1986	23.1	3.9
1987	5.02	1.01
1988	2.89	0.58
1989	2.02	0.37

2.5.4.9 Dust Mass Loading

The ^{137}Cs in air, 1 m above ground level, given in the scenario description is shown in Figure 2. The concentration of ^{137}Cs dropped steadily for 15 days after the passage of the

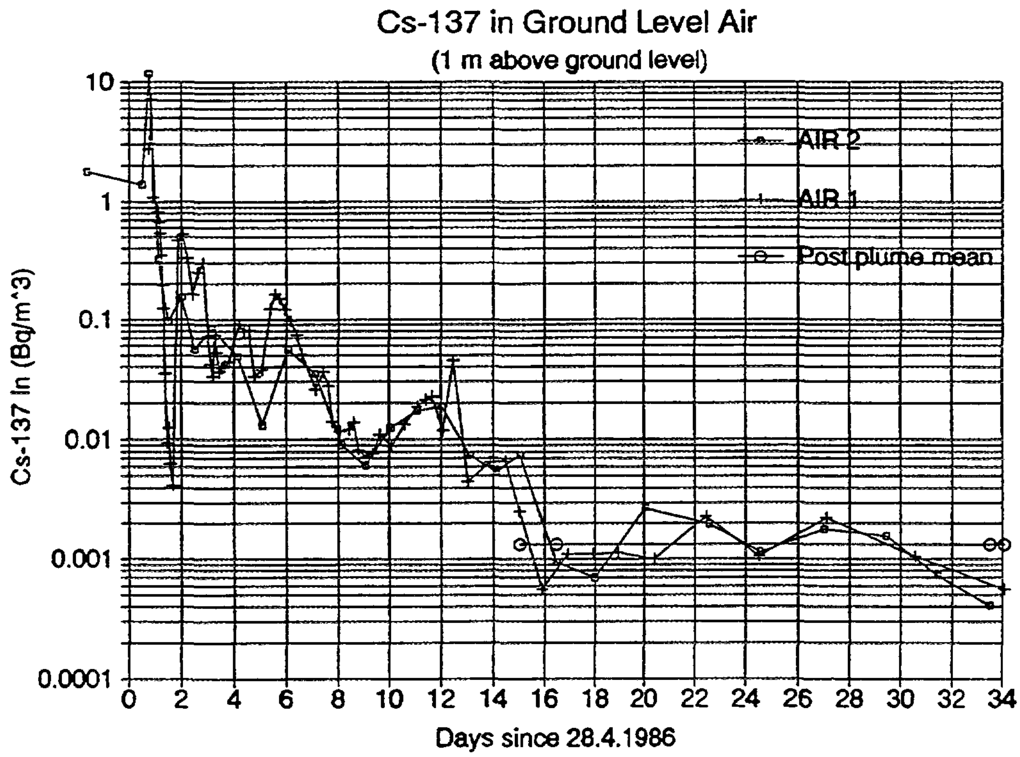

FIGURE 2 ^{137}Cs Concentration in Air, 1 Meter above Ground Level

first plume, and then steadied at a value of 0.0013 Bq m^{-3}. These air concentrations were from two monitoring stations in population region 8. The areal deposition in the population region was 13,600 Bq m^{-2}. Combination of these values with an assumed soil bulk density of 1.6 g cm^{-3} and the depth of contamination of 0.1 m gave a mass loading of 0.0156 g m^{-3}. The dilution due to soil mixing (mixing depth 0.2 m) was not considered because it was not likely to have occurred within 15 days of plume passage. The calculated mass loading factor was used to calculate the inhalation dose for the first year after plume arrival. The RESRAD default of 0.0002 g m^{-3} was used for later years.

2.5.4.10 Depth of Soil Mixing

The depth of mixing was set to the value of the common plough depth of 20 cm.

2.5.4.11 Depth of Roots

The depth of roots was set to 20 cm.

2.5.4.12 Fraction of Groundwater Usage

The scenario description states that 40% of the population use surface water for household use, and the rest use groundwater. The same proportion of source was assumed for irrigation water and for livestock water.

2.5.4.13 Occupancy Factor

The fraction of time that an average individual spends indoors was assumed to be 0.85. The shielding factor of a building structure against external radiation was assumed to be 0.4. The filtration factor for dust was assumed to be 0.4.

2.5.4.14 Inhalation Rate

An inhalation rate of 7,300 $m^3\ a^{-1}$ was used.

2.5.4.15 Erosion Rate

Because of the vast extent of the contaminated region, erosion would only redistribute the ^{137}Cs within the contaminated area and not significantly affect the results. Hence the erosion rate was set at zero.

2.5.4.16 Human Food Consumption Rates

The consumption rates of adults and children for various kinds of foods were combined to obtain the consumption rates for the six food classes required by RESRAD (Table 3). The proportions of food items in each food class are given in the footnotes to the table. These proportions were used to compute the composite soil-to-food, and composite intake-to-meat transfer factors for the intake and dose runs.

2.5.4.17 Livestock Consumption Rates

The consumption rates of cattle (beef) and dairy cows are discussed in the scenario description. The silage, hay, and pasture feed rates were categorized as fodder, and the rest of the feeds were apportioned between barley and oats in the ratio of their production in the study area. Although the feeding rates varied within the study region, the consumption rates were not subjected to a statistical analysis. Since the feeding rates of pork and poultry and the water intake rates of beef cattle and dairy cows were not stipulated in the scenario description, the values in Scenario CB were used. Table 4 gives the consumption rates that were used in the runs to determine the ^{137}Cs contents of beef, milk, and pork.

Since the version of RESRAD used in this study allowed only one meat and one milk pathway and since the meat livestock and the dairy livestock are fed the same single feed (a generic fodder), a two-step, weighted-averaging procedure was required to arrive at the livestock feed rates and the livestock intake-to-edible product transfer factors. The procedure is described in Appendix A.

TABLE 3 Human Food Consumption Rates

RESRAD Food Category	Consumption (kg a^{-1})		
	Man	Woman	Child
Nonleafy[a]	300	280	211
Leafy	12.8	16.4	18.0
Milk	330	220	274
Meat and poultry[b]	75	54	71
Fish	5.5	3.7	5.0
Other seafood	0	0	0

[a] 44% fruit, 23% potato, 6% roots, 1% peas/beans, 15% wheat, 6% rye, 2% barley, 2% oats.

[b] 33% beef, 41% pork, 9% poultry, 17% eggs.

TABLE 4 Livestock Feed Consumption Rates

Feed	Consumption (kg d^{-1})			
	Dairy Cows	Beef Cattle	Pork	Poultry
Fodder	36.3	11.7	-	-
Barley	3.82	2.14	2	0.03
Oats	2.76	1.54	-	0.03
Rye	-	-	-	0.03
Wheat	-	-	-	0.03
Water	60	50	8	0.25

2.5.4.18 Soil-to-Plant Root Uptake Factors

The mean and the geometric standard deviation of the soil-to-plant transfer factor (dry weight basis) used in this study are listed in Table 5, along with the typical values of dry weight/fresh weight from IAEA (1992). The 95% uncertainty factor given in the IAEA (92) document were adjusted for areal and temporal averaging by a factor of 3 following the guidance in that document; for a lognormal distribution, the geometric standard deviation is then the 6th root of the 95% uncertainty factor.

TABLE 5 Soil-to-Plant (Root) Uptake Transfer Factors Used in this Study

	Root Uptake Transfer Factor (unitless)				
Plant	Mean	Geometric Standard Deviation	Lower σ Bound	Upper σ Bound	Dry/Wet Weight
Fodder	0.15	1.44	0.050	0.448	0.10
Barley	0.03	1.47	0.009	0.095	0.86
Oats	0.059	1.47	0.019	0.187	0.86
Rye	0.015	1.65	0.003	0.067	0.86
Wheat	0.018	1.47	0.006	0.057	0.86
Pea, bean	0.023	1.65	0.005	0.103	0.25
Potato	0.1	1.65	0.022	0.449	0.21
Root vegetable	0.28	1.57	0.072	1.084	0.13
Fruit vegetable	0.22	1.47	0.069	0.699	0.06
Spinach	0.24	1.47	0.076	0.762	0.08

2.3.4.19 Intake-to-Food Product (Livestock) Transfer Factors

Table 6 gives the distribution statistics for the intake-to-livestock food product transfer factors from IAEA (1992).

2.3.4.20 Water-to-Fish Bioaccumulation Factor

The distribution statistics for fresh water-to-fish transfer factor (bioaccumulation factor, in units of L/kg) for ^{137}Cs from IAEA (1992) are as follows: minimum = 30, likeliest = 2,000, maximum = 3,400. This factor correlates the equilibrium concentration in fish to the concentration in water.

TABLE 6 Intake-to-Animal Product Transfer Factors Used in this Study

	Transfer Factor		
Product	Minimum	Likeliest	Maximum
Eggs (d kg^{-1})	0.06	0.45	2.5
Poultry (d kg^{-1})	0.3	12	12
Pork (d kg^{-1})	0.03	0.24	1.1
Milk (d L^{-1})	0.001	0.0079	0.027
Beef (d kg^{-1})	0.015	0.051	0.056
veal (d kg^{-1})	0.04	0.18	0.56

3. COMPARISON OF OBSERVED DATA AND MODEL PREDICTIONS

The predictions for the ^{137}Cs concentrations in pasture, beef, milk, barley (oats), berries, wheat (rye), and fish deviate from the measured values. These deviations are discussed in the following sections.

3.1 TOTAL DEPOSITION

The total deposition was estimated on the basis of the scenario description. The estimated value is in good agreement with the observed value.

3.2 FOOD ITEMS CONTRIBUTING TO TOTAL DIET

3.2.1 Milk

The measured concentration in milk increased to about 30 Bq kg^{-1} by June 1986, remained in the range of 20-30 Bq kg^{-1} until the first quarter of 1987, and then declined with a half-life of 1.3 years to a value of 3 Bq kg^{-1} at the end of 1990. The RESRAD predictions declined from 3.3 to 2.7 Bq kg^{-1}. One reason for the low predictions is the underprediction (by RESRAD) of the ^{137}Cs concentration in the feed. Figure 3 illustrates the effect of the underprediction of the feed concentrations. If the milk transfer factor is applied to the specified dairy cow feed consumption rates and the measured feed (pasture, barley, oats) concentrations, the estimated range encompasses the observed range, although the spread of the estimates is much greater than the spread of the observed values (Figure 3).

3.2.2 Beef

The measured concentration in beef rose rapidly to about 100 Bq kg^{-1} by July 1986, and remained in the 100s until the second quarter of 1987, and then declined with a half-life of 1.2 years, to a value of 10 Bq kg^{-1} at the end of 1990. The RESRAD predictions declined from 4.5 to 3.5 Bq kg^{-1}. One reason for the low predictions could be the choice of distribution for the intake-to-animal product transfer factor; the transfer factor for "beef" was used instead of that of "veal" (cattle under one year of age). Another reason is the underprediction (by RESRAD) of the ^{137}Cs concentration in the feed. Figure 4 illustrates the effects of the choice of transfer factor and the underprediction of feed concentrations. If the beef transfer factor is applied to the specified cattle feed consumption rates and the measured feed (pasture, barley, oats) concentrations, the upper bound of the estimate is lower than the lower bound of the measured concentration in beef. If the veal transfer factors are used instead of beef transfer factors, the estimated range encompasses the observed range, although the spread of the estimates is much greater than the spread of the observed values.

3.2.3 Pork

The measured concentration in pork rose to a maximum in the second quarter of 1987 and then declined slowly and leveled off. The RESRAD code, being an equilibrium (nondynamic) model, was not able to predict the initial rise of pork concentration; but RESRAD predictions are in good agreement with the observed concentrations after the second quarter of 1988.

3.2.4 Cereals

The measured values of the concentration of ^{137}Cs in oats and barley show similar trends — a high value in the first year is followed by a drop in the second year and a rise over the next two years. Because of a misinterpretation of the required endpoints, the ^{137}Cs content in a mixed cereal (60% wheat, 24% oats, 8% barley, and 8% rye) was determined instead of the content in wheat and in rye. The observed ^{137}Cs content in rye and wheat dropped sharply in the second year and then declined slowly over the next three years.

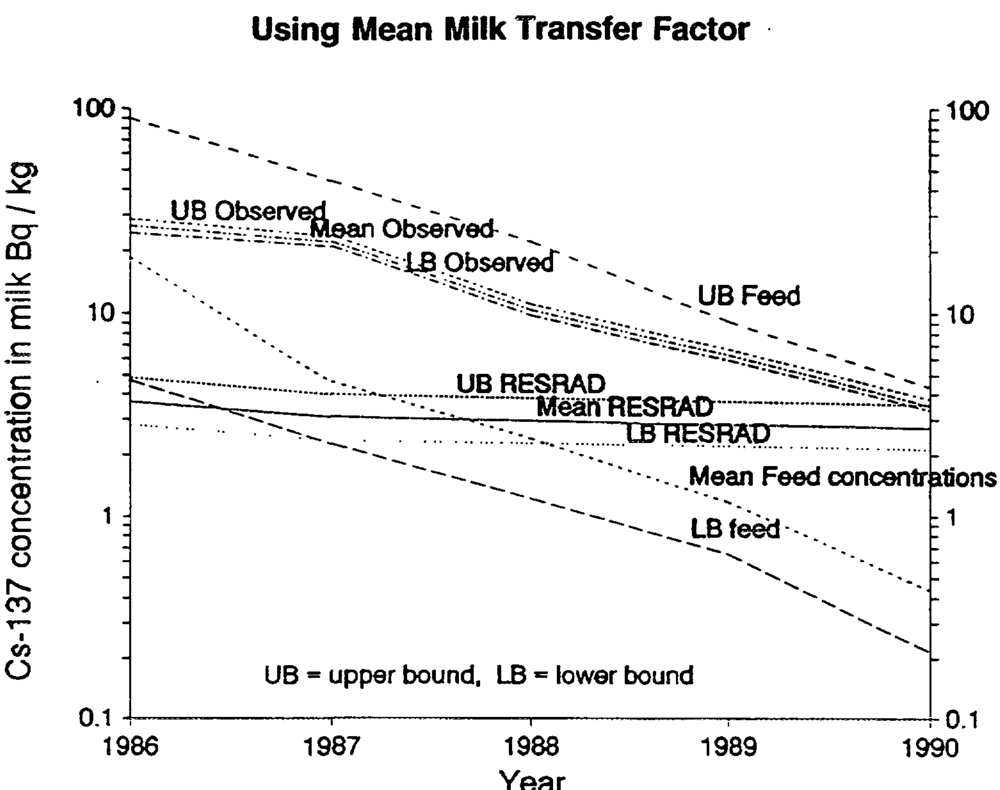

FIGURE 3 Comparison of Observed ^{137}CS Concentrations in Milk with Estimates Based on Measured and RESRAD-Predicted Concentrations in Animal Feed

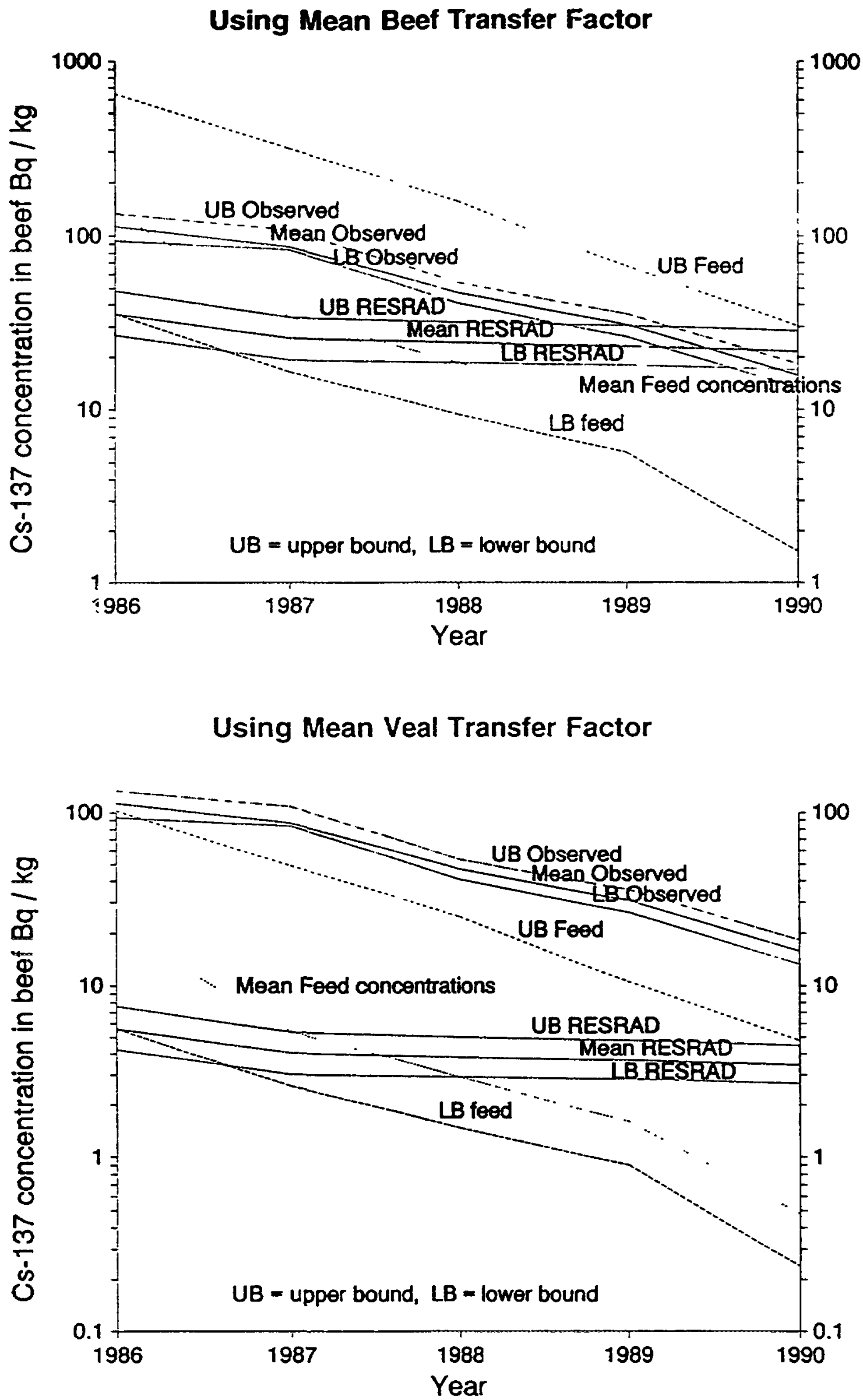

FIGURE 4 Comparison of Observed ^{137}CS Concentrations in Beef with Estimates Based on Beef and Veal Transfer Factors and on Measured and RESRAD-Predicted Concentrations in Animal Feed

3.2.5 Fish

The RESRAD predictions of ^{137}Cs content of fish agrees with the measured concentration in 1986, but is about one-fifth of the measured concentrations for the following four years. This difference could be due to the following reasons. RESRAD uses the equilibrium bioaccumulation factor, that is, the transfer factor used is simply the correlation coefficient between the equilibrium ^{137}Cs content of the edible fish and the content in water (IAEA 1992). In this scenario, the content in water falls with time. Thus, the amount of cesium in the fish includes the cesium accumulated when the water was richer in cesium. Assuming equilibrium with the water content at the time of observation will underpredict the content in fish in all but the first year. Secondly, the measurements included three classes of fish; nonpredatory, mixed-predatory, and predatory. The ^{137}Cs in the nonpredatory fish increased in 1986 and then declined over the years (Saxén 1990; Saxén and Koskelainen 1987); the RESRAD predictions agreed with these measured values. The content in predatory fish lagged the concentration in water, as would be expected because of the time required to travel up the food chain. The countrywide (Finland) annual transfer-factor (fish/water) for different years are given in Table 7 (Saxén and Koskelainen 1992).

