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Testing of environmental transfer models using Chernobyl fallout data from the Iput River catchment area, Bryansk Region, Russian Federation

Report of the Dose Reconstruction Working Group of BIOMASS Theme 2

Part of the IAEA Co-ordinated Research Project on Biosphere Modelling and Assessment (BIOMASS)

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FOREWORD

The IAEA Programme on *BIO*sphere *M*odelling and *ASS*essment (BIOMASS) was launched in Vienna in October 1996. The programme was concerned with developing and improving capabilities to predict the transfer of radionuclides in the environment. The programme had three themes:

Theme 1: Radioactive Waste Disposal. The objective was to develop the concept of a standard or reference biosphere for application to the assessment of the long term safety of repositories for radioactive waste. Under the general heading of "Reference Biospheres", six Task Groups were established:

Task Group 1: Principles for the Definition of Critical and Other Exposure Groups.

Task Group 2: Principles for the Application of Data to Assessment Models.

Task Group 3: Consideration of Alternative Assessment Contexts.

Task Group 4: Biosphere System Identification and Justification.

Task Group 5: Biosphere System Descriptions.

Task Group 6: Model Development.

Theme 2: Environmental Releases. BIOMASS provided an international forum for activities aimed at increasing the confidence in methods and models for the assessment of radiation exposure related to environmental releases. Two working groups addressed issues concerned with the reconstruction of radiation doses received by people from past releases of radionuclides to the environment and the evaluation of the efficacy of remedial measures.

Theme 3: Biosphere Processes. The aim of this theme was to improve capabilities for modelling the transfer of radionuclides in particular parts of the biosphere identified as being of potential radiological significance and where there were gaps in modelling approaches. This topic was explored using a range of methods including reviews of the literature, model inter-comparison exercises and, where possible, model testing against independent sources of data. Three working groups were established to examine the modelling of: (1) long term tritium dispersion in the environment; (2) radionuclide uptake by fruits; and (3) radionuclide migration and accumulation in forest ecosystems.

This report describes results of the studies undertaken by the Dose Reconstruction Working Group under Theme 2. The IAEA wishes to acknowledge the contribution of the Theme 2 Working Group Leader, K. Thiessen of the United States of America, to the preparation of this report. The IAEA Scientific Secretary for this publication was initially. K.-L. Sjoeblom and subsequently. C. Robinson of the Division of Radiation and Waste Safety.

CONTENTS

SUMMARY

This publication has been produced by Working Group 1 which is concerned with the evaluation of the reliability of methods used for dose reconstruction for specific individuals and members of specific population subgroups.

This Working Group has developed and used model-testing scenarios to examine one or more aspects of the dose reconstruction assessment process. This process includes the following elements:

(1) Evaluation of the source term, or the nature, amount, and conditions of the release;

(2) Evaluation of the environmental transport of the contaminants, including dispersion, chemical transformation, persistence, and time-dependent concentrations of the contaminants in various environmental media;

(3) Description and evaluation of potential pathways for human exposure to the contaminants;

(4) Estimation of the internal and external doses to humans; and

(5) Estimation of the resulting health risks to exposed individuals and populations.

This exercise provides an opportunity for comparison of assessment methods and conceptual approaches, for testing models for the specified level of the assessment with actual measurements, and for identifying the most important sources of uncertainty with respect both to that part of the assessment and to the overall assessment.

The scenario discussed in this report relates to the accidental release of ^{137}Cs from the Chernobyl Nuclear Power Plant in April 1986 and its deposition in the Iput River catchment area, Bryansk Region, Russian Federation.

1. INTRODUCTION

1.1. CHERNOBYL ACCIDENT AND MODEL TESTING

The accident at the Chernobyl nuclear power plant on 26 April 1986 was the most serious one on record in nuclear power engineering. The accident led to contamination of vast areas in Europe, across a range of climatic characteristics and economic situations.