TABLE 7 Observed Countrywide Average Annual Transfer Factors ($Bq\ kg^{-1}$ fish/$Bq\ kg^{-1}$ water) in Finland

	Non-predatory	Mixed-Predatory	Predatory
1986	300	400	200
1987	4,100	8,700	8,700
1988	5,000	11,000	16,000
1989	3,600	11,000	16,000
1990	4,200	12,000	17,000

Source: Saxén and Koskelainen (1992).

3.3 HUMAN INTAKE

The blind predictions of ^{137}Cs intake of adult humans (male and female) for the first half of 1986 and the second half of 1990 are close to the estimated values; however, the predictions for the intermediate times are about a half to a third of the estimated values. The blind predictions for intake of a child are within a factor of two of the estimated value.

3.4 WHOLE-BODY CONCENTRATION

The whole-body concentrations were calculated outside the RESRAD code with the human intake data. The equations used are described in Appendix B. The blind predictions of adult whole-body concentration compared very well with estimates by the Finnish Centre for Radiation and Nuclear Safety (STUK). The STUK estimates for males are contained within the uncertainty of limits of the RESRAD predictions, as are those for females from 1986 to 1990. The predictions for females in 1991 are almost twice the STUK estimates. The blind predictions for the whole-body concentration of children are about twice the STUK estimates throughout the prediction period.

3.5 RADIOLOGICAL DOSE

The blind predictions of total dose compare very well with the dose estimated by STUK for the periods April 1986 to April 1987 and April 1986 to December 1990. However, the prediction for the lifetime dose is 2.5 times the estimated value.

The RESRAD predictions for external dose are 1.5 to 4 times the estimated values. While the predicted and estimated inhalation dose from resuspension for the first year are comparable, the predictions for the periods April 1986 to December 1990 and April 1986 to lifetime are 10 to 40 times greater. The inhalation dose is four orders of magnitude lower than the total dose and, hence, does not affect the predictions of the total dose. The predictions for the dose due to ingestion are comparable to the estimated values.

3.6 POST-OBSERVATION MODELING

After the RESRAD predictions were compared with the measured and estimated values, the following changes were made to the RESRAD inputs. The time fraction spent outdoors was increased from 0.05 to 0.15; the indoor shielding factor for external radiation was reduced from 0.7 to 0.4; the mass loading for inhalation was set to the RESRAD default value one year after the passage of the contaminated plume; the transfer factors for veal were used instead of those of beef; and the averaging scheme for the composite meat transfer factor was changed to the leaf uptake dominant scheme shown in Appendix A.

The revised RESRAD predictions for intake agree with the STUK estimates for 1986 for adult males, females, and children. The predictions for the next four years are 4 to 2 times lower than the STUK estimates. The revised predictions for adult whole-body concentration are lower than the STUK estimates, although the STUK estimates are within the RESRAD uncertainty limits. The revised predictions for the whole-body concentration of children agree very well with the STUK estimates.

STUK revised their estimates for inhalation and ingestion doses. The revised total dose predictions are within 1.3 to 2.4 times the revised STUK estimates. The revised predictions for external dose are 1 to 3 times the STUK estimates. The revised predictions for inhalation dose from resuspension are half the revised STUK estimates. The revised predictions for the dose due to ingestion are comparable to the revised STUK estimated values for the first year and for the period April 1986 to lifetime, while the predictions are 2.0 times higher than the estimates for the period April 1986 to December 1990.

4 SUGGESTIONS TO EXTEND CAPABILITY OF RESRAD

This scenario required a wide range of animal and human diets. As mentioned before, RESRAD considers one animal feed that is applicable to both the meat and milk pathway. The human food "meat" represents all the different meats consumed by man. The intake-to-animal product transfer factors in Table 6 vary widely, by up to a factor of 500, between the different meats. The types and quantity of feed consumed by the different animals also differ greatly (Table 4). The differences between the soil-to-edible plant transfer factor for the different animal feeds, although not as great as for the animal transfer factors, are also significant (Table 5).

Foliage-to-food transfer factors (foliar deposition, sprinkler irrigation) for pasture differ from those for grains. Representing these widely differing meats and animal feeds by a single fodder and a single meat category requires rather involved approximate averaging schemes. If this averaging is to be done outside RESRAD, it defeats the purpose of a stochastic code and also increases the likelihood of human error. Hence, it is necessary to allow for a number of animal products and animal feeds — three to four animal products and two to four animal feeds should be sufficient.

Consideration should also be given to increasing the number of plant products for human consumption. The user should be able to input different values of soil-to-edible plant transfer factors and foliage-to-food translocation factors for the plant products and the animal feeds.

5 SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

A nondynamic model RESRAD was used to simulate Scenario S which requires the prediction of media concentrations under dynamic conditions. Our experience showed that although RESRAD is not specifically designed for this type of application, with proper selection of input parameters, the code can be used to predict media concentrations, especially for the later years after arrival of the plume. From this experience, we learned to predict media concentrations with uncertainties. We successfully incorporated a Monte Carlo LHS routine into RESRAD and extended RESRAD from a deterministic model to a stochastic (probabilistic) model.

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ACKNOWLEDGEMENTS

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APPENDIX A:

CALCULATION OF COMPOSITE LIVESTOCK FEED INTAKE RATES AND COMPOSITE TRANSFER FACTORS FOR THE HUMAN ^{137}CS INTAKE, RADIOACTIVE DOSE, AND BODY BURDEN RUNS

The composite soil-to-plant (root uptake) transfer factor for nonleafy vegetables was the weighted average of the root uptake transfer factors, RTF_i, of all the nonleafy vegetables; the weights being proportional to the human consumption rates, C_i, of the different food items in this class:

$$C_{nonleafy} = C_{barley} + C_{oats} + C_{rye} + C_{wheat} + C_{pea,bean} + C_{potato} + C_{root} + C_{fruit}$$
$$RTF_{nonleafy} = (RTF_{barley} \cdot C_{barley} + RTF_{oats} \cdot C_{oats} + RTF_{rye} \cdot C_{rye} + RTF_{wheat} \cdot C_{wheat} + RTF_{pea,bean} \cdot C_{pea,bean} + RTF_{potato} \cdot C_{potato} + RTF_{root} \cdot C_{root} + RTF_{fruit} \cdot C_{fruit})/C_{nonleafy}$$
$$RTF_{nonleafy} = RTF_{barley} \cdot 0.02 + RTF_{oats} \cdot 0.02 + RTF_{rye} \cdot 0.06 + RTF_{wheat} \cdot 0.15 + RTF_{pea,bean} \cdot 0.01 + RTF_{potato} \cdot 0.23 + RTF_{root} \cdot 0.44 + RTF_{fruit} \cdot 0.06$$

The composite soil-to-plant (root uptake) transfer factor for "fodder" was based on the feed consumption characteristics, CD_i, of the dairy cows and was computed as follows:

$$CD_{fodder} = CD_{barley} + CD_{oats} + CD_{pasture}$$
$$RTF_{fodder} = (RTF_{barley} \cdot CD_{barley} + RTF_{oats} \cdot CD_{oats} + RTF_{pasture} \cdot CD_{pasture})/CD_{fodder}$$
$$RTF_{fodder} = RTF_{barley} \cdot 0.09 + RTF_{oats} \cdot 0.06 + RTF_{pasture} \cdot 0.85$$

The composite intake-to-edible "meat" transfer factor, IMF_{meat}, was computed using the expression:

$$C_{meat} = C_{beef} + C_{pork} + C_{poultry} + C_{eggs}$$
$$IMF_{meat} = (IMF_{beef} \cdot C_{beef} + IMF_{pork} \cdot C_{pork} + IMF_{poultry} \cdot C_{poultry} + IMF_{eggs} \cdot C_{eggs})/C_{meat}$$
$$IMF_{meat} = IMF_{beef} \cdot 0.33 + IMF_{pork} \cdot 0.41 + IMF_{poultry} \cdot 0.09 + IMF_{eggs} \cdot 0.17$$

The water intake for meat depends on the water intake, W_i, of the different livestock products, the human consumption rates of these products, and the composite meat transfer factor above:

$$W_{meat} = \frac{W_{beef} \cdot IMF_{beef} \cdot C_{beef} + W_{pork} \cdot IMF_{pork} \cdot C_{pork} + W_{poultry} \cdot IMF_{poultry} \cdot C_{poultry} + W_{eggs} \cdot IMF_{eggs} \cdot C_{eggs}}{IMF_{meat} \cdot C_{meat}}$$
$$W_{meat} = (50 \cdot IMF_{beef} \cdot 0.33 + 8 \cdot IMF_{pork} \cdot 0.41 + 0.25 \cdot IMF_{poultry} \cdot 0.09 + 0.25 \cdot IMF_{eggs} \cdot 0.17)/IMF_{meat}$$

The fodder intake rate for meat, F_{meat}, used in the initial (blind) predictions is a two-way weighted average of the different animal feeds, F_i, the two weights being the human consumption rates of the different meat products and the root uptake transfer factor. The expression used is:

$$F_{meat} = \frac{\sum_{beef} + \sum_{pork} + \sum_{poultry} + \sum_{eggs}}{RTF_{fodder} \cdot C_{meat}}$$

$$\sum_{beef} = (F^{beef}_{pasture} \cdot RTF_{pasture} + F^{beef}_{barley} \cdot RTF_{barley} + F^{beef}_{oats} \cdot RTF_{oats}) \cdot C_{beef}$$

$$\sum_{pork} = F^{pork}_{barley} \cdot RTF_{barley} \cdot C_{pork}$$

$$\sum_{poultry} = (F^{poultry}_{barley} \cdot RTF_{barley} + F^{poultry}_{oats} \cdot RTF_{oats} + F^{poultry}_{rye} \cdot RTF_{rye} + F^{poultry}_{wheat} \cdot RTF_{wheat}) \cdot C_{poultry}$$

$$\sum_{eggs} = (F^{eggs}_{barley} \cdot RTF_{barley} + F^{eggs}_{oats} \cdot RTF_{oats} + F^{eggs}_{rye} \cdot RTF_{rye} + F^{eggs}_{wheat} \cdot RTF_{wheat}) \cdot C_{eggs}$$

It was later realized that the above weighting scheme was inappropriate. One of two other weighting schemes could be used, depending on the dominant animal intake subpathways. If the dominant animal feed intake subpathway involved uptake through the roots of the feed plants, a three-way weighting involving the human consumption rates of the different meat products, the intake-to-edible product transfer factors of the different meat products, and the root uptake transfer factor is appropriate; if not, a two-way weighting involving the human consumption rates of the different meat products and the intake-to-edible product transfer factors of the different meat products is appropriate.

If root uptake is dominant the following expression is used:

$$F_{meat} = \frac{\sum_{beef} + \sum_{pork} + \sum_{poultry} + \sum_{eggs}}{RTF_{fodder} \cdot C_{meat} \cdot IMF_{meat}}$$

$$\sum_{beef} = (F^{beef}_{pasture} \cdot RTF_{pasture} + F^{beef}_{barley} \cdot RTF_{barley} + F^{beef}_{oats} \cdot RTF_{oats}) \cdot C_{beef} \cdot IMF_{beef}$$

$$\sum_{pork} = F^{pork}_{barley} \cdot RTF_{barley} \cdot C_{pork} \cdot IMF_{pork}$$

$$\sum_{poultry} = (F^{poultry}_{barley} \cdot RTF_{barley} + F^{poultry}_{oats} \cdot RTF_{oats} + F^{poultry}_{rye} \cdot RTF_{rye} + F^{poultry}_{wheat} \cdot RTF_{wheat}) \cdot C_{poultry} \cdot IMF_{poultry}$$

$$\sum_{eggs} = (F^{eggs}_{barley} \cdot RTF_{barley} + F^{eggs}_{oats} \cdot RTF_{oats} + F^{eggs}_{rye} \cdot RTF_{rye} + F^{eggs}_{wheat} \cdot RTF_{wheat}) \cdot C_{eggs} \cdot IMF_{eggs}$$

If leaf uptake is dominant the expression becomes:

$$F_{meat} = \frac{\sum_{beef} + \sum_{pork} + \sum_{poultry} + \sum_{eggs}}{C_{meat} \cdot IMF_{meat}}$$

$$\sum_{beef} = (F^{beef}_{pasture} + F^{beef}_{barley} \cdot + F^{beef}_{oats}) \cdot C_{beef} \cdot IMF_{beef}$$

$$\sum_{pork} = F^{pork}_{barley} \cdot C_{pork} \cdot IMF_{pork}$$

$$\sum_{poultry} = (F^{poultry}_{barley} + F^{poultry}_{oats} + F^{poultry}_{rye} + F^{poultry}_{wheat}) \cdot C_{poultry} \cdot IMF_{poultry}$$

$$\sum_{eggs} = (F^{eggs}_{barley} + F^{eggs}_{oats} + F^{eggs}_{rye} + F^{eggs}_{wheat}) \cdot C_{eggs} \cdot IMF_{eggs}$$

APPENDIX B

CALCULATION OF BODY BURDEN

The body burden was estimated for six monthly intervals from December 31, 1986, to December 31, 1990, by assuming (as RESRAD does) a constant intake of ^{137}Cs for the six-month period. ^{137}Cs balance in the body requires:

$$r_{int}dt - \lambda_e q dt = dq$$

where

r_{int} = constant intake rate of ^{137}Cs,

t = time,

λ_e = effective half-life of ^{137}Cs (biological and radiological), and

q = total amount of ^{137}Cs in body.

rearranging, $\frac{dq}{dt} = -\lambda_e q + r_{int}$ and integrating gives $q = Ae^{-\lambda_e t} + \frac{r_{int}}{\lambda_e}$. Applying the initial condition, $q = q_o$ at $t = 0$ gives:

$$q = \frac{r_{int}}{\lambda_e} + \left(q_o - \frac{r_{int}}{\lambda_e}\right)e^{-\lambda_e t} \quad ,$$

substituting for total body content of ^{137}Cs in terms of body weight and concentration,

$$c = \left[\frac{r_{int}}{\lambda_e} + \left(c_o bw_o - \frac{r_{int}}{\lambda_e}\right)e^{-\lambda_e t}\right] / bw$$

where

c, c_o = concentration of ^{137}Cs in body at time t and time 0,

r_{int} = constant intake rate of ^{137}Cs,

λ_e = effective half life of ^{137}Cs (biological and radiological), and

bw, bw_o = body weight at time t and time 0.

II.11. DOSDIM

1. MODEL DESCRIPTION AND EVALUATION OF MODEL PERFORMANCE: DOSDIM MODEL

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Centre d'étude de l'énergie nucléaire,
Mol, Belgium

2. GENERAL MODEL DESCRIPTION

2.1. Name of model, model developer, model user.

DOSDIM (DOse DIstribution Model)

P. GOVAERTS, N. LEWYCKYJ, Th. ZEEVAERT - SCK•CEN, Mol (Belgium)

Users : T. Zeevaert
N. Lewyckyj

2.2. Important model characteristics.

2.2.1. Intended purpose of the model in radiation assessment

DOSDIM was developed to assess the impact to man from routine and accidental atmospheric releases. It is a compartmental, deterministic, radiological model.

For an accidental release, dynamic transfers are used in opposition to a routine release for which equilibrium transfer factors are used. Parameter values were chosen to be conservative.

Transfers between compartments are described by first-order differential equations.

The following pathways are allowed for in DOSDIM :

- External irradiation from the passing cloud
- External irradiation from deposited materials
- Inhalation from the cloud and the resuspension
- Ingestion of contaminated food.

2.2.2. Intended accuracy of the model predictions

In the initial version of DOSDIM, a conservative bias was introduced for regulatory purposes. However, for the CB-scenario the degree of conservatism was reduced and more realistic i.e. unbiased predictions were aimed at. Finally for the S-scenario, a probability distribution functions were associated to the different parameters and an uncertainty analysis was provided.

2.2.3. Method used for deriving uncertainty estimates

In order to make stochastic calculations a Latin Hypercube Sampling code was applied to DOSDIM. For each parameter a statistic distribution (e.g. normal, log normal...) is defined and the number of runs is determined by the percentiles asked for. For the S-scenario, 500 runs were made.

2.2.4. Past experiences using this model

In this last version, DOSDIM was only used for VAMP-MPA scenarios (CB and S). A preliminary version was however used before in the framework of an exploitation licence for SCK•CEN and in a dose assessment study for routine releases from a concerning calculations of doses to population in case of a routine release from a Belgian manufactury of fuel elements.

2.2.5. Modifications made for this scenario

Comparatively with the version used for the CB-scenario, DOSDIM model was improved by :

- adding an uncertainty analysis using Latin Hypercube Sampling method
- modelling winter and summer grains separately
- dividing potatoes in early and late species
- modifying the model of the beef contamination in order to obtain more realistic results in the early phase
- modifying the model of the pig contamination in a dynamic way
- adding dynamic compartments for predatory and non-predatory freshwater fishes
- adding the contribution to the dose of seafishes using equilibrium transfer factors
- dividing human intake and whole-body concentrations in five different classes (man, woman, child 15 years, child 1 year, infant 3 months) according to ICRP 56 recommendations

- weighing all calculations for the different places in the S-region according to the foodstuff production

Unfortunately our predictions concerning the deposition were not in agreement with the data given in the "Description of S-scenario - 1991". We restarted the calculations from the observed deposition data. The vegetation growing period and the animal feeding practices were adapted according to the description of the scenario.We expressed also the translocation as a constant percentage of the deposited activity.

2.3. References describing detailed documentation of model

- Commission of the European Communities
  "Seminar on the transfer of radioactive materials in the terrestrial environment subsequent to an accidental release to atmosphere"
  11-15 April 1983, Dublin (Ireland), Volume II, p. 607-637.
- IAEA-CEC
  "VAMP Multiple Pathways Assessment - Model description - Test scenario CB"
  June 1993

2.4. Model structure (see flow chart)

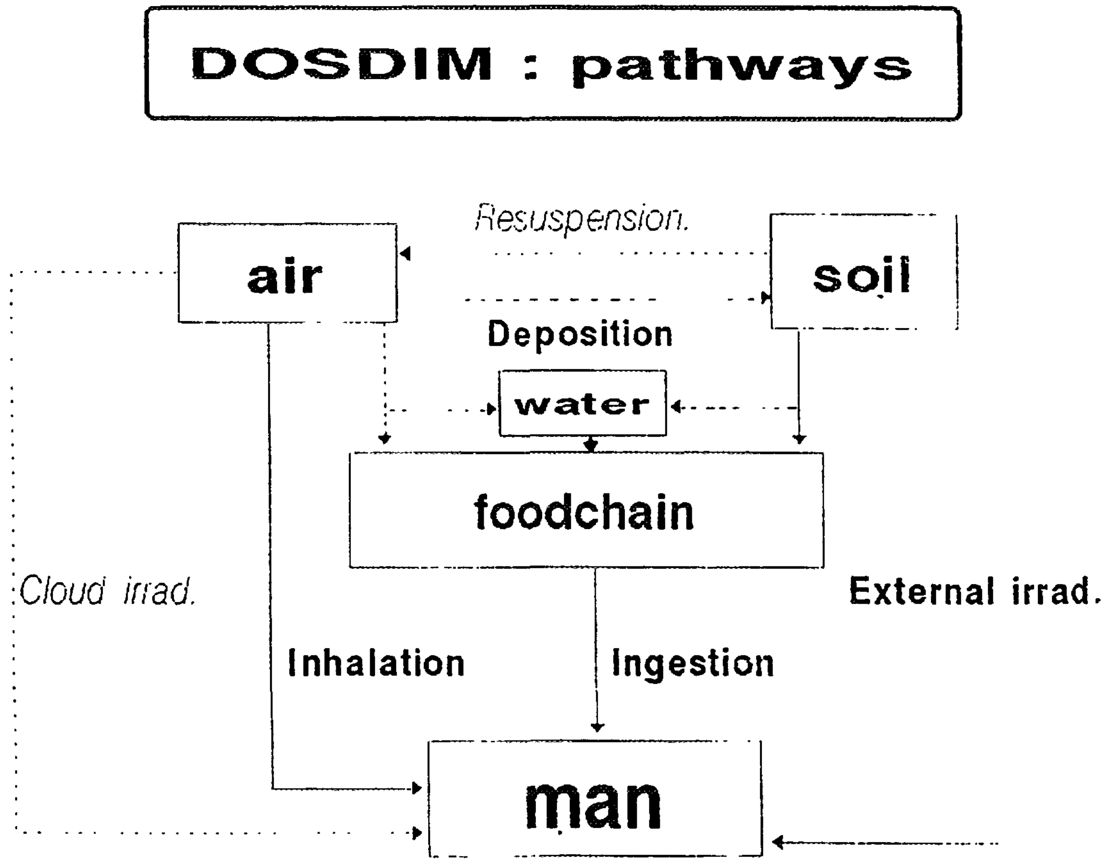
On the flow chart, the interrupted lines represent transfers in the DOSDIM model which were not considered in the S-scenario and the continuous ones the effective structure of the version used for this exercise.

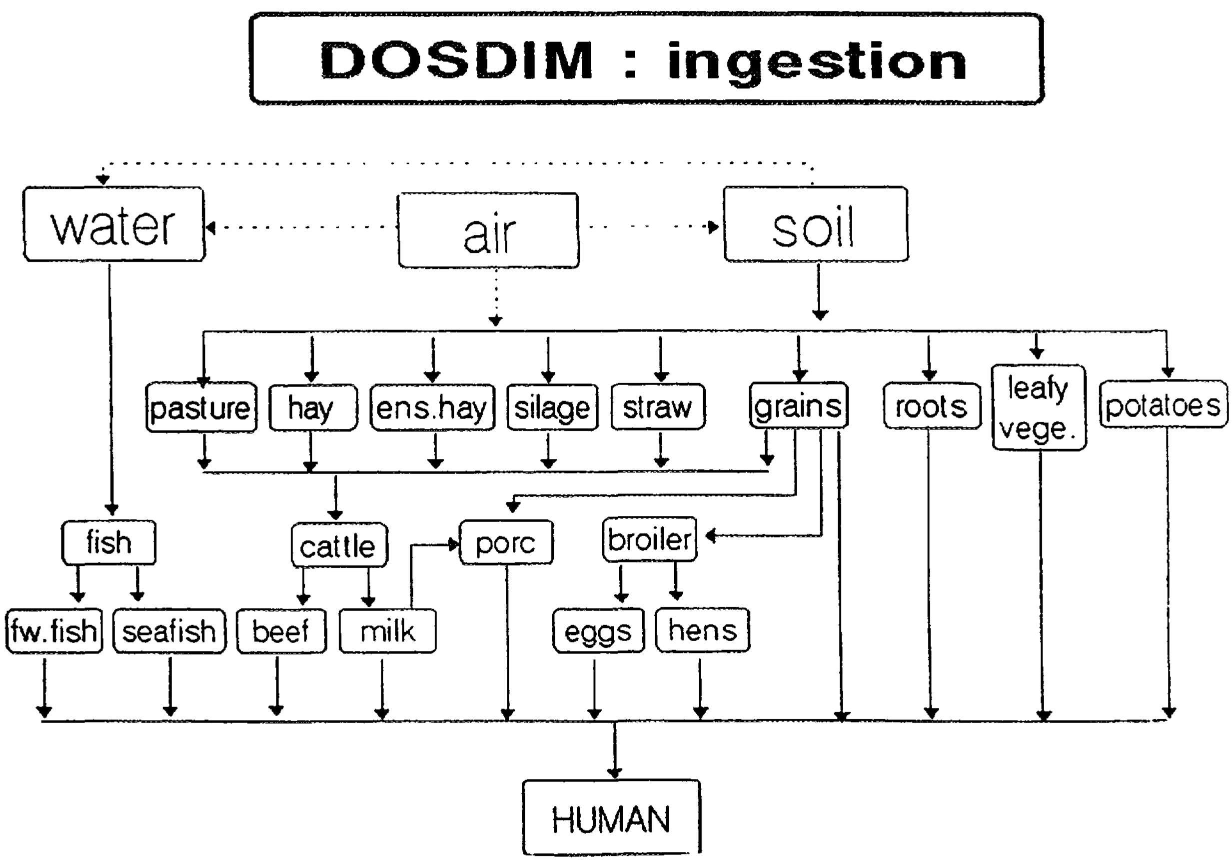
2.5. Description of procedure, equations and parameters used in different components of the model

In this description, only modifications or improvements with respect to the description and individual evaluation for CB-scenario are mentioned.

2.5.1. Total deposition

The calculated deposition does not agree with the observed one probably due to the uncertainties of data (small amount of sites for air concentration measurements) and


DOSDIM : pathways
Resuspension.
air
soil
Deposition
water
foodchain
Cloud irrad.
External irrad.
Inhalation
Ingestion
man


DOSDIM : ingestion
water
air
soil
pasture
hay
ens.hay
silage
straw
grains
roots
leafy vege.
potatoes
fish
cattle
porc
broiler
fw.fish
seafish
beef
milk
eggs
hens
HUMAN

to the size of the particles. We start our predictions from the observed deposition assuming an initial value of 19900 Bq/m^2 on 01.05.86.

2.5.2. Food items contributing to total diet

2.5.2.1. Vegetation

For this scenario we have taken into account the following vegetables or crops with their dry matter content expressed in percentage

for humans :	root crops	12 %
	cereals	86 %
	rye	86 %
	leafy vegetables	10 %
	tubers	22 %
for animals :	pasture	20 %
	hay	83 %
	ensilaged hay	22 %
	grains	86 %
	straw	86 %
	ensilage	45 %

The plant contamination was calculated in the same way as for CB, exception made for the translocation which was expressed in percentage of the interception. To determine the Bv values we use a standard type of soil with a pH = 6 and with the following composition: sand 45 % ; clay 35 % ; loam 20 %.

The probability distribution functions are given between parenthesis. LN represents a log normal distribution, U a uniform distribution and GSD the geometrical standard deviation. The parameters used were :

The lixiviation parameter λ_s = $4.29\ 10^{-2}$ (LN ; GSD = 10) for grass

$8.58\ 10^{-2}$ (LN ; GSD = 10) for the other crops

	$(R/Y)_{fw}$	$(Bv)_{fw}$	Translocation (%)
pasture	0.38 LN ; GSD = 1.6	$1.66\ 10^{-2}$ LN ; GSD = 4.6	-
hay	1.58 LN ; GSD = 1.6	$6.91\ 10^{-2}$ LN ; GSD = 4.6	-
ensilaged hay	0.42 LN ; GSD = 1.6	$1.83\ 10^{-2}$ LN ; GSD = 4.6	-
leafy vegetables	0.15 LN ; GSD = 1.6	$1.53\ 10^{-2}$ LN ; GSD = 3.1	-
straw	0.25 U ; [0.1 ; 0.4]	$1.32\ 10^{-1}$ LN ; GSD = 3.1	-
grains	0.625 U ; [0.25 ; 1.0]	$1.35\ 10^{-2}$ LN ; GSD = 4.6	10 U [3 ; 17]
rye	0.625 U ; [0.25 ; 1.0]	$1.35\ 10^{-2}$ LN ; GSD = 4.6	15 U [5 ; 25]
tubers	0.107 LN ; GSD = 2.8	$1.99\ 10^{-2}$ LN ; GSD = 2.8	15 U [5 ; 25]
root crops	0.107 LN ; GSD = 2.8	$3.95\ 10^{-3}$ LN ; GSD = 4.6	-
ensilage	0.15 LN ; GSD = 1.6	$6.89\ 10^{-2}$ LN ; GSD = 3.1	-

where the fw index represents the fresh weight value.

The weathering decay is $\lambda_w = 4.62\ 10^{-2}$ (LN ; GSD = 1.3) for the grass (pasture, hay and ensilaged hay) and $\lambda_w = 2.31\ 10^{-2}$ (LN ; GSD = 1.6) for the rest of the crops. The food and feedstuffs were harvested and consumed according to the following tables :

	Feedstuffs or foodstuffs	Harvest or cut	Period of consumption
Humans	cereals	25.09	01.11 - 31.10
	early potatoes	01.07	01.08 - 30.09
	late potatoes	15.09	01.10 - 31.07
	rye	21.07	25.09 - 24.09
	root crops	15.09	01.08 - 31.07

	Feedstuffs or foodstuffs	Harvest or cut	Period of consumption
Animals	pasture	no cut	15.05 - 20.09
	hay	01.07	21.09 - 14.05
	ensilaged hay	15.06 15.09	20.09 - 15.05 15.05 - 20.09
	grains	01.09	01.11 - 31.10
	straw	01.09	01.11 - 31 10

2.5.2.2. Milk

Cows were fed with uncontaminated feed until 25.05.86. The feeding regime was supposed to be as follows :

	Winter (kg dw/d)	Summer (kg dw/d)
Pasture	-	9.4
Hay	4.0	-
Grains	2.7	2.7
Ensilaged hay	4.6	2.3
Complete feed	2.2	-
Concentrates	1.1	-
Others	0.6	0.6
Total	15.2	15.0

The coefficients a_i for the milk model for Cs-137 (see CB-scenario) are respectively:

$a_1 = 1.1\ 10^{-3}$ (LN ; GSD = 2.0)

$a_2 = 1.9\ 10^{-4}$ (LN ; GSD = 2.0) $\Rightarrow f_m = 4.0\ 10^{-3}$

$a_3 = 2.3\ 10^{-5}$ (LN ; GSD = 2.0)

2.5.2.3. Beef

The feeding regime was supposed to be as follows :

	Winter (kg dw/d)	Summer (kg dw/d)
Pasture	-	3.0
Hay	2.4	-
Grains	2.0	2.0
Ensilaged hay	1.2	0.6
Complete feed	0.5	-
Concentrates	0.4	-
Others	0.3	0.3
Total	6.8	6.1

The beef model was revised according to Coughtrey et al. (83) for a beef of 500 kg with 300 kg meat.

$$f_{f,beef}(t) = (b1\ e^{-\beta 1.t} + b2\ e^{-\beta 2.t}) \ .\ b3\ .\ e^{-\lambda .t}$$

where $b1 = 0.1$; $b2 = 0.9$

$b3 = 7.0\ 10^{-4}$ (LN ; GSD = 2.2) $\Rightarrow f_f\,(\text{beef}) = 3\ 10^{-2}$ d/kg

$\beta 1 = 6.93\ 10^{-1}$; $\beta 2 = 2.07\ 10^{-2}$

$f_{f,beef}(t) =$ time-dependent concentration in beef after a single intake at time $t = 0$

2.5.2.4. Pork

The model used for the calculation of the contamination of the pig meat is the same as for the beef meat. The parameter values for a pig of 100 kg with 25 kg meat are then

$$f_{f,pork}(t) = (c1\ e^{-\gamma 1.t} + c2\ e^{-\gamma 2.t}) \ .\ c3\ .\ e^{-\lambda .t}$$

where $c1 = 0.1$; $c2 = 0.9$

$c3 = 9.6\ 10^{-3}$ (LN ; GSD = 2.2)

$\gamma1 = 3.3\ 10^{-1}$; $\gamma2 = 2.5\ 10^{-2}$

$f_{f,pork}$ (t) = time-dependent concentration in pork after a single intake at time t = 0

2.5.2.5. Freshwater fish (non predatory)

If C_w represents the caesium concentration in water (see scenario description), the concentration in non predatory freshwater fish is then given by :

$$C_{ffs\text{-}np}(t) = [(\lambda_r + \lambda_p).C_w(i).\ C_F] - [(\lambda_r + \lambda_p)\ C_{ffs\text{-}np}(t\text{-}1)]$$

where : $C_F = 3000$ l/kg (LN ; GSD = 3.5)

C_w (i) = concentration in the water on the i-th day

$\lambda_p = 6.94\ 10^{-3}$

$C_{ffs\text{-}np}$ (t) = isotope concentration at time t for the freshwater fish-np

λ_r = physical decay of the isotope

2.5.2.6. Freshwater fish (predatory)

The model of the predatory freshwater fish is :

$$C_{ffs\text{-}p}(t) = [(\lambda_r + \lambda_p).Q_F.\ C_{ffs\text{-}np}(t)] - [(\lambda_r + \lambda_p)\ C_{ffs\text{-}p}(t\text{-}1)]$$

where : $\lambda_p = 2.31\ 10^{-3}$

$Q_F = 1.0$ kg/y (U ; [0.4 ; 1.6])

$C_{ffs\text{-}p}$ (t) = isotope concentration at time t for the freshwater fish-p

2.5.2.7. Marine fish

The seafish concentrations were taken from the description of S-scenario document.