The Chernobyl accident provided a unique opportunity for specialists in radioecological modelling to test the reliability of their models using post-Chernobyl data on contamination of terrestrial and aquatic environments in various regions of Europe. In the period 1986–1995, the International Atomic Energy Agency, with the support of the European Commission, carried out a coordinated research project on the **VA**lidation of Environmental **M**odel **P**redictions for the Transfer of Radionuclides in Terrestrial, Urban and Aquatic Environments and the Acquisition of Data for that Purpose (VAMP). In parallel, work was done on the international cooperative BIOMOVS (**B**iospheric **M**odel **V**alidation **S**tudy) and BIOMOVS II programmes to test models designed to predict environmental transfer and bioaccumulation of radionuclides. A special objective of the BIOMOVS II programme was to test the accuracy of predictions of environmental assessment models for selected pathways and environmental components.

Within the framework of the VAMP and BIOMOVS II programmes, several scenarios based on post-Chernobyl data were prepared and used for model testing. The BIOMOVS II Post-Chernobyl scenarios were specialized and aimed at testing models for individual processes of radionuclide transfer in the environment, including wind resuspension, wash-off, and transfer within an aquatic ecosystem (BIOMOVS II, 1996a; 1996b; 1996c; Garger et al., 1999; Konoplev et al., 1999; Kryshev et al., 1999).

Within the framework of the VAMP programme, the Multiple Pathways Assessment Working Group tested models using two large, integrated scenarios combining all pathways of exposure to the resident population in the contaminated area. A special objective of the Multiple Pathways Assessment Working Group in VAMP was to make a complete environmental assessment, including all possible exposure pathways, as well as to evaluate the significance of individual exposure pathways to the total exposures.

The first multiple-pathways scenario, Scenario CB (Central Bohemia), described the post-Chernobyl radioecological situation in Central Europe (IAEA, 1995). The average level of contamination with ^{137}Cs in this region was 5570 Bq m^{-2} (95% confidence interval, 4050 to 7660 Bq m^{-2}), and the test data covered a three-year period (1986–1989).

The second multiple-pathways scenario, Scenario S (Southern Finland), was more complicated than Scenario CB and included additional pathways, such as aquatic and semi-natural pathways of human exposure to ^{137}Cs (IAEA, 1996a). The contamination levels in Scenario S were about 4 times higher than in Scenario CB and amounted to 19,900 Bq m^{-2} (95% confidence interval, 13,900 to 25,900 Bq m^{-2}).

Both of these scenarios considered areas far from the site of the Chernobyl accident. The ^{137}Cs contamination levels of these areas were not high enough to warrant serious agricultural or other countermeasures. In contrast, the Iput Scenario (Iput River catchment area) deals with ^{137}Cs contamination of a catchment basin and agricultural area in the Bryansk Region of Russia, which was heavily contaminated after the Chernobyl accident. The Iput Scenario was initially prepared during the period 1992–1994, too late for use during the VAMP programme.

Consequently, this modelling exercise was postponed until the new BIOMASS programme was launched in 1996.

1.2. OBJECTIVES OF THE BIOMASS PROGRAMME

The **BIO**sphere **M**odelling and **ASS**essment **M**ethods (BIOMASS) programme was launched by the IAEA in October 1996. The BIOMASS programme is designed to address important radiological issues associated with accidental and routine releases and with solid waste management. Three important areas involving environmental assessment modelling are covered: Theme 1, Radioactive waste disposal (emphasis on reference biospheres); Theme 2, Environmental Releases (including remediation of areas contaminated as a result of nuclear accidents, unrestricted releases or poor management practices, and reconstruction of radiation doses received due to accidental or poorly controlled releases); and Theme 3, Biosphere Processes (current emphases on tritium, fruit trees, and forests).

The general goals of the BIOMASS programme can be summarized as follows:

(1) To provide an international focal point in the area of biospheric assessment modelling for the exchange of information and in order to respond to biospheric assessment needs expressed by other international groups (within and outside IAEA).

(2) To develop methods (including models, computer codes and measurement techniques) for the analysis of radionuclide transfer in the biosphere for use in radiological assessments.

(3) To improve models and modelling methods by model testing, comparison and other approaches.

(4) To develop international consensus, where appropriate, on biospheric modelling philosophies, approaches, and parameter values.

The Iput scenario modelling exercise is the second test exercise of the Dose Reconstruction Working Group of Theme 2, which also includes the Remediation Assessment Working Group. The main objective of Theme 2 is to provide an international forum for activities aimed at increasing the credibility and confidence in methods and models for the assessment of radiation exposure related to environmental releases.