2.5.3. Human intake

Human intakes were taken according the scenario description. The considered foodstuffs were : rye, cereals other than rye, leafy vegetables, root crops, potatoes, milk and milk products, beef meat, pork meat, freshwater fishes, seafishes, chicken and eggs. For children a mean value was calculated from consumption rates of boys and girls. Games, mushrooms and fruits were neglected.

2.5.4. Whole-body concentration

The whole-body concentrations were predicted for 5 age categories :

- men
- women
- children 15 years old
- children 1 year old
- infants 3 months

according to ICRP-56 recommendations.

We predicted only mean whole-body concentrations (no distribution) with 95 % confidence intervals for each age category.

2.5.5. Dose calculations

2.5.5.1. External doses

The external dose from the cloud was neglected. Concerning soil irradiation we used an average value of 2 different models :

a. Dose = $C_s \cdot SF \cdot D_{cfg} \cdot T$

where C_s = the concentration in the root zone of the soil

SF = the shielding factor = 0.29

D_{cfg} = the dose conversion factor for ground deposition

= $8.0\ 10^{-14}\ Svh^{-1}/Bq\ m^{-3}$

$T = (1-e^{-\lambda s.t}) / \lambda_s$ with $\lambda_s = 0.023$

b. Model from Gale

$$\text{Dose} = \{\int_0^t [0.63 \exp(-1.13\ t) + 0.37 \exp(-0.0075\ t)] \exp(-\lambda_s . t)\ dt\}.D.SF.D_{cfg}$$

where D = total deposition

2.5.5.2. Ingestion doses

Dose = $Q_{HB} \cdot D_{cfi}$

where Q_{HB} = total human intake until the date of dose calculation

D_{cfi} = the dose conversion factor for ingestion

= $1.4\ 10^{-8}$ Sv/Bq for man and woman

= $1.3\ 10^{-8}$ Sv/Bq for children

2.5.5.3. Inhalation doses

The inhalation dose due to resuspension was neglected. Starting from the observed deposition data and a dry deposition velocity v_d of 10^{-3} m/s, a height of the plume of 1000 m and an average rainfall rate of 1.5 mm/h, we estimated average air concentrations. Admitting an average inhalation rate of 0.3 m^3/h and a dose conversion factor D_{cfc} of 8.6 10^{-9} Sv h^{-1}/Bq m^{-3} we obtained the average inhalation dose due to the cloud.

3. COMPARISON OF OBSERVED DATA AND MODEL PREDICTIONS

In our first version of predictions, a calculation code error and a misunderstanding of the results given by the LHS code lead to the fact that all the results were given with mistakes especially for wheat and freshwater fish.

3.1. Total deposition

As mentioned before, we started our modelling from the observed deposition data.

3.2. Food items contributing to total diet

3.2.1. Milk

DOSDIM overestimates the milk concentration in the early phase (05/86 - 08/86). This is probably due to strong feeding ban or to a lesser contamination of the grassland. From 09/86 until 07/87 the predictions are in good agreement with the observations. After that, DOSDIM underestimates the milk concentration by a factor of 5 to 10. This can be explained by giving continuously contaminated feed (which was stored from 86) or by high transfer factors from the different feedstuffs to the cow. Furthermore, DOSDIM does not have the same decrease from I/88 till IV/90 (half period of 2 years) due to the soil fixation. This aspect must be improved in the future.

3.2.2. Beef

We observed exactly the same behaviour for beef predictions as for the milk predictions due to the same kind of feeding regimes.

3.2.3. Pork

The predictions for pork are not in good agreement with the observations. Despite of the good dynamics from III/87 until IV/90, there is still one order of magnitude underestimation. This is probably due to the bad predictions of the two major components of the pig feed : milk and grains.

3.2.4. Freshwater fish

The dynamics of the predictions for freshwater fish are in very good agreement with the observations. Unfortunately, in the first version of predictions, a calculation code error was made and we took a C_F value which did not take into account the dependence on the concentration of K in the water according to Vanderploeg et al., 1975 (1000 l/kg instead of 3000 l/kg).

3.2.5. Leafy vegetables

During the first months there is a large difference between our predictions and the observations regarding the dynamic behaviour. The observations seem to indicate that there was no direct deposition on the leafy vegetables (in opposition to our assumptions).

3.2.6. Wheat

The predictions seem to be in good agreement with the observed data exception made for the first year where we have assumed that there was no direct deposition. We observed also the same difference in dynamic behaviour as mentioned for milk (decrease with a half period of about 2 years).

3.2.7. Rye

For rye we overestimated the concentration by a factor of 4 for the first year (due to the assumption of direct deposition) and underestimations for the rest of the time (factor 2 to 4).

3.2.8. Pasture vegetation

For pasture we obtained a slight overestimation during the first year. The dynamics of our predictions do not reflect the fixation of caesium by the soil (see 3.2.1. milk).

3.3. Human intake

Large discrepancies (factor 10 to high) were obtained in June 86 and underestimations (factor 5) from IV/87 to the end. This is mainly due to the bad estimation of the concentration in milk and freshwater fish.

3.4. Whole-body

3.4.1. <u>Mean whole-body concentration in man</u>

The bad dynamics from a factor of 7 too high to a factor of 2 too low) of the predictions is mainly due to the bad predictions for milk and freshwater fish.

3.4.2. <u>Distribution of whole-body concentrations (man)</u>

not calculated

3.5. Dose calculations

3.5.1. <u>External doses</u>

3.5.1.1. External doses from cloud

neglected

3.5.1.2. External doses from ground exposure

External doses predicted are in good agreement with those estimated in the scenario. A small discrepancy appears for the predictions of 1990 (factor of 2).

3.5.2. <u>Ingestion doses</u>

An overestimation of a factor of 3 is observed in our predictions probably due to the milk concentration for the first month. For 1990 the DOSDIM predictions are much better due to the big influence of freshwater fish consumption.

3.5.3. <u>Inhalation doses</u>

3.5.3.1. Inhalation due to resuspension

neglected

3.5.3.2. Inhalation from the cloud

The DOSDIM predictions concerning cloud inhalation doses are a factor of 10 too high, probably due to the conversion from observed deposition data to air concentrations.

4. EXPLANATION OF MAJOR SOURCES OF MISPREDICTIONS

4.1. Recommendations of changes to the model

As observed in chapter 3, DOSDIM needs to take into account the soil fixation in a more realistic way. Furthermore, we may improve DOSDIM model by :

- revising our hypothesis concerning the milk contamination
- adding model for mushrooms, wild berries and game for semi-natural ecosystems
- calculating the deposition in function of the LAI
- calculating the deposition in function of the particle size
- adding a sensitivity analysis

4.2. Examples of how changes improve calculations

Replacing the predicted milk contamination by the observed values and fish by the corrected predictions, the human caesium intake calculated by DOSDIM is improved and the predictions are in closer agreement with the observations (see fig. 1 and fig. 2).

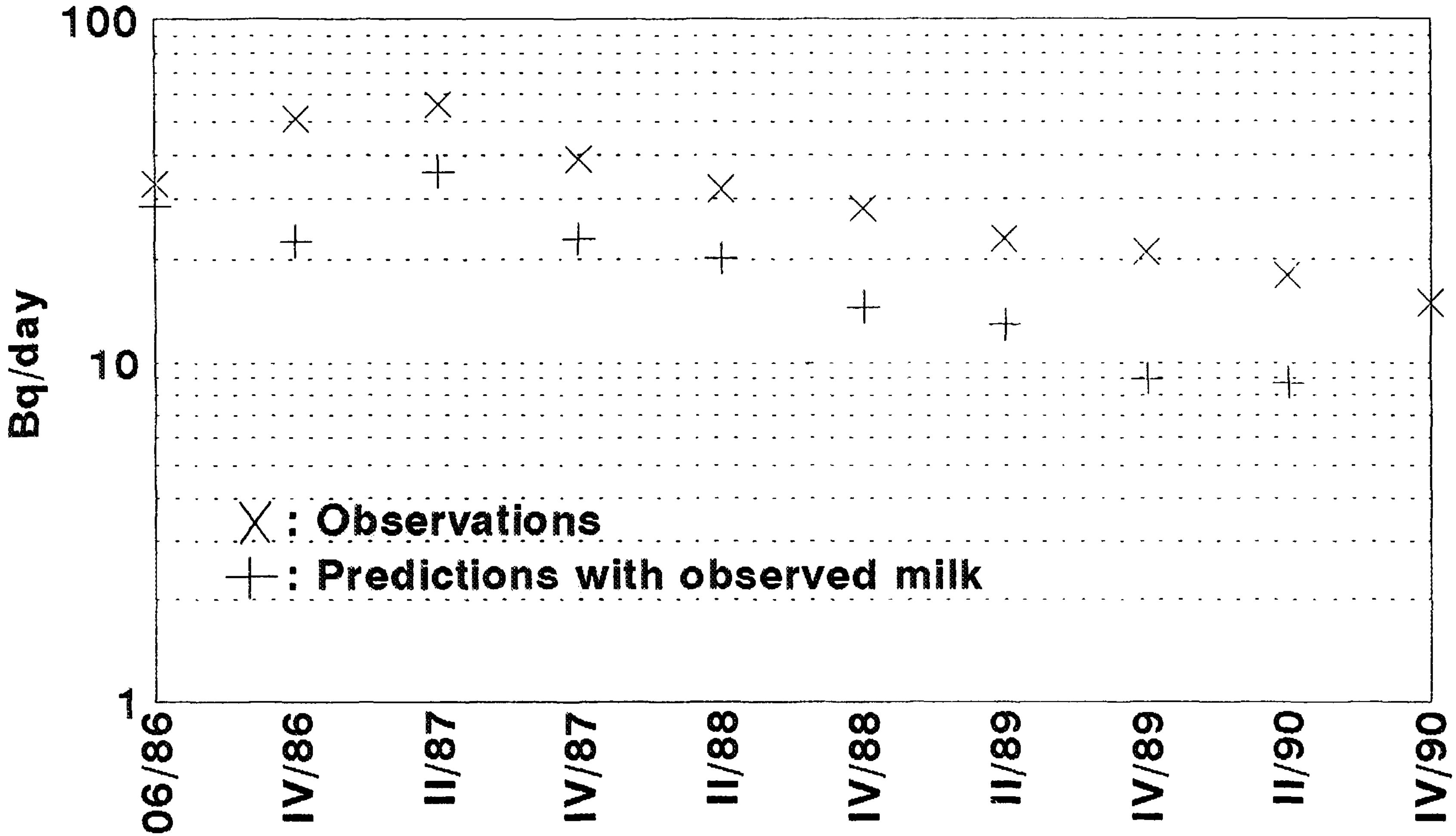


FIG. 1. Human Cs-137 intake (man).

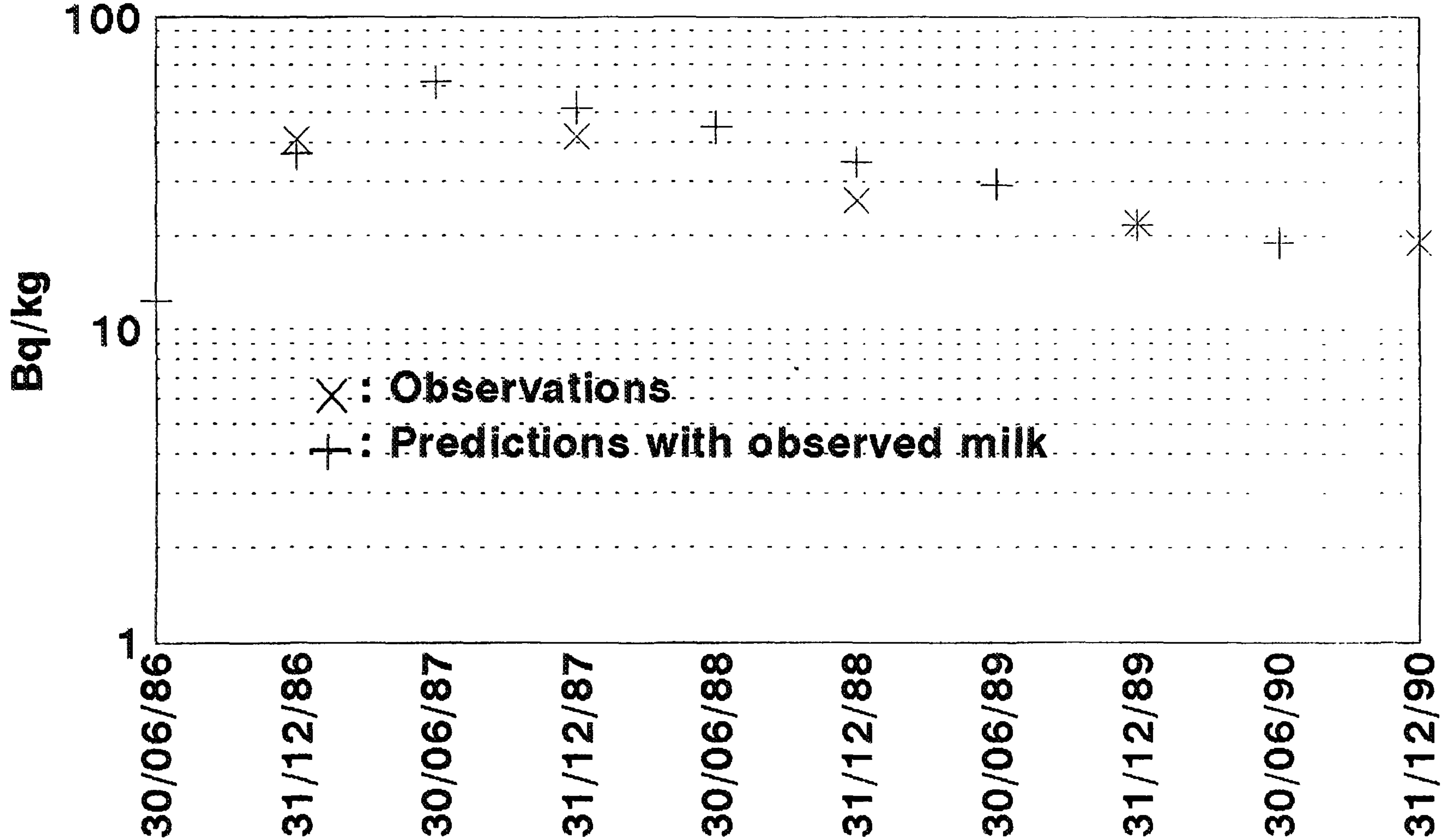


FIG. 2. Cs-137 concentration in whole body.

5. SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

The S-scenario was a good opportunity to validate our sub-models concerning freshwater fish (non predatory and predatory).

Furthermore, DOSDIM model has been made more flexible in order to be able to be applied to various regions.

On the other hand, we have observed that good predictions may appear as a result of compensation errors.

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Appendix III

DOCUMENTATION OF MODEL PREDICTIONS FOR SCENARIO S

TABLE III.1. SUMMARY OF OBS. DATA AND MODEL PREDICTIONS FOR SCENARIO S

Name->		OBS.	Zeevaert/	Peterson/	Horyna/	Suolanen/	Kanyar/	Krajewski/	Galeriu/	Sazykina/	Bergström/	Attwood/	Yu/
CODE->		DATA	DOSDIM	CHERPAC	SCHRAADLO	DETRA	TERNIRBU	CLRP	LINDOZ	ECOMOD	ECOSAFE	FARMLAND	RESRAD
III.2.	Total deposition	(•)		(•)	(•)	(•)	(•)	(•)	(•)	(•)		•	(•)
III.3.	Total inventory	(•)		•		(•)		(•)	(•)			•	(•)
III.4.	Leafy vegetables	(•)	(•)	(•)		(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.5.	Wheat	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.6.	Rye	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.7.	Milk	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.8.	Beef	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.9.	Pork	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.10.	Pasture veg.	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)		(•)	•	(•)
III.11.	Barley	(•)	(•)	(•)		(•)	(•)	(•)	(•)			•	(•)
III.12.	Oats	(•)	(•)	(•)		(•)	(•)					•	(•)
III.13.	Small game	(•)		(•)		(•)		(•)		(•)		•	
III.14.	Big game	(•)		(•)		(•)		(•)	(•)	(•)	(•)	•	
III.15.	Mushrooms	(•)		(•)	(•)	(•)		(•)	(•)	(•)	(•)	•	
III.16.	Berries	(•)		(•)		(•)		(•)	(•)	(•)	(•)		(•)
III.17.	Fish	(•)	(•)	(•)		(•)	(•)		(•)	(•)	(•)	•	(•)
III.18.	Daily intake, man	(•)	(•)	(•)		(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.19.	Daily intake, woman	(•)	(•)	(•)		(•)	(•)	(•)	(•)	(•)	(•)	•	(•)
III.20.	Daily intake, child	(•)	(•)	(•)		(•)	(•)	(•)	(•)		(•)	•	(•)
III.21.	Whole body, man	(•)	(•)	(•)	(•)	(•)	(•)	(•)	(•)		(•)	•	(•)
III.22.	Whole body, woman	(•)	(•)	(•)		(•)	(•)	(•)	(•)		(•)	•	(•)
III.23.	Whole body, child	(•)	(•)	(•)		(•)	(•)	(•)	(•)		(•)	•	(•)
III.24.	WB distr., man	•		(•)		(•)	(•)						•
III.25.	Ext. dose, cloud	(•)		(•)	•	(•)	(•)	(•)		(•)		•	
	Ext. dose, ground	(•)	(•)	(•)	•	(•)	(•)	(•)	(•)	(•)		•	(•)
III.26.	Inh. dose, cloud	(•)	(•)	(•)	(•)	(•)	(•)	•	(•)	(•)		•	
	Inh. dose, resusp.	(•)			•	(•)	(•)		(•)	(•)		•	(•)
III.27.	Ingestion dose	(•)	(•)	(•)		(•)	(•)		•	(•)		•	(•)
III.28.	Total dose	(•)	(•)	(•)		(•)	(•)	(•)		(•)		•	(•)

• only arithmetic mean
(•) both arithmetic mean and 95% confidence interval

TABLE III.2 PREDICTIONS FOR SCENARIO S
TOTAL [WET AND DRY] DEPOSITION OF CS-137 (Bq/m2)

observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
19900	13930	25870				20000	4000	57000	16000	11000	20000	20000	13800	26100	20300	12000	30000

Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
19000	6500	58000	9036						20000	14000	26000	20000	16000	24000	16800	3000	45000

TABLE III.3 PREDICTIONS FOR SCENARIO S
CS-137 TOTAL INVENTORY (BQ)

observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
3.5E+15	2.5E+15	4.6E+15				3.5E+15						2.9E+15	2.0E+15	3.8E+15	3.4E+15	2.0E+15	5.0E+15

Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
3.4E+15	3.1E+14	3.1E+16	1.6E+15									3.5E+15	2.8E+15	4.2E+15			

TABLE III.4 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN LEAFY VEGETABLES (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986				25.20	7.900	57.50	18.00	1.400	44.00	1800.00	600.00	2900.00				8.00	4.00	24.00
Jun 1986	*	*	*	12.700	1.900	34.30	4.10	0.160	12.00	260.00	89.00	430.00	18.90	12.20	25.50	8.00	4.00	24.00
Jul 1986	3.30	1.40	8.90	7.000	0.420	22.70	5.80	0.430	27.00	120.00	51.00	220.00	24.50	17.10	31.90	12.00	6.00	36.00
Aug 1986				4.000	0.083	15.70	5.20	0.430	26.00	54.00	20.00	97.00	17.40	12.20	22.60	11.00	6.00	36.00
Sep 1986				2.400	0.018	11.20	5.20	0.420	26.00	41.00	5.70	120.00	17.10	11.90	22.20	10.00	5.00	30.00
year:																		
1987	2.50	1.40	6.70	0.039	0.0013	0.23	0.56	0.070	2.80	2.30	0.70	6.20	1.60	1.10	2.00	15.00	7.00	45.00
1988	1.20	0.60	4.40	0.015	0.0009	0.07	0.55	0.068	2.70	0.92	0.29	1.60	1.10	1.00	1.50	10.00	5.00	30.00
1989	2.70	1.00	3.70	0.014	0.0008	0.07	0.53	0.065	2.70	1.30	0.31	1.90	0.70	0.60	0.80	9.00	5.00	30.00
1990	0.50	0.20	1.60	0.014	0.0008	0.07	0.52	0.064	2.60	1.00	0.30	1.70	0.65	0.50	0.80	9.00	5.00	30.00

* observed values for 1986

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986	226.00	79.00	650.00	594.00			31.30	19.50	43.20	4.80	2.40	7.20						
Jun 1986	125.00	44.00	360.00	146.00			13.90	8.02	19.80	2.90	1.60	4.20						
Jul 1986	61.00	21.00	175.00	47.00			6.70	3.65	9.75	2.10	1.30	2.60						
Aug 1986	31.00	11.00	89.00	10.20			3.59	1.91	5.26	1.60	1.10	2.10						
Sep 1986	15.00	5.30	43.00	4.48			2.19	1.19	3.19	1.30	1.00	1.60	9.90	7.20	11.90			
year:																		
1987	0.20	0.07	0.60	0.32			0.92	0.52	1.33	1.40	1.00	1.90	9.50	7.00	11.50			
1988	0.19	0.07	0.57	0.29			0.89	0.50	1.28	0.80	0.50	1.30	9.30	6.80	11.20			
1989	0.18	0.06	0.54	0.27			0.86	0.49	1.24	0.50	0.30	0.60	9.10	6.60	11.00			
1990	0.17	0.06	0.51	0.27			0.83	0.47	1.20	0.20	0.16	0.32	8.90	6.50	10.70			

TABLE III.5 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN WHEAT (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	4.90	3.43	7.35	2.05	0.035	13.60	3.60	0.510	16.00	7.20	3.20	15.00	4.90	3.40	6.30	10.20	5.00	30.00
harvest 1987	0.53	0.37	0.74	2.00	0.034	13.30	0.54	0.051	2.20	0.70	0.23	1.30	0.40	0.30	0.50	0.80	0.40	2.40
harvest 1988	0.57	0.40	0.80	1.97	0.033	13.00	0.53	0.050	2.10	0.56	0.15	0.98	0.30	0.20	0.40	0.70	0.30	2.00
harvest 1989	0.40	0.32	0.60	1.91	0.032	12.70	0.51	0.049	2.10	0.57	0.24	0.88	0.20	0.16	0.30	0.70	0.30	2.00
harvest 1990	0.26	0.18	0.39	1.86	0.032	12.40	0.50	0.047	2.00	0.50	0.21	0.80	0.20	0.16	0.30	0.60	0.30	2.00

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	2.40	0.80	6.90	0.37			25.70	17.80	33.60	6.90	4.30	9.50	2.00	1.40	2.60	13.00	3.00	31.00
harvest 1987	0.30	0.10	0.90	0.36			18.10	12.40	23.80	5.20	3.40	6.90	1.80	1.20	2.40	1.60	0.20	4.00
harvest 1988	0.29	0.09	0.87	0.35			13.20	8.74	17.60	4.30	2.60	6.00	1.80	1.20	2.40	1.60		
harvest 1989	0.27	0.09	0.81	0.34			9.91	6.27	13.50	4.30	2.60	6.00	1.70	1.20	2.30	1.60		
harvest 1990	0.26	0.08	0.78	0.33			7.63	4.57	10.70	2.60	1.70	3.40	1.70	1.10	2.20	1.50		

TABLE III.6 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN RYE (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	28.00	14.00	44.80	214.00	9.640	752.00	19.00	2.100	75.00	32.00	15.00	65.00	34.00	23.80	44.20	60.50	30.00	200.00
harvest 1987	2.80	1.96	3.36	1.94	0.032	12.90	0.84	0.080	3.40	0.89	0.29	1.80	0.50	0.40	0.60	1.30	0.70	4.00
harvest 1988	3.50	2.45	4.55	1.89	0.032	12.60	0.82	0.077	3.30	0.72	0.24	1.60	0.30	0.20	0.40	1.20	0.60	4.00
harvest 1989	1.00	0.80	1.40	1.85	0.031	12.30	0.79	0.075	3.20	0.72	0.21	1.60	0.25	0.17	0.34	1.10	0.60	4.00
harvest 1990	1.00	0.70	1.40	1.80	0.030	12.00	0.77	0.073	3.10	0.65	0.23	1.30	0.21	0.16	0.27	1.00	0.50	3.00

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	28.00	9.80	81.00	0.42			25.70	17.80	33.60	4.30	2.60	6.00	2.00	1.40	2.60	29.00	5.00	56.00
harvest 1987	0.40	0.10	1.20	0.41			18.10	12.40	23.80	3.40	1.70	5.20	1.80	1.20	2.40	1.70	0.20	4.50
harvest 1988	0.38	0.10	1.14	0.40			13.20	8.74	17.60	3.40	1.70	5.20	1.80	1.20	2.40	1.60		
harvest 1989	0.36	0.09	1.08	0.39			9.91	6.27	13.50	2.60	1.70	3.40	1.70	1.20	2.30	1.60		
harvest 1990	0.34	0.09	1.02	0.38			7.63	4.57	10.70	1.70	0.90	2.60	1.70	1.10	2.20	1.50		

TABLE III.7 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN MILK (Bq/L)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986	1.90	1.52	2.28	60.30	9.78	216.00	8.70	3.20	67.00	1.70	0.56	3.40				2.80	1.40	8.40
Jun 1986	27.70	24.93	30.47	259.00	40.40	909.00	61.00	15.00	550.00	22.00	6.40	38.00	30.60	24.50	36.60	34.00	17.00	102.00
Jul 1986	26.40	24.02	28.78	102.00	9.71	410.00	19.00	2.60	230.00	18.00	8.90	29.00	10.30	7.60	13.10	20.00	10.00	60.00
Aug 1986	21.30	19.38	23.22	44.20	3.24	184.00	7.00	0.91	80.00	13.00	6.80	22.00	8.00	5.50	10.40	12.00	6.00	36.00
Sep 1986	20.30	18.47	22.13	22.00	1.60	94.40	4.30	0.64	37.00	10.00	3.90	21.00	7.40	5.40	9.40	34.00	17.00	102.00
quarterly avg.:																		
IV 1986	30.10	28.29	31.91	40.90	5.56	140.00	14.00	1.80	170.00	17.00	6.10	30.00	7.20	5.50	9.00	66.00	33.00	200.00
I 1987	32.70	31.07	34.99	62.00	5.65	237.00	15.00	1.80	180.00	16.00	5.30	30.00	7.00	5.40	8.70	71.00	35.00	210.00
II 1987	27.50	25.85	29.43	29.70	2.84	111.00	2.70	0.50	21.00	12.00	5.10	19.00	5.60	4.10	7.00	50.00	25.00	150.00
III 1987	14.40	13.68	15.26	3.80	0.36	16.70	1.90	0.36	10.00	7.60	2.30	12.00	5.80	4.00	7.60	16.00	8.00	48.00
IV 1987	13.80	13.11	14.77	1.91	0.23	7.85	1.80	0.35	10.00	5.30	2.10	9.70	3.25	2.60	3.90	4.00	2.00	12.00
I 1988	13.10	12.31	14.02	1.46	0.11	6.98	1.80	0.33	10.00	2.80	0.81	4.70	2.75	1.90	3.60	3.20	1.60	10.00
II 1988	12.10	11.37	12.95	1.43	0.13	6.87	1.30	0.24	6.90	2.10	0.71	3.30	2.75	1.90	3.60	2.40	1.20	7.20
III 1988	8.00	7.60	8.48	1.37	0.04	10.10	1.20	0.23	6.70	1.20	0.30	1.90	5.00	3.40	6.50	1.40	0.70	5.00
IV 1988	8.40	7.98	8.99	1.47	0.12	7.31	1.10	0.17	6.50	1.10	0.28	1.80	2.50	1.70	3.30	1.30	0.60	4.00
I 1989	8.20	7.71	8.77	1.36	0.08	6.77	1.10	0.17	6.50	0.96	0.20	1.90	2.30	1.60	3.00	1.20	0.60	4.00
II 1989	7.30	6.86	7.81	1.38	0.12	6.70	0.90	0.14	4.90	0.86	0.06	1.80	2.30	1.60	5.00	0.90	0.50	3.00
III 1989	4.90	4.66	5.24	1.34	0.04	9.86	0.80	0.14	4.70	0.49	0.09	0.91	4.30	3.00	5.70	0.70	0.40	3.00
IV 1989	4.70	4.42	5.03	1.43	0.12	7.14	0.80	0.12	4.70	0.43	0.14	0.73	2.20	1.50	2.80	0.30	0.20	3.00
I 1990	4.20	3.95	4.49	1.32	0.08	6.61	0.80	0.12	4.70	0.41	0.23	0.87	1.90	1.35	2.50	0.30	0.20	2.00
II 1990	3.80	3.61	4.07	1.35	0.11	6.54	0.70	0.11	3.80	0.34	0.18	0.64	2.00	1.40	2.60	0.30	0.20	2.00
III 1990	3.20	3.04	3.42	1.30	0.03	9.63	0.70	0.11	3.70	0.27	0.14	0.39	3.80	2.60	5.00	0.30	0.20	2.00
IV 1990	2.90	2.73	3.10				0.60	0.10	3.70	0.23	0.11	0.37	1.80	1.30	2.30	0.30	0.20	2.00

TABLE III.7 (cont.)
CONCENTRATIONS IN MILK (Bq/L)

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986	7.70	2.70	22.10	0.38			48.40	29.20	67.50	2.00	1.00	3.00				6.70	1.00	19.00
Jun 1986	40.00	14.00	115.00	1.44			43.40	24.20	62.50	48.00	30.00	66.00				40.00	10.00	110.00
Jul 1986	35.00	12.30	100.70	0.31			21.30	11.30	31.20	16.00	11.00	21.00				21.00	3.50	50.00
Aug 1986	25.00	8.80	71.90	0.18			11.70	6.27	17.20	10.00	6.00	14.00				9.00	1.40	25.00
Sep 1986	21.00	7.40	60.40	3.11			7.46	4.21	10.70	25.00	17.00	33.00				8.00	1.90	20.00
quarterly avg.:																		
IV 1986	35.00	12.30	100.70	145.00			43.20	25.10	61.20	28.00	22.00	54.00	3.30	0.70	6.20	39.00	5.00	100.00
I 1987	36.00	12.60	103.50	357.00			43.20	25.10	61.20	33.00	24.00	56.00				40.00	5.00	102.00
II 1987	29.00	10.20	83.40	254.00			3.62	2.11	5.14	19.00	12.00	26.00				20.00	7.00	90.00
III 1987	16.00	5.60	46.00	20.20			3.59	2.09	5.09	3.00	2.00	4.00				10.00	4.00	41.00
IV 1987	7.10	2.50	20.40	16.70			3.46	1.98	4.94	6.00	4.00	8.00	3.00	0.70	5.70	2.00	0.50	10.00
I 1988	6.00	2.10	17.30	34.00			3.43	1.96	4.90	6.00	4.00	8.00				2.00	0.50	5.00
II 1988	4.60	1.60	13.20	28.30			3.50	2.04	4.96	3.00	2.00	4.00				1.00	0.30	4.00
III 1988	2.10	0.70	6.00	3.78			3.47	2.02	4.91	1.00	0.60	1.40				1.00	0.20	3.00
IV 1988	3.30	1.20	9.50	7.78			3.34	1.92	4.77	2.00	1.40	2.60	2.90	0.70	5.50	1.00	0.20	2.80
I 1989	3.10	1.10	8.90	17.30			3.31	1.90	4.72	2.00	1.50	2.50				0.70	0.20	1.50
II 1989	2.70	0.90	7.80	16.30			3.38	1.97	4.78	1.00	0.60	1.40				0.70	0.20	2.00
III 1989	1.90	0.70	5.50	2.75			3.35	1.95	4.74	0.50	0.20	0.80						
IV 1989	1.80	0.60	5.20	4.18			3.23	1.85	4.60	1.00	0.60	1.40	2.80	0.60	5.40			
I 1990	1.60	0.60	4.60	10.40			3.20	1.84	4.56	1.00	0.60	1.40						
II 1990	1.80	0.60	5.20	10.30			3.26	1.90	4.62	0.60	0.40	0.80						
III 1990	1.90	0.70	5.50	1.88			3.23	1.89	4.58	0.20	0.10	0.30						
IV 1990	1.60	0.60	4.60	3.18			3.12	1.79	4.44	0.40	0.20	0.60	2.70	0.60	5.30			