1.3. THE OBJECTIVES OF THE IPUT SCENARIO EXERCISE

The primary objective of the Iput Scenario modelling exercise is the reconstruction of the radiological situation and assessment of doses in the local territory of Russia highly contaminated with ^{137}Cs of Chernobyl origin. In Russia, this test area has the highest levels of radioactive contamination resulting from the Chernobyl accident.

The test area is located about 200 km to the northeast of the Chernobyl Nuclear Power Plant. Contamination of the test area was caused by the passage of the radioactive Chernobyl cloud from 28 to 30 April 1986. Most of the ^{137}Cs deposition was localized in the middle and lower parts of the Iput River catchment area, hence the name of the scenario. The contaminated area is about 1000 km^2, with a density of contamination up to 1,500,000 Bq m^{-2} or higher in some local places.

Teams of specialists from three Russian research institutes, together with SENES Oak Ridge, Inc. (USA), developed the Iput Scenario.

(1) The team of specialists from the Institute of Experimental Meteorology, SPA “Typhoon”, headed by Academician I.I. Kryshev and Dr. T.G. Sazykina was in charge of the data on radioactive contamination of the environment and geophysical data. This team in cooperation with SENES coordinated the project activities.

(2) The team of specialists from the Institute of Agricultural Radiology and Agroecology headed by Dr. S.V. Fesenko and Prof. N.I. Sanzharova was in charge of the information about radioactive contamination of the agricultural produce and characteristics of agricultural ecosystems.

(3) The team of specialists from the Institute of Radiation Hygiene headed by Prof. M.I. Balonov was in charge of the data for testing the models with respect to the ^{137}Cs content in humans and dosimetric information.

The Iput scenario belongs to the same category of complex scenarios as the CB and S scenarios tested under the VAMP programme. However, the Iput scenario has a number of special features that are of importance for model improvement.

Unlike the CB and S scenarios, where the contamination levels of the areas were relatively low, the Iput scenario deals with an area with a very high average contamination level of 800,000 Bq m^{-2} and a spotty distribution of higher deposition amounting to 1,480,000 Bq m^{-2} in some places. A variety of countermeasures were implemented in the test area because of the high contamination levels. Each of these countermeasures had a specific effect aimed at reducing the levels of exposure of the local population. During this exercise, modellers from different countries had the opportunity to model the countermeasures that were taken and to analyze their effectiveness.

Among the interesting aspects of the Iput scenario are the selection and analysis of test data on radioactive contamination of environmental compartments under conditions of considerable non-uniformity (spotty character) of ^{137}Cs deposition. The test area includes a great variety of components of agricultural lands, as well as forest and aquatic ecosystems, combining all major pathways of exposure in a contaminated area in a moderate climate.

The test scenario deals with a real situation of sudden accidental contamination of an agricultural area, for which the individual input data usually used in radioecological models are either unavailable or incomplete during the early period after the accident. The Iput test scenario was developed for analysis and prediction of the long term radioecological situation in a contaminated area. Whereas the CB scenario covers a 3 1/2-year period (1986–1989), and the S scenario 5-year period (1986–1991), the Iput scenario provided a unique opportunity to test models over a 10-year period (1986–1995 or 1996, depending on the endpoint). Thus, the Iput scenario is the most comprehensive scenario to date based on post-Chernobyl data.

1.4. DESCRIPTION OF THE IPUT SCENARIO

The test area is located in the Novozybkov district of the Bryansk Region of Russia (coordinates 52º 30’-40’ N, 31º 50’-32º E), in the western part of Russia. The test area is close to Ukraine to the south and Belarus to the west.

Surveys in the areas of Russia across which the radioactive clouds passed after the Chernobyl accident revealed very high contamination of the local area in the Novozybkov district of the Bryansk Region. This local area turned out to be the most highly contaminated area in Russia with respect to ^{137}Cs of Chernobyl origin. Earlier versions of the Iput scenario included the entire contaminated catchment area, but later the authors decided to simplify the scenario and consider only the most highly contaminated part of the Iput River watershed.

The regions of Russia contaminated after the Chernobyl accident area shown in Figure 1, where the most highly contaminated area is indicated. Data on the contamination of environmental components and on doses to humans in the test area were gathered during the course of systematic investigation carried out by Russian specialists over many years. The Institute of Agricultural Radiology performed measurements and prepared data sets (both input and test data) on contamination of lands and food products. SPA "Typhoon" took measurements of hydrometeorological parameters and contamination of water bodies. The Institute of Radiation Hygiene carried out detailed investigations of radiation doses to the local population, using actual measurements of the ^{137}Cs content in the local residents.

A detailed description of the scenario is given in Annex I. Annex I also includes the data used for testing model predictions for each requested endpoint, as well as detailed descriptions of sampling procedures, measurement methods and statistical data processing techniques.

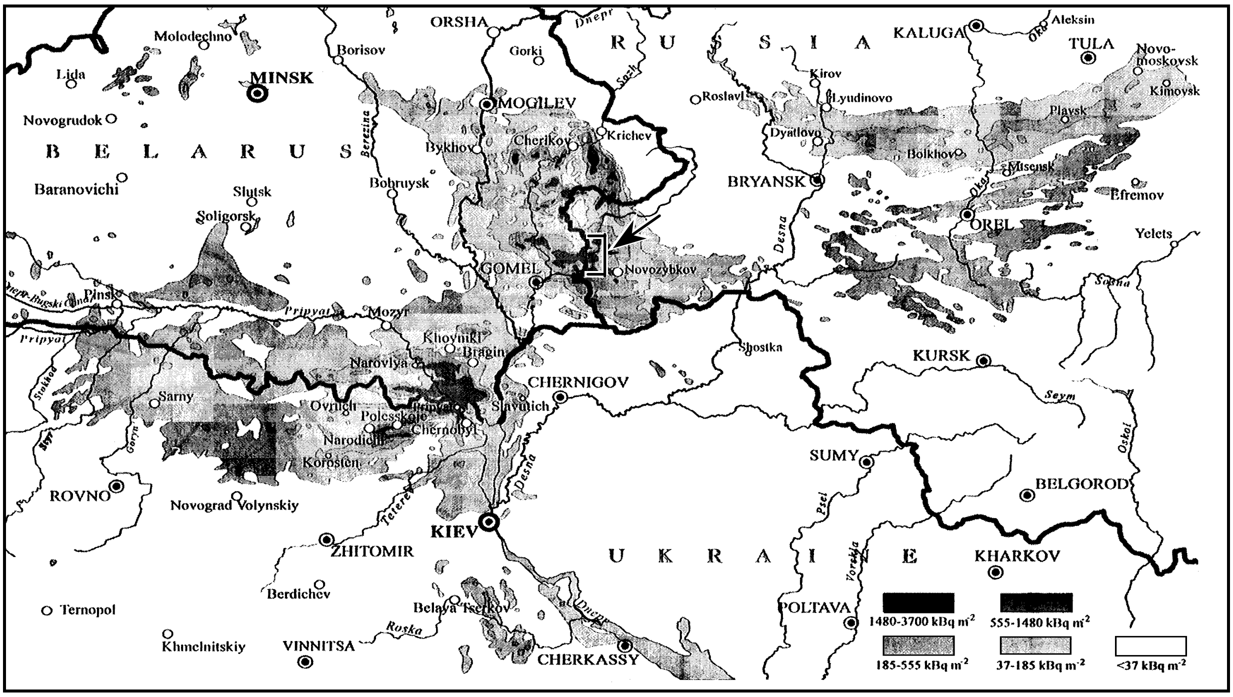

FIG. 1. The regions of Russia, Belarus and Ukraine contaminated with Cs-137 as a result of the Chernobyl accident. The Iput test area is indicated by an arrow.

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

(1) measurements of environmental ^{137}Cs in the test area (air concentrations, ground contamination, total deposition, and soil samples/vertical profiles);

(2) descriptions of the protective measures taken;

(3) environmental information (meteorological characteristics, topographical description, climatic conditions of inland waters and forests);

(4) agricultural information (practices by seasons, types of cultivated soils, production and use of feeds);

(5) information on agricultural production (foodstuffs);

(6) information on the collection of natural products (mushrooms, wild berries, and fish);

(7) information on food distribution; and

(8) information about the population (age, dwelling and industrial structures, as well as food consumption).