TABLE III.8 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN BEEF (Bq/kg)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986	9.20	6.16	12.51	20.00	1.94	79.90	0.71	0.11	1.90	2.10	0.52	7.10				0.70	0.30	2.00
Jun 1986	41.00	33.21	49.61	322.00	26.60	2222.00	0.25	0.04	0.65	5.50	0.80	10.00	167.00	135.00	200.00	37.00	18.00	110.00
Jul 1986	97.00	79.54	116.40	323.00	22.10	1420.00	56.00	6.90	420.00	78.00	25.00	140.00	155.00	120.00	190.00	44.00	22.00	180.00
Aug 1986	106.00	87.98	125.08	213.00	14.40	1005.00	110.00	14.00	850.00	60.00	26.00	120.00	125.00	94.00	155.00	37.00	18.00	110.00
Sep 1986	100.00	80.00	121.00	127.00	7.93	924.00	130.00	16.00	990.00	59.00	23.00	96.00	115.00	86.00	144.00	37.00	18.00	110.00
quarterly avg.:																		
IV 1986	126.00	104.58	147.42	122.00	10.50	618.00	67.00	7.10	510.00	61.00	28.00	91.00	116.00	88.00	144.00	110.00	55.00	330.00
I 1987	134.00	116.58	154.10	239.00	12.40	1289.00	40.00	2.80	350.00	56.00	26.00	89.00	115.00	87.00	143.00	160.00	80.00	480.00
II 1987	120.00	105.60	134.40	184.00	8.83	1003.00	39.00	2.60	340.00	52.00	28.00	86.00	102.00	77.00	128.00	140.00	70.00	420.00
III 1987	69.00	60.72	77.97	34.90	1.93	178.00	15.00	1.20	120.00	23.00	10.00	70.00	80.50	57.00	104.00	65.00	35.00	200.00
IV 1987	58.00	50.46	66.70	8.29	0.68	36.00	5.20	0.55	27.00	16.00	6.80	32.00	55.00	38.00	72.00	30.00	15.00	90.00
I 1988	57.00	48.45	66.12	4.86	0.28	24.80	4.70	0.49	23.00	12.00	4.50	20.00	48.00	33.00	63.00	9.00	4.00	27.00
II 1988	59.00	51.33	66.67	4.03	0.21	17.50	4.70	0.49	23.00	12.00	3.90	21.00	46.00	32.00	60.00	8.00	4.00	26.00
III 1988	39.00	34.32	43.68	3.13	0.11	19.10	3.60	0.35	17.00	5.70	1.10	12.00	60.00	41.00	79.00	4.10	2.00	12.00
IV 1988	33.00	29.04	37.29	3.51	0.18	17.80	3.00	0.25	15.00	4.00	1.00	7.00	45.00	31.00	59.00	3.30	1.60	10.00
I 1989	45.00	38.25	52.20	4.06	0.15	21.30	2.90	0.24	15.00	3.70	0.82	8.10	40.50	28.00	53.00	2.80	1.60	8.40
II 1989	34.00	28.90	39.10	3.82	0.19	16.90	2.90	0.23	15.00	3.20	0.81	10.00	39.00	27.00	51.00	2.20	1.10	7.00
III 1989	24.00	20.64	27.60	3.03	0.10	18.60	2.40	0.19	12.00	2.20	0.83	3.90	52.50	36.00	69.00	1.60	0.80	5.00
IV 1989	20.00	17.20	22.80	3.42	0.17	17.40	2.20	0.17	11.00	1.80	0.62	3.70	38.00	26.00	50.00	1.30	0.70	4.00
I 1990	21.00	17.85	24.36	3.95	0.15	20.80	2.10	0.17	11.00	1.70	0.86	3.20	34.00	23.60	44.00	1.10	0.50	4.00
II 1990	17.00	14.45	19.55	3.72	0.18	16.50	2.10	0.17	11.00	1.50	0.61	2.20	33.00	23.00	43.00	1.00	0.50	4.00
III 1990	13.00	10.92	15.08	2.96	0.09	18.20	1.80	0.15	9.00	1.20	0.57	2.00	45.00	31.00	60.00	0.70	0.40	3.00
IV 1990	12.00	9.96	14.04				1.70	0.14	8.40	1.00	0.48	1.70	34.00	25.00	43.00	0.60	0.30	3.00

TABLE III.8 (cont.)
CONCENTRATIONS IN BEEF (Bq/kg)

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986	4.60	1.60	13.00	1.25						2.00	1.20	2.80				9.00	2.00	25.00
Jun 1986	28.00	9.80	81.00	22.90						160.00	120.00	200.00				47.00	7.00	80.00
Jul 1986	141.00	49.00	406.00	15.80						142.00	104.00	180.00				46.00	8.00	79.00
Aug 1986	109.00	38.00	313.00	14.60						90.00	56.00	124.00				28.00	6.00	50.00
Sep 1986	76.00	27.00	219.00	18.80			54.80	24.60	84.90	70.00	44.00	96.00				25.00	4.00	40.00
quarterly avg.:																		
IV 1986	109.00	38.00	313.00	2220.00			43.00	18.70	67.30	110.00	70.00	150.00	4.50	2.50	6.50	50.00	10.00	110.00
I 1987	128.00	45.00	368.00	7530.00			36.50	15.30	57.60	125.00	90.00	160.00				60.00	11.00	120.00
II 1987	116.00	41.00	334.00	8380.00			27.80	12.70	42.90	50.00	30.00	70.00				25.00	5.00	85.00
III 1987	61.00	21.00	175.00	1800.00			21.20	10.90	31.60	20.00	14.00	26.00				15.00	4.00	65.00
IV 1987	33.00	12.00	95.00	502.00			17.60	9.62	25.50	18.00	13.00	23.00	3.80	2.20	5.70	7.00	2.00	26.00
I 1988	22.00	7.70	63.00	745.00			15.50	8.75	22.20	16.00	11.00	21.00				6.00	2.00	20.00
II 1988	18.00	6.30	52.00	869.00			14.30	8.16	20.40	16.00	11.00	21.00				6.00	2.00	20.00
III 1988	8.40	2.90	24.00	245.00			13.60	7.77	19.30	14.00	10.00	18.00				5.50	1.60	18.00
IV 1988	9.90	3.50	28.00	118.00			13.10	7.52	18.70	13.00	9.00	17.00	3.70	2.10	5.50	5.40	1.60	18.00
I 1989	10.00	3.50	29.00	385.00			12.80	7.35	18.30	12.00	8.00	16.00				5.40	1.60	18.00
II 1989	9.90	3.50	28.00	938.00			12.60	7.23	18.00	10.00	6.00	14.00				5.30	1.60	17.00
III 1989	6.80	2.40	20.00	147.00			12.40	7.13	17.70	10.00	6.00	14.00				5.30	1.50	17.00
IV 1989	6.50	2.30	19.00	230.00			12.30	7.05	17.50	8.00	4.00	12.00	3.60	2.00	5.30	5.30	1.50	17.00
I 1990	6.00	2.10	17.00	219.00			12.20	6.97	17.30	8.00	5.00	13.00						
II 1990	6.00	2.10	17.00	292.00			12.00	6.90	17.20	6.00	3.00	9.00						
III 1990	6.80	2.40	20.00	99.50			11.90	6.84	17.00	5.00	3.00	7.00						
IV 1990	6.00	2.10	17.00	71.30			11.80	6.78	16.90	5.00	3.00	7.00	3.50	2.00	5.20			

TABLE III.9 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN PORK (Bq/kg)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986	0.80	0.40	1.20	0.05	0.0027	0.24	0.66	0.1200	1.90	0.36	0.11	0.93				1.00	0.50	3.00
Jun 1986	3.40	1.36	7.82	1.16	0.0640	5.85	0.33	0.0320	1.10	0.57	0.30	1.10	5.60	4.60	6.60	4.80	2.40	14.00
Jul 1986	6.60	2.64	16.50	1.33	0.0680	6.37	0.16	0.0067	0.68	1.70	0.65	2.90	9.70	7.80	11.60	6.00	3.00	18.00
Aug 1986	6.20	4.34	8.68	0.94	0.0430	4.68	0.08	0.0016	0.43	4.20	2.20	7.60	6.90	5.20	8.60	4.80	2.40	14.00
Sep 1986	8.10	5.67	11.34	0.58	0.0270	2.97	0.04	0.0004	0.30	6.20	3.10	9.80	8.90	6.40	11.30	4.10	2.00	12.00
quarterly avg.:																		
IV 1986	9.10	5.46	15.47	0.55	0.0440	3.66	2.90	0.3800	16.00	4.80	2.30	8.90	12.60	8.90	16.30	20.00	10.00	60.00
I 1987	15.00	12.00	19.50	1.04	0.0620	6.25	3.70	0.4500	21.00	6.10	2.80	12.00	13.40	9.40	17.30	26.00	13.00	78.00
II 1987	13.00	11.70	15.60	0.97	0.0500	5.79	3.80	0.4500	22.00	6.90	2.80	12.00	13.60	9.60	17.60	26.00	13.00	78.00
III 1987	13.00	11.70	15.60	0.62	0.0210	3.99	3.80	0.4500	22.00	6.70	1.90	11.00	10.80	7.60	14.00	22.00	11.00	66.00
IV 1987	8.70	7.83	10.44	0.54	0.0100	3.69	2.70	0.3400	17.00	6.30	1.80	11.00	3.10	2.10	4.00	7.00	3.00	20.00
I 1988	6.50	5.20	7.80	0.52	0.0079	3.64	2.70	0.3200	16.00	5.40	2.20	9.70	2.10	1.40	2.70	2.20	1.10	5.00
II 1988	6.20	4.96	8.06	0.52	0.0073	3.63	2.70	0.3200	16.00	4.40	1.70	9.30	2.10	1.50	2.70	1.60	0.80	5.00
III 1988	6.10	4.27	8.54	0.52	0.0065	3.61	2.70	0.3200	16.00	4.20	1.70	9.10	3.40	2.30	4.40	1.30	0.60	4.00
IV 1988	5.70	4.56	7.41	0.51	0.0066	3.56	1.10	0.1000	6.80	3.90	1.50	8.70	1.70	1.10	2.20	1.20	0.60	4.00
I 1989	5.90	4.72	7.67	0.50	0.0070	3.55	0.58	0.0580	4.20	3.30	1.40	6.40	1.60	1.10	2.10	1.00	0.50	4.00
II 1989	6.00	4.20	7.80	0.50	0.0069	3.54	0.57	0.0540	4.10	2.80	1.20	4.90	1.70	1.20	2.20	1.00	0.50	4.00
III 1989	5.60	4.48	7.28	0.50	0.0063	3.53	0.57	0.0540	4.10	2.40	1.20	4.20	2.90	2.00	3.80	0.90	0.50	4.00
IV 1989	7.20	5.76	8.64	0.49	0.0064	3.48	0.56	0.0520	4.00	1.60	0.96	2.90	1.40	1.00	1.80	0.80	0.40	4.00
I 1990	6.70	6.03	8.04	0.49	0.0068	3.46	0.55	0.0520	3.90	1.00	0.52	2.00	1.35	0.90	1.80	0.70	0.30	3.00
II 1990	6.80	5.44	8.16	0.49	0.0067	3.46	0.55	0.0520	4.00	1.00	0.63	2.10	1.40	1.00	1.80	0.60	0.30	3.00
III 1990	6.50	3.90	10.40	0.49	0.0062	3.45	0.55	0.0520	4.00	0.83	0.44	2.00	2.50	1.70	3.30	0.60	0.30	3.00
IV 1990	6.50	5.20	8.45				0.54	0.0510	3.90	0.80	0.42	1.90	1.25	1.00	1.50	0.60	0.30	3.00

TABLE III.9 (cont.)
CONCENTRATIONS IN PORK (Bq/kg)

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
monthly avg.:																		
May 1986										1.00	0.60	1.40				7.00	2.00	15.00
Jun 1986	1.20	0.40	3.50							5.00	3.00	7.00				20.00	9.00	40.00
Jul 1986	2.30	0.80	6.60							6.00	3.00	9.00				22.00		
Aug 1986	4.30	1.50	12.40							8.00	5.00	11.00				23.00		
Sep 1986	6.50	2.30	18.70				8.20	3.3900	13.00	10.00	6.00	14.00				24.00		
quarterly avg.:																		
IV 1986	11.00	3.90	31.60				7.54	3.0100	12.10	22.00	16.00	28.00	7.10	1.80	16.70	25.00	10.00	50.00
I 1987	14.00	4.90	40.30	0.024			6.94	2.6700	11.20	21.00	15.00	27.00				22.00		
II 1987	8.50	3.00	24.40	0.024			6.41	2.3700	10.40	12.00	7.00	17.00				20.00		
III 1987	4.40	1.50	12.70	0.024			5.92	2.1000	9.74	5.00	3.00	7.00				18.00		
IV 1987	2.70	0.90	7.80	0.024			5.49	1.8700	9.12	3.00	1.50	4.50	5.90	1.50	14.20	18.00	8.00	41.00
I 1988	2.40	0.80	6.90	0.023			5.10	1.6600	8.54	3.00	1.50	4.50				18.00		
II 1988	1.90	0.70	5.50	0.023			4.75	1.4800	8.02	2.00	1.00	3.00				16.00		
III 1988	0.90	0.30	2.60	0.023			4.43	1.3200	7.54	2.00	1.00	3.00				14.00		
IV 1988	1.40	0.50	4.00	0.023			4.14	1.1700	7.10	1.50	1.00	2.00	5.70	1.40	13.70	14.00	6.00	32.00
I 1989	1.20	0.40	3.50	0.023			3.87	1.0400	6.69	1.50	1.00	2.00				13.00		
II 1989	1.00	0.40	2.90	0.023			3.63	0.9300	6.32	1.20	0.70	1.70				9.00	4.00	20.00
III 1989	0.70	0.20	2.00	0.023			3.40	0.8310	5.97	1.20	0.70	1.70				5.00	2.40	11.00
IV 1989	0.70	0.20	2.00	0.023			3.20	0.7410	5.65	1.00	0.60	1.40	5.50	1.40	13.20	4.80		
I 1990	0.60	0.20	1.70	0.022			3.01	0.6620	5.36	1.00	0.60	1.40						
II 1990	0.70	0.20	2.00	0.022			2.84	0.5920	5.08	0.80	0.40	1.20						
III 1990	0.70	0.20	2.00	0.022			2.68	0.5290	4.83	0.50	0.30	0.90						
IV 1990	0.60	0.20	1.70	0.022			2.53	0.4720	4.59	0.50	0.20	0.80	5.40	1.30	12.90			

TABLE III.10 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN PASTURE VEGETATION (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
May-1986	1500.0	1000.0	2300.0	4025.0	1389.000	10170.0	1100.0	750.00	5300.0	900.0	320.00	2300.0				6800.0	3000.0	20000.0
Jul-1986	40.0	10.0	200.0	84.3	2.840	398.0	72.0	9.60	700.0	190.0	71.00	380.0	335.0	220.0	450.0	398.0	200.0	1200.0
May-1987				4.9	0.081	32.2	8.5	1.70	40.0	8.6	4.10	14.0	80.0	50.0	110.0	9.0	5.0	30.0
Jul-1987	20.0	10.0	200.0	4.8	0.080	32.0	8.3	1.70	35.0	9.1	3.50	16.0	69.0	45.0	92.0	5.0	2.0	15.0
May-1988				4.7	0.079	31.4	5.4	1.00	23.0	2.1	0.45	4.2				3.4	2.0	11.0
Jul-1988	10.0	5.0	100.0	4.7	0.079	31.2	5.4	1.00	23.0	2.3	0.41	4.3				1.8	1.0	6.0
May-1989				4.6	0.077	30.6	3.9	0.65	17.0	0.8	0.20	1.8				0.9	0.5	3.0
Jul-1989	4.0	2.0	40.0	4.6	0.075	30.5	3.9	0.65	16.0	1.2	0.31	2.3				0.8	0.4	3.0
May-1990				4.5	0.072	29.9	3.1	0.51	13.0	0.4	0.13	1.0	38.5	27.0	50.0	0.5	0.2	2.0
Jul-1990	2.0	1.0	20.0	4.5	0.072	29.7	3.1	0.50	13.0	0.7	0.20	1.4	34.0	23.0	45.0	0.4	0.2	2.0

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
May-1986	39559.0	13846.0	113772	1030.00												2000.0	360.0	8000.0
Jul-1986	1039.0	364.0	2988.0	14.90			113.0	68.9	156.0				5.7	4.5	7.1	460.0	110.0	1100.0
May-1987	6.8	2.4	20.0	7.90												4.2	1.0	9.0
Jul-1987	19.0	6.7	55.0	8.95			52.3	35.2	69.3				5.5	4.3	6.9	4.2	1.0	9.0
May-1988	3.6	1.3	10.0	6.48												4.2	1.0	9.0
Jul-1988	12.0	4.2	35.0	6.98			50.4	34.0	66.9				5.4	4.2	6.7	4.2	1.0	9.0
May-1989	2.3	0.8	6.6	5.06												4.0	1.0	8.0
Jul-1989	8.5	2.9	24.0	5.43			48.7	32.8	64.5				5.2	4.1	6.5	4.0	1.0	8.0
May-1990	1.7	0.6	4.9	3.88														
Jul-1990	7.4	2.6	21.0	4.17			47.0	31.7	62.3				5.1	4.0	6.4			

TABLE III.11 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN BARLEY (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	3.70	2.22	7.03	2.05	0.035	13.60	7.30	0.530	47.00	6.70	3.00	13.00	9.70	6.81	12.64	10.90	5.00	30.00
harvest 1987	0.70	0.49	1.05	2.00	0.034	13.30	0.71	0.067	2.90	0.82	0.25	1.30	0.75	0.53	0.98	0.90	0.50	3.00
harvest 1988	0.70	0.56	0.91	1.97	0.033	13.00	0.69	0.065	2.80	0.60	0.17	1.00	0.59	0.41	0.76	0.80	0.40	2.50
harvest 1989	1.50	1.05	2.10	1.91	0.032	12.70	0.67	0.063	2.70	0.58	0.15	0.91	0.46	0.32	0.59	0.75	0.30	2.50
harvest 1990				1.86	0.032	12.40	0.65	0.061	2.60	0.52	0.16	0.87	0.36	0.25	0.46	0.70	0.30	2.50

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	3.00	1.10	8.60	0.456									6.40	5.10	9.10			
harvest 1987	0.40	0.10	1.20	0.442									6.20	4.90	8.80			
harvest 1988	0.38	0.10	1.14	0.429									6.00	4.80	8.60			
harvest 1989	0.36	0.09	1.08	0.417									5.90	4.70	8.40			
harvest 1990	0.34	0.08	1.02	0.404									5.70	4.60	8.20			

TABLE III.12 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN OATS (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	8.70	4.35	17.40	2.05	0.035	13.60	8.00	1.100	34.00	3.20	1.70	8.60						
harvest 1987	1.70	1.19	2.38	2.00	0.034	13.30	0.77	0.073	3.10	0.96	0.28	2.10						
harvest 1988	3.40	2.72	4.42	1.97	0.033	13.00	0.75	0.071	3.00	0.89	0.27	1.80						
harvest 1989	5.40	4.32	7.02	1.91	0.032	12.70	0.73	0.069	2.90	0.70	0.30	1.90						
harvest 1990				1.86	0.032	12.40	0.71	0.067	2.80	0.67	0.23	1.40						