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

(1) annual (1986–1996) average concentrations in leafy vegetables and potatoes;

(2) annual (1986–1996) average concentrations in cereals (wheat, rye);

(3) annual (1986–1996) average concentrations in animal feeds (hay);

(4) monthly (1986) and quarterly (1987–1996) average concentrations in milk;

(5) monthly (1986) and quarterly (1987–1996) average concentrations in beef;

(6) monthly (1986) and quarterly (1987–1990) average concentrations in pork;

(7) annual (1986–1996) average concentrations in mushrooms;

(8) annual (1986–1996) average concentrations in wild berries;

(9) annual (1986–1996) average concentrations in freshwater fish;

(10) average daily intake by humans (men and women);

(11) average concentrations in the whole body of humans (men and women);

(12) distributions of whole body concentrations for adult men;

(13) external dose (cloud and ground exposure);

(14) inhalation dose (cloud and resuspension);

(15) ingestion dose, with a summary of the three principal foods; and

(16) total dose from all pathways.

The test data for most endpoints are actual observations for those endpoints, including ^{137}Cs concentrations in feed, foodstuffs and whole body content. For those endpoints that could not be directly measured (i.e., doses), the authors of the scenario provided independent estimates based on observations.

1.5. STRUCTURE OF THE REPORT

Section 1 provides a brief description of recent international programmes designed for testing and improving radioecological models of radionuclide transfer in the environment. The objectives and tasks of the BIOMASS programme, as well as the role of the Iput Scenario in Theme 2 “Environmental Releases,” are described. A brief introduction to the Iput Scenario is provided. Section 2 summarizes the participants in the test exercise and the models they used. Section 3 reviews the modelling approaches used by the participants for the description of the ^{137}Cs transfer to man via various exposure pathways. Section 4 gives an analysis of the procedures for parameter selection in a blind test, together with sources of information on the parameter values. Section 5 provides a comparative analysis of model predictions. Section 6 gives a summary of the reasons for mispredictions in the Iput scenario exercise. Section 7 gives a summary of participants' experience in model testing, using the Iput scenario. Section 8 describes the major conclusions drawn from the test exercise. Annex I includes the scenario description and documentation of data for the Iput scenario. Annex II includes descriptions of models used by participants in the test exercise. Annex III contains tables of the individual model predictions along with the test data or authors' estimates for each endpoint of the Iput scenario.

2. PARTICIPANTS AND MODELS

Eight participants submitted results for the Iput scenario. In addition, the authors of the scenario made a full set of model predictions to check the completeness of data and evaluate the most suitable values of key parameters. A list of participants is given in Table 1. The status of the models and their previous use in model testing, via international or national exercises, are indicated. Detailed model documentation is given in Annex II.

Models developed for different regions of the world (Europe, America, Australia and Asia) were used in the Iput scenario exercise. Summaries of the models are provided below:

— **LIETDOS (Lithuanian Dose assessment model):** LIETDOS is a radionuclide migration and radiological consequences evaluation model created in the Institute of Physics, Radiation Protection Department, Lithuania. The model and computer software package are intended to simulate radionuclide atmospheric dispersion and migration via various environmental pathways and to assess human exposures and doses. The LIETDOS model is deterministic. Later versions of LIETDOS will include options for probabilistic calculations.

  LIETDOS has been tested during the international BIOMASS programme using the “Hanford” and “Iput River” scenarios. In cooperation with the Lithuanian Republic Ministry of Environment and other authorities, LIETDOS has been used in practice for revision of the Ignalina NPP routine release limitation system as well as for updating and human dose assessment in the case of some hypothetical Ignalina NPP accidents.