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
harvest 1986	3.10	1.10	8.90	0.858									8.20	6.10	12.30			
harvest 1987	0.40	0.10	1.20	0.832									7.90	5.90	12.00			
harvest 1988	0.38	0.10	1.14	0.808									7.70	5.70	11.70			
harvest 1989	0.36	0.09	1.08	0.784									7.50	5.60	11.40			
harvest 1990	0.34	0.08	1.02	0.761									7.40	5.50	11.10			

TABLE III.13 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN SMALL GAME (Bq/kg)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	220	145	356				380	80	1600				600	300	1200			
1987							330	81	1100				550	200	1100			
1988	250	173	415				410	57	2000				400	200	800			
1989	230	161	377				290	52	1700				350	150	700			
1990	220	150	343				200	60	390				300	150	600			

	Suolanen/DETRA			Attwood/FARMLAND		Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	duck	goose	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	390	137	1122	23.20	24.80				200	120	280						
1987	371	130	1067	1.47	1.58				240	160	320						
1988	355	124	1021	1.24	1.33				640	440	840						
1989	344	120	989	0.96	1.03				400	250	550						
1990	334	117	961	0.74	0.80				480	300	660						

TABLE III.14 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN BIG GAME (Bq/kg)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	250	230	310				210	76	810				300	150	600	400	200	1500
1987	210	200	270				220	68	710				250	120	500	400	200	1500
1988	270	250	330				220	61	700				200	100	400	350	200	1500
1989	250	240	310				220	57	700				200	100	400	300	150	1500
1990	220	210	290				190	54	700				150	100	300	270	150	1500

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	273	96	785	11.90			394	368	420	140	100	180						
1987	259	91	745	0.47			381	355	406	180	120	240						
1988	252	88	725	0.41			368	343	393	360	200	520						
1989	244	85	702	0.31			355	331	380	260	200	320						
1990	236	83	679	0.23			343	319	367	300	180	420						

TABLE III.15 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN WILD, EDIBLE MUSHROOMS (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	330	230	550				340	26.0	1600				1100	200	5000	700	300	2000
1987	370	130	910				440	38.0	3200				1000	200	5000	800	300	2500
1988	460	270	840				530	1.8	2900				950	190	4750	980	400	3000
1989	670	360	1500				470	7.3	6500				900	180	4500	780	400	3000
1990	510	360	1000				380	4.0	4100				900	180	4500	600	300	2000

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	703	246	2022	1490			2050	1860	2240	1000	600	1400				170	10	1100
1987	678	237	1950	1330			1980	1800	2160	900	500	1400				170	10	1100
1988	659	231	1895	1260			1910	1740	2090	1200	800	1600				170	10	1100
1989	641	224	1844	998			1850	1680	2020	900	600	1200				170	10	1000
1990	624	218	1795	798			1790	1620	1950	700	400	1000				170	5	800

TABLE III.16 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN WILD BERRIES (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	110	80	160				99	23	240				45	15	135	200	100	600
1987	90	60	150				64	30	280				30	10	90	120	60	400
1988	150	100	250				110	36	380				15	5	45	80	40	300
1989	130	90	220				80	31	170				15	5	45	60	30	200
1990	120	80	220				69	18	140				15	5	45	40	20	150

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	140	49	403				138	113	163	180	120	240	1.6	1.0	2.5			
1987	136	48	391				134	110	158	150	110	190	1.5	0.9	2.3			
1988	132	46	380				129	106	152	210	150	270	1.4	0.8	2.3			
1989	129	45	371				125	102	147	170	130	210	1.4	0.8	2.2			
1990	125	44	360				121	99	142	200	140	260	1.3	0.8	2.1			

TABLE III.17 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN FRESHWATER FISH (Bq/kg f.w.)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	940	752	1504	216	9.2	1243	1400	470	4200	1400	580	2800				557	200	3000
1987	1580	1422	2054	328	13.9	2004	1600	530	4800	1200	690	1800				870	300	4000
1988	1020	918	1326	280	12.2	1707	1200	400	3600	660	380	1000				810	300	4000
1989	760	684	988	210	9.2	1299	930	310	2800	330	230	450				677	250	3000
1990	630	567	1008	171	7.5	1058	690	230	2100	170	110	230				533	200	2500

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
1986	374	131	1076	1730			1030	866	1260	800	500	1100	1600	270	2500			
1987	1342	470	3860	795			1210	928	1490	720	360	1080	330	56	550			
1988	1156	405	3325	456			978	736	1220	450	250	650	190	32	320			
1989	708	248	2036	323			767	572	961	330	200	460	140	22	220			
1990	374	131	1076	305			608	451	764	240	150	330	130	21	210			

TABLE III.18 PREDICTIONS FOR SCENARIO S
HUMAN INTAKE, WOMAN (Bq/d)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
June 1986	25.0	22.3	28.3	177.0	22.2	612.0	43.0	17.0	310.0	18.0	11.0	27.0	23.9	19.2	28.6	18.5	9.0	55.0
IV 1986	33.0	31.4	35.6	50.7	16.6	132.0	30.0	13.0	130.0	33.0	19.0	51.0	26.4	20.5	32.2	55.0	27.0	160.0
II 1987	37.0	35.2	41.1	44.0	11.0	118.0	25.0	11.0	60.0	28.0	12.0	37.0	25.1	19.5	30.8	36.8	18.0	110.0
IV 1987	21.0	19.5	23.9	36.9	3.8	26.9	19.0	8.0	38.0	16.0	11.0	21.0	5.1	3.5	6.7	22.6	11.0	67.0
II 1988	26.0	24.4	30.2	6.0	2.1	19.1	17.0	7.4	36.0	9.3	5.7	13.0	4.9	3.3	6.4	9.0	4.5	27.0
IV 1988	15.0	14.0	17.3	5.5	2.1	17.0	14.0	6.2	30.0	5.6	3.6	9.3	4.2	2.9	5.6	14.0	7.0	42.0
II 1989	18.0	16.9	21.1	5.1	2.0	15.2	13.0	5.3	26.0	4.2	2.3	7.0	4.1	2.8	5.5	7.0	3.5	21.0
IV 1989	12.0	10.8	15.1	4.9	2.0	14.3	11.0	4.3	22.0	2.7	1.9	5.1	4.4	3.8	4.9	12.0	6.0	36.0
II 1990	12.0	11.2	16.1	4.8	1.9	13.5	9.5	3.8	19.0	2.4	1.8	3.9	3.6	2.4	4.8	9.3	4.6	28.0
IV 1990	9.5	8.6	11.9				8.2	3.3	17.0	1.8	1.3	2.6	3.3	2.4	4.2	9.3	4.6	28.0

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
June 1986	26.0	9.1	75.0	95.9			31.8	18.7	44.9	53.0	40.0	66.0						
IV 1986	29.0	10.0	83.0	237.0			23.4	19.3	24.7	40.0	28.0	52.0	27.0	15.0	40.0			
II 1987	29.0	10.0	83.0	592.0			20.2	17.8	22.5	30.0	22.0	38.0						
IV 1987	17.0	6.0	49.0	45.5			18.6	16.5	20.7	20.0	14.0	26.0	14.0	9.0	21.0			
II 1988	15.0	5.3	43.0	72.7			17.2	15.3	19.2	17.0	12.0	22.0						
IV 1988	13.0	4.6	37.0	23.5			16.2	14.4	18.0	16.0	11.0	21.0	12.0	8.0	19.0			
II 1989	12.0	4.2	35.0	64.1			15.4	13.7	17.1	13.0	9.0	17.0						
IV 1989	9.7	3.4	28.0	23.1			14.3	12.7	15.9	12.0	8.0	16.0	11.0	7.0	17.0			
II 1990	7.8	2.7	22.0	27.9			13.7	12.1	15.2	10.0	7.5	12.5						
IV 1990	6.6	2.3	19.0	12.1			13.0	11.6	14.5	10.0	7.5	12.5	11.0	7.0	17.0			

TABLE III.19 PREDICTIONS FOR SCENARIO S
HUMAN INTAKE, MAN (Bq/d)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
June 1986	35.0	31.2	39.2	262.0	32.6	914.0	65.0	21.0	430.0	19.0	10.0	29.0	35.1	28.2	42.0	24.7	12.0	75.0
IV 1986	47.0	44.7	50.8	72.7	23.1	190.0	39.0	16.0	200.0	33.0	22.0	50.0	28.3	21.8	34.8	74.0	37.0	230.0
II 1987	52.0	49.4	57.2	62.4	15.9	167.0	31.0	13.0	73.0	32.0	21.0	42.0	26.6	20.4	32.8	49.0	25.0	150.0
IV 1987	30.0	27.9	33.9	14.8	5.5	39.8	25.0	9.7	47.0	17.0	14.0	22.0	6.5	4.4	8.5	30.2	15.0	90.0
II 1988	39.0	36.7	45.6	8.8	3.1	28.4	22.0	8.4	42.0	9.9	7.3	14.0	6.1	4.1	8.0	12.0	6.0	36.0
IV 1988	22.0	20.5	25.3	8.2	3.0	25.1	19.0	7.2	35.0	6.8	5.1	9.3	5.4	3.7	7.0	18.7	9.0	58.0
II 1989	26.0	24.2	30.4	7.6	3.0	22.6	17.0	6.2	33.0	5.8	4.1	7.7	5.2	3.5	6.8	9.3	4.0	28.0
IV 1989	16.0	14.6	19.5	7.3	2.9	21.3	14.0	5.2	28.0	4.1	2.9	5.9	4.6	3.1	6.0	15.9	8.0	48.0
II 1990	17.0	15.8	23.0	7.0	2.9	20.1	13.0	4.8	23.0	3.4	2.6	5.4	4.5	3.0	5.9	12.4	6.0	36.0
IV 1990	13.0	11.8	16.0				11.0	4.1	20.0	2.7	1.5	3.6	4.1	3.0	5.2	12.3	6.0	36.0

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
June 1986	37.0	13.0	106.0	97.8			42.2	27.2	57.2	75.0	60.0	90.0						
IV 1986	41.0	14.0	118.0	333.0			29.9	25.5	34.3	59.0	46.0	72.0	39.0	22.0	58.0			
II 1987	43.0	15.0	124.0	812.0			26.5	23.2	29.8	42.0	30.0	54.0						
IV 1987	24.0	8.4	69.0	61.9			24.6	21.6	27.7	28.0	18.0	38.0	20.0	12.0	30.0			
II 1988	21.0	7.4	60.0	99.1			22.7	19.8	25.5	22.0	15.0	29.0						
IV 1988	18.0	6.3	52.0	31.7			21.2	18.6	23.9	20.0	13.0	27.0	17.0	11.0	26.0			
II 1989	16.0	5.6	46.0	85.7			20.1	17.6	22.6	16.0	10.0	22.0						
IV 1989	13.0	4.6	37.0	25.2			18.5	16.1	20.8	15.0	10.0	20.0	16.0	10.0	24.0			
II 1990	11.0	3.9	32.0	37.7			17.6	15.4	19.8	13.0	9.0	17.0						
IV 1990	9.0	3.2	26.0	15.9			16.7	14.6	18.8	13.0	9.0	17.0	15.0	10.0	24.0			

TABLE III.20 PREDICTIONS FOR SCENARIO S
HUMAN INTAKE, CHILD (Bq/d)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
June 1986	25.0	22.5	28.0	224.0	26.8	783.0	46.0	12.0	380.0	17.0	11.0	25.0	24.0	19.2	28.6	22.5	11.0	68.0
IV 1986	32.0	30.4	33.9	56.3	14.5	156.0	23.0	9.2	160.0	30.0	21.0	40.0	25.0	19.4	30.5	60.5	30.0	180.0
II 1987	33.0	31.4	35.3	47.1	8.8	137.0	15.0	7.1	47.0	25.0	17.0	35.0	23.7	18.3	29.1	40.8	21.0	120.0
IV 1987	18.0	17.1	19.6	7.1	2.1	15.8	10.0	4.5	22.0	13.0	9.6	17.0	5.0	3.4	6.6	20.7	10.0	61.0
II 1988	19.0	18.1	20.9	3.0	0.9	8.9	8.9	3.9	20.0	8.4	5.8	12.0	4.7	3.2	6.2	5.9	3.0	18.0
IV 1988	13.0	12.4	14.3	2.9	0.9	9.3	7.3	3.2	17.0	6.4	4.3	8.7	4.2	2.8	5.5	9.7	5.0	30.0
II 1989	12.0	11.4	13.1	2.8	0.8	7.9	6.4	2.8	14.0	4.7	3.5	6.1	4.1	2.8	5.4	4.2	2.0	13.0
IV 1989	9.8	9.1	11.7	2.7	0.8	8.8	5.4	2.3	12.0	3.3	2.4	4.4	3.6	2.4	4.8	7.9	4.0	24.0
II 1990	6.7	6.4	7.6	2.7	0.8	7.6	4.8	2.1	10.0	3.0	2.1	4.0	3.5	2.4	4.6	6.0	3.0	18.0
IV 1990	7.5	7.1	8.9				4.2	1.8	8.9	2.4	1.5	3.5	3.2	2.4	4.1	6.1	3.0	18.0

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
June 1986	32.0	11.0	92.0	103.0			40.0	20.0	59.9									
IV 1986	31.0	11.0	89.0	291.0			18.2	13.7	22.6				33.0	17.0	49.0			
II 1987	28.0	9.8	81.0	702.0			14.0	11.9	16.1									
IV 1987	13.0	4.6	37.0	51.6			12.7	10.8	14.6				15.0	9.0	23.0			
II 1988	11.0	3.9	32.0	84.0			11.8	10.0	13.6									
IV 1988	8.8	3.1	25.0	25.6			11.1	9.4	12.8				13.0	8.0	20.0			
II 1989	8.2	2.9	24.0	72.5			10.6	9.0	12.2									
IV 1989	6.8	2.4	20.0	20.0			9.9	8.4	11.5				12.0	8.0	18.0			
II 1990	5.6	2.0	16.0	31.2			9.5	8.0	11.1									
IV 1990	5.1	1.8	15.0	12.3			9.1	7.6	10.6				12.0	8.0	18.0			

TABLE III.21 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN WHOLE BODY, WOMAN (Bq/kg)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
30-Jun-86	4.7	4.0	5.6	69.6	9.2	233.0	15.0	6.4	110.0	1.7	1.2	2.3	3.9	3.1	4.6	5.3	3.0	15.0
31-Dec-86	27.1	22.8	32.3	66.8	26.7	166.0	49.0	22.0	210.0	12.0	7.1	19.0	32.7	23.7	37.7	50.2	25.0	130.0
30-Jun-87	36.7	31.2	43.2	57.8	16.1	152.0	53.0	23.0	170.0	17.0	9.2	24.0	50.7	42.0	63.4	58.5	28.0	150.0
31-Dec-87	30.3	25.8	35.7	20.2	7.3	49.0	43.0	17.0	94.0	16.0	9.2	23.0	41.0	31.2	50.8	37.2	18.0	100.0
30-Jun-88	19.8	17.5	22.4	9.1	3.5	25.6	37.0	13.0	74.0	13.0	8.8	20.0	20.5	15.0	26.0	21.7	10.0	50.0
31-Dec-88	17.1	15.1	19.3	7.0	2.7	21.5	31.0	11.0	61.0	12.0	6.1	18.0	15.4	10.8	20.0	18.6	9.0	45.0
30-Jun-89	16.8	14.0	20.1	6.3	2.4	18.5	27.0	10.0	57.0	9.9	4.3	15.0	11.3	7.8	14.8	13.6	6.0	29.0
31-Dec-89	14.4	12.0	17.3	6.0	2.4	17.7	23.0	8.1	49.0	7.9	3.4	12.0	11.3	7.7	15.0	14.8	7.0	30.0
30-Jun-90	10.7	9.5	12.2	5.8	2.3	16.4	21.0	7.5	41.0	6.3	3.2	10.0	6.1	4.2	8.1	13.6	7.0	30.0
31-Dec-90	10.8	9.5	12.3				17.0	6.1	34.0	3.7	1.8	5.8	6.4	4.3	8.5	13.6	7.0	30.0

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
30-Jun-86	8.4	6.6	12.0	105.0			23.9	14.2	33.6									
31-Dec-86	39.0	30.0	58.0	219.0			33.9	27.4	40.3				42.0	24.0	61.0			
30-Jun-87	53.0	41.0	78.0	710.0			37.9	33.0	42.8				26.0	16.0	40.0			
31-Dec-87	40.0	31.0	59.0	173.0			34.5	30.6	38.5				24.0	16.0	33.0			
30-Jun-88	30.0	23.0	44.0	106.0			31.3	27.7	34.9				21.0	14.0	31.0			
31-Dec-88	25.0	20.0	37.0	41.1			29.1	25.7	32.4				21.0	13.0	31.0			
30-Jun-89	22.0	17.0	33.0	69.6			27.2	24.1	30.3				19.0	12.0	29.0			
31-Dec-89	19.0	15.0	28.0	42.3			25.2	22.3	28.0				19.0	12.0	29.0			
30-Jun-90	16.0	12.0	24.0	36.9			23.7	21.0	26.4				19.0	12.0	28.0			
31-Dec-90	13.0	10.0	19.0	19.3			22.5	19.9	25.0				19.0	12.0	28.0			

TABLE III.22 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN WHOLE BODY, MAN (Bq/kg)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
30-Jun-86	7.2	5.8	8.9	112.0	14.5	377.0	19.0	7.6	130.0	1.6	1.0	2.3	4.9	3.9	5.8	5.5	2.5	12.0
31-Dec-86	41.1	33.0	51.1	146.0	45.3	376.0	61.0	27.0	320.0	10.0	5.5	15.0	31.4	24.1	38.7	59.0	30.0	130.0
30-Jun-87	50.4	44.2	57.4	145.0	43.5	372.0	67.0	30.0	290.0	16.0	10.0	22.0	48.4	37.3	59.5	82.0	40.0	180.0
31-Dec-87	41.6	36.5	47.3	71.1	25.7	163.0	58.0	22.0	150.0	20.0	12.0	27.0	38.9	28.9	47.9	59.0	30.0	130.0
30-Jun-88	30.1	26.3	34.4	34.9	13.9	84.9	51.0	18.0	120.0	17.0	11.0	24.0	20.2	14.6	25.8	38.0	19.0	100.0
31-Dec-88	25.9	22.6	29.7	22.4	9.1	60.2	43.0	16.0	89.0	13.0	7.6	18.0	16.3	11.4	21.2	29.0	15.0	80.0
30-Jun-89	25.8	21.3	31.3	17.7	7.2	50.2	38.0	13.0	77.0	9.8	4.9	15.0	12.1	8.3	15.8	22.0	10.0	50.0
31-Dec-89	22.2	18.3	26.9	15.7	6.3	46.8	31.0	12.0	65.0	8.5	5.1	14.0	12.4	8.5	16.4	22.0	10.0	50.0
30-Jun-90	18.0	15.7	20.7	14.7	6.0	41.2	28.0	9.9	57.0	6.7	4.2	10.0	9.8	6.7	12.9	20.5	10.0	50.0
31-Dec-90	18.1	15.8	20.8				24.0	8.2	48.0	4.0	2.5	5.7	10.2	6.5	14.0	20.2	10.0	50.0

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
30-Jun-86	10.0	7.8	15.0	95.1			27.8	17.6	37.9							10.0	6.0	18.0
31-Dec-86	47.0	37.0	70.0	319.0			51.9	41.9	61.9				49.0	27.0	73.0	23.0	15.0	42.0
30-Jun-87	75.0	59.0	111.0	1150.0			64.6	55.7	73.4				31.0	18.0	46.0	40.0	21.0	75.0
31-Dec-87	59.0	46.0	87.0	479.0			63.1	55.4	70.9				27.0	17.0	42.0	31.0	17.0	58.0
30-Jun-88	43.0	34.0	64.0	275.0			58.5	51.3	65.8				24.0	15.0	37.0	7.1	3.9	13.5
31-Dec-88	34.0	27.0	50.0	126.0			54.2	47.5	61.0				23.0	15.0	36.0	4.6	2.8	9.0
30-Jun-89	29.0	23.0	43.0	132.0			50.4	44.1	56.8				22.0	14.0	34.0	3.0	1.6	5.7
31-Dec-89	25.0	20.0	37.0	72.9			46.4	40.5	52.3				22.0	14.0	33.0	2.4	1.3	4.7
30-Jun-90	21.0	16.0	31.0	68.1			43.3	37.8	48.8				21.0	13.0	32.0			
31-Dec-90	17.0	13.0	25.0	41.9			40.7	35.5	45.9				21.0	13.0	32.0			

TABLE III.23 PREDICTIONS FOR SCENARIO S
CONCENTRATIONS IN WHOLE BODY, CHILD (Bq/kg)

	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
30-Jun-86	7.0	5.4	9.1	156.0	15.2	390.0	26.0	9.4	210.0	1.6	1.1	2.3	5.2	4.2	6.1	5.8	3.0	15.0
31-Dec-86	40.2	31.1	52.1	128.0	36.9	320.0	44.0	18.0	300.0	9.2	5.6	13.0	24.6	19.0	30.2	45.3	23.0	120.0
30-Jun-87	34.1	26.1	44.5	117.0	28.9	327.0	34.0	14.0	170.0	13.0	7.2	17.0	31.7	24.6	30.8	46.0	23.0	120.0
31-Dec-87	28.1	21.5	36.7	44.6	12.9	104.0	21.0	9.4	52.0	13.0	7.2	16.0	16.6	12.2	20.7	23.0	11.0	55.0
30-Jun-88	18.8	14.9	23.6	16.1	5.5	38.8	18.0	8.0	43.0	10.0	5.3	14.0	6.9	4.8	9.0	10.5	5.0	25.0
31-Dec-88	16.2	12.9	20.3	8.6	3.3	21.5	15.0	6.7	34.0	7.1	4.0	10.0	6.9	4.6	9.0	9.0	5.0	25.0
30-Jun-89	12.6	10.1	15.8	6.6	2.3	19.0	13.0	5.8	30.0	5.0	3.3	6.9	5.3	3.6	7.0	5.6	3.0	15.0
31-Dec-89	10.8	8.7	13.5	5.9	1.9	17.3	11.0	4.7	24.0	4.1	2.4	6.6	5.9	4.0	7.8	7.0	3.0	19.0
30-Jun-90	9.2	6.8	12.4	5.7	1.8	17.6	9.8	4.3	22.0	3.4	1.9	5.7	4.6	3.1	6.0	6.1	3.0	20.0
31-Dec-90	9.3	6.9	12.5				8.4	3.6	18.0	2.6	1.5	4.4	5.6	4.3	6.8	6.2	3.0	20.0

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
30-Jun-86	25.0	20.0	37.0	105.0			55.4	27.8	82.9									
31-Dec-86	51.0	40.0	75.0	227.0			46.4	34.2	58.5				85.0	44.0	125.0			
30-Jun-87	64.0	50.0	95.0	607.0			43.8	36.5	51.1				48.0	28.0	72.0			
31-Dec-87	38.0	30.0	56.0	57.4			37.4	32.2	42.7				40.0	25.0	61.0			
30-Jun-88	24.0	19.0	36.0	71.2			33.8	28.9	38.6				31.0	19.0	47.0			
31-Dec-88	19.0	15.0	28.0	21.7			31.3	26.7	35.8				29.0	18.0	44.0			
30-Jun-89	18.0	14.0	27.0	59.7			29.3	25.0	33.6				25.0	16.0	38.0			
31-Dec-89	15.0	12.0	22.0	19.0			27.2	23.1	31.4				23.0	15.0	35.0			
30-Jun-90	12.0	9.4	18.0	26.3			25.7	21.8	29.7				21.0	14.0	32.0			
31-Dec-90	11.0	8.6	16.0	10.4			24.4	20.6	28.2				20.0	13.0	31.0			

TABLE III.24 PREDICTIONS FOR SCENARIO S
DISTRIBUTION OF WHOLE BODY CONTENT - MAN (Bq/kg)

fractile (%) *	observed			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
31-Dec-87																		
97.5	11.9						21.0	10.0	42.0	10.0	4.8	11.0						
68	31.8						28.0	14.0	56.0	16.0	9.7	21.0						
50	35.9						53.0	24.0	99.0	20.0	13.0	25.0						
32	43.8						110.0	50.0	190.0	22.0	15.0	29.0						
2.5	90.3						170.0	64.0	270.0	47.0	30.0	65.0						
31-Dec-90																		
97.5	3.8						7.8	3.7	12.0	1.2	0.5	1.8						
68	10.2						11.0	4.9	16.0	1.8	1.2	2.5						
50	12.7						23.0	9.9	32.0	2.3	1.6	3.1						
32	16.8						52.0	21.0	68.0	3.2	2.2	4.1						
2.5	101.0						78.0	30.0	100.0	6.2	4.0	8.5						

fractile (%) *	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
31-Dec-87																		
97.5	8.0	5.0	15.0										19.0					
68	40.0	30.0	62.0										25.0					
50	48.0	38.0	80.0										27.0					
32	55.0	44.0	85.0										28.0					
2.5	165.0	140.0	195.0										39.0					
31-Dec-90																		
97.5	1.3	1.0	2.0										13.0					
68	10.8	8.0	17.0										19.0					
50	13.8	10.0	21.0										21.0					
32	16.0	11.0	23.0										23.0					
2.5	38.8	34.0	54.0										32.0					

* fractile of a CCDF or (1-p), where p is a fractile of CDF.
CCDF = Complementary Cumulative Distribution Function
CDF = Cumulative Distribution Function

TABLE III.25 PREDICTIONS FOR SCENARIO S
EXTERNAL DOSE

	estimated			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
cloud exposure (nSv)	5.0	1.0	25.0				13.0	6.7	19.0	2.2	1.4	3.1	6.2	2.7	9.7			
ground exposure (mSv)																		
27-Apr-86 - 30-Apr-87	0.060	0.040	0.090	0.040	0.005	0.075	0.043	0.020	0.082	0.031	0.018	0.038	0.044	0.031	0.057	0.063	0.030	0.200
27-Apr-86 - 31-Dec-90	0.190	0.110	0.280	0.090	0.014	0.160	0.082	0.038	0.150	0.095	0.052	0.150	0.116	0.081	0.150	0.160	0.080	0.500
27-Apr-86 - lifetime	0.670	0.350	1.100				0.086			0.330	0.160	0.510	0.176	0.124	0.232	0.640	0.320	2.000

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
cloud exposure (nSv)	0.53	0.18	1.50	24.0						13.0	7.0	19.0				36.0		
ground exposure (mSv)																		
27-Apr-86 - 30-Apr-87	0.050	0.020	0.160	0.224						0.076	0.056	0.096	0.063	0.049	0.075			
27-Apr-86 - 31-Dec-90	0.160	0.050	0.460	0.742						0.240	0.180	0.300	0.300	0.230	0.360	0.200		
27-Apr-86 - lifetime	0.700	0.250	2.000	2.500						1.300	0.900	1.700	1.870	1.450	2.220			

TABLE III.26 PREDICTIONS FOR SCENARIO S
INHALATION DOSE (nSv)

	estimated			Zeevaert/DOSDIM			Peterson/CHERPAC			Kanyar/TERNIRBU			Krajewski/CLRP			Galeriu/LINDOZ		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
inhalation from cloud	200	40	1000	15000	3500	50000	220	120	440	230	150	320	1100			570	250	1500
inhalation of resuspension																		
27-Apr-86 - 30-Apr-87	50	10	250							3.4	2.0	4.2				150	100	300
27-Apr-86 - 31-Dec-90	58	12	290							5.2	2.7	8.1				200		
27-Apr-86 - lifetime	63	13	315							10.0	5.1	18.0				250		

	Suolanen/DETRA			Attwood/FARMLAND			Bergstroem/ECOSAFE			Sazykina/ECOMOD			Yu/RESRAD			Horyna/SCHRAADLO		
	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper	mean	lower	upper
inhalation from cloud	120	11	1100	2070						1400	1000	1800				2700	500	6000
inhalation of resuspension																		
27-Apr-86 - 30-Apr-87	1.2	0.4	3.5	13						25	15	35	27	21	32			
27-Apr-86 - 31-Dec-90	5.0	1.7	15.0	15						30	17	42	28	22	33	5		
27-Apr-86 - lifetime	33.0	11.0	96.0	19						45	30	60	36	28	43			

TABLE III.27 PREDICTIONS FOR SCENARIO S
INGESTION DOSE (mSv)

	estimated values	Zeevaert/DOSDIM	Peterson/CHERPAC	Kanyar/TERNIRBU	Krajewski/CLRP	Galeriu/LINDOZ
27-Apr-86 - 30-Apr-87						
total:	0.100	0.479	0.190	0.160	0.133	0.240
lower conf. interval	0.080	0.199	0.082	0.062	0.102	
upper conf. interval	0.120	1.466	0.960	0.230	0.165	
food type 1:	0.052 milk	0.283 milk	0.068 fish	0.078 fish		0.158 milk
food type 2:	0.016 fish	0.051 fish	0.044 milk	0.059 milk		0.028 fish
food type 3:	0.012 beef	0.050 beef	0.032 fruit	0.011 beef		0.016 meat
27-Apr-86 - 31-Dec-90						
total:	0.310	0.596	0.540	0.260	0.276	0.584
lower conf. interval	0.230	0.228	0.230	0.110	0.204	
upper conf. interval	0.390	1.731	1.400	0.410	0.348	
food type 1:	0.112 milk	0.302 milk	0.250 fish	0.120 fish		0.234 milk
food type 2:	0.096 fish	0.119 fish	0.092 fruit	0.092 milk		0.175 fish
food type 3:	0.030 beef	0.052 beef	0.070 milk	0.020 beef		0.051 mush.
27-Apr-86 - lifetime						
total:	0.700		0.880	0.330	0.311	
lower conf. interval	0.560			0.110	0.230	
upper conf. interval	2.720			0.560	0.400	
food type 1:	0.273 fish		0.340 fish	0.170 fish		
food type 2:	0.126 milk		0.180 fruit	0.100 milk		
food type 3:	0.066 mushr.		0.097 milk	0.022 beef		

TABLE III.27 (cont.)
INGESTION DOSE (mSv)

	Suolanen/DETRA	Attwood/FARMLAND	Bergstroem/ECOSAFE	Sazykina/ECOMOD	Yu/RESRAD	Horyna/SCHRAADLO
27-Apr-86 - 30-Apr-87						
total:	0.180	1.930		0.230	0.160	
lower conf. interval	0.060			0.170	0.060	
upper conf. interval	0.520			0.300	0.220	
food type 1:	0.110 milk			0.100 milk	0.120 fish	
food type 2:	0.030 fish			0.070 fish	0.015 milk	
food type 3:	0.030 beef			0.030 beef	0.013 beef	
27-Apr-86 - 31-Dec-90						
total:	0.530	3.480		0.500	0.340	
lower conf. interval	0.190			0.380	0.210	
upper conf. interval	1.520			0.650	0.500	
food type 1:	0.230 fish			0.190 fish	0.170 fish	
food type 2:	0.180 milk			0.140 milk	0.065 milk	
food type 3:	0.050 beef			0.045 beef	0.054 beef	
27-Apr-86 - lifetime						
total:	0.610	3.980		1.080	1.450	
lower conf. interval	0.210			0.810	0.870	
upper conf. interval	1.750			1.350	2.110	
food type 1:	0.260 fish			0.300 fish	0.450 fish	
food type 2:	0.190 milk			0.180 milk	0.400 milk	
food type 3:	0.050 beef			0.070 beef	0.320 beef	

TABLE III.28 PREDICTIONS FOR SCENARIO S
TOTAL DOSE, MAN (mSv)

	estimated values	Zeevaert/DOSDIM	Peterson/CHERPAC	Kanyar/TERNIRBU	Krajewski/CLRP	Galeriu/LINDOZ
27-Apr-86 - 30-Apr-87						
total:	0.160	0.535	0.230	0.190	0.178	
lower conf. interval	0.140	0.208	0.111	0.081	0.133	
upper conf. interval	0.180	1.600	0.999	0.260	0.223	
pathway 1:	0.100 ing	0.479 ing	0.190 ing	0.160 ing	0.133 ing	
pathway 2:	0.060 ext	0.040 ext	0.043 ext	0.031 ext	0.044 ext	
pathway 3:	0.00026 inh	0.016 inh	0.00022 inh	0.00023 inh	0.001 inh	
27-Apr-86 - 31-Dec-90						
total:	0.500	0.702	0.620	0.360	0.393	
lower conf. interval	0.450	0.245	0.243	0.160	0.282	
upper conf. interval	0.580	1.940	2.190	0.570	0.494	
pathway 1:	0.310 ing	0.596 ing	0.540 ing	0.260 ing	0.276 ing	
pathway 2:	0.190 ext	0.090 ext	0.082 ext	0.095 ext	0.116 ext	
pathway 3:	0.00026 inh	0.016 inh	0.00022 inh	0.00023 inh	0.001 inh	
27-Apr-86 - lifetime						
total:	1.370		0.970	0.660	0.490	
lower conf. interval	1.100			0.310	0.352	
upper conf. interval	3.500			1.000	0.627	
pathway 1:	0.700 ing		0.880 ing	0.330 ing	0.311 ing	
pathway 2:	0.670 ext		0.086 ext	0.330 ext	0.178 ext	
pathway 3:	0.00027 inh		0.00022 inh	0.00024 inh	0.001 inh	

TABLE III.28 (cont.)
TOTAL DOSE, MAN (mSv)

	Suolanen/DETRA	Attwood/FARMLAND	Bergstroem/ECOSAFE	Sazykina/ECOMOD	Yu/RESRAD	Horyna/SCHRAADLO
27-Apr-86 - 30-Apr-87						
total:	0.230	2.037		0.320	0.220	
lower conf. interval				0.230	0.120	
upper conf. interval				0.400	0.300	
pathway 1:	0.050 ext			0.230 ing	0.160 ing	
pathway 2:	0.180 ing			0.076 ext	0.063 ext	
pathway 3:	0.00012 inh			0.0014 inh	0.00003 inh	
27-Apr-86 - 31-Dec-90						
total:	0.690	3.808		0.730	0.640	
lower conf. interval				0.560	0.480	
upper conf. interval				0.930	0.850	
pathway 1:	0.160 ext			0.500 ing	0.340 ing	
pathway 2:	0.530 ing			0.240 ext	0.300 ext	
pathway 3:	0.00012 inh			0.0014 inh	0.00003 inh	
27-Apr-86 - lifetime						
total:	1.300	5.083		2.380	3.310	
lower conf. interval	0.600			1.700	2.660	
upper conf. interval	3.700			3.100	4.290	
pathway 1:	0.700 ext			1.300 ext	1.870 ext	
pathway 2:	0.610 ing			1.080 ing	1.450 ing	
pathway 3:	0.00012 inh			0.0014 inh	0.00004 inh	

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