TABLE 1. LIST OF PARTICIPANTS AND MODELS IN THE IPUT SCENARIO EXERCISE

Model	Key participant(s)	Organization	Country	Previous experience with the model
LIETDOS (Lithuanian Dose assessment model) Computer codes: Visual Basic and FORTRAN	Tatiana Nedveckaite, Vitold Filistovic	Institute of Physics, Radiation Protection Department	Lithuania	Revision and updating of the release limitation system at Ignalina NPP, Lithuania. Assessment of radioecological consequences of the Chernobyl accident for Lithuania. Hanford scenario of the BIOMASS programme.
RadCon (Radiological Consequences model) Computer code: JAVA	Jagoda Crawford, Renate Domel	Australian Nuclear Science and Technology Organization	Australia	RadCon has been used in a study of the potential environmental impact on Australia following a hypothetical accidental release in the region.
TAMDYN-UV Computer code: PASCAL	Bela Kanyár	University of Veszprém	Hungary	CB and S scenarios of the VAMP programme. Hanford scenario of the BIOMASS programme.
CLRP (Concentration Levels Rapid Predictions) Computer code: EXCEL	Pawel Krajewski	Central Laboratory for Radiological Protection, Department of Radiation Hygiene	Poland	Assessment of radioecological consequences of the Chernobyl Accident for Poland. CB and S scenarios of the VAMP programme. Hanford scenario of the BIOMASS programme.
SPADE (Soil Plant Animal Dynamic Evaluation) Computer code: FORTRAN	Zitouni Ould-Dada	Food Standards Agency	UK	Model was used in the CB scenario of the VAMP programme and in an intercomparison of the UK terrestrial foodchain models (1995).
SENES Computer code: EXCEL	Iulian Apostoaei	SENES Oak Ridge, Inc.	USA	Developed for the present exercise.
OSCAAR (Off-Site Consequence Analysis Code for Atmospheric Releases in reactor accidents) Computer code: FORTRAN	Toshimitsu Homma	Japanese Atomic Energy Research Institute	Japan	Probabilistic safety assessment of nuclear reactors in Japan. Hanford scenario of the BIOMASS programme.
LINDOZ Computer code: FORTRAN	Dan Galeriu	Institute of Physics and Nuclear Engineering	Romania	CB and S scenarios of the VAMP programme. The 1994 version of the model was used with an early version of the scenario.
Authors calculations: ECOMOD (Ecological Model) Computer code: FORTRAN	Alexander Kryshev, Tatiana Sazykina	SPA "Typhoon", Obninsk	Russia	Assessment of radioecological situation in the area of the Leningrad NPP, Russia, before and after the Chernobyl accident. S scenario of the VAMP programme. Hanford scenario of the BIOMASS programme.

— **RadCon (Radiological Consequences model):** RadCon, a flexible and user friendly radiological consequences model, has been designed and implemented at the Australian Nuclear Science and Technology Organization (ANSTO). Currently the model incorporates exposure from the ground, exposure from the cloud, ingestion and inhalation, with aquatic and resuspension pathways under consideration for future implementation. Atmospheric dispersion has been decoupled from the dose calculation; with the implementation of a preprocessor, appropriate atmospheric transport codes may be used with RadCon. Alternatively, ground deposition data may be input directly. RadCon seperates the required input data/parameters from the code, thus making it easy to adapt the calculations to any climatic site, even though the current parameters and data are focused for use in tropical and subtropical Australia and the South East Asian region. RadCon has been designed and implemented with a graphical user interface (GUI), in a manner similar to a geographic information system, to allow the user to specify options over a two dimensional calculation region, particularly useful in this region of large spatial variability, as well as local diversity. The Java programming language was chosen for implementation, giving access to a GUI toolkit library and portability across computer platforms.

— **TAMDYN-UV model:** TAMDYN-UV is a research radioecological model developed at the University of Veszprém, Hungary. TAMDYN-UV is a compartmental model that includes both dynamic and steady state parts. The processes of ^{137}Cs transfer in terrestrial ecosystems are simulated by dynamic forms, by compartments, and by ordinary differential equations. Uncertainties are produced by Monte Carlo simulations.

— **CLRP (Concentration Levels Rapid Predictions) model:** The CLRP model was created in 1989 at the Central Laboratory for Radiological Protection, Department of Radiation Hygiene, Warsaw, Poland. Originally, the CLRP model was developed as a part of the research project "LONG LIVED POST-CHERNOBYL RADIOACTIVITY AND RADIATION PROTECTION CRITERIA FOR RISK REDUCTION," which was performed in co-operation with the U.S. Environmental Protection Agency. In subsequent years, the model was intensively developed and extended for many radionuclides (up to 20 radionuclides of 44 elements). The aim of this code is to simulate the transport of radionuclides through the terrestrial environment to the human body. During the period 1989–1995, CLRP code performance for ^{137}Cs was checked out within the frame of the international VAMP programme on the basis of the CB and S scenarios.

— **SPADE (*S*oil *P*lant *A*nimal *D*ynamic *E*valuation):** SPADE is the name given to a suite of codes used to assess the impact of potential radioactive discharges on man through the ingestion of contaminated food. These codes were developed in the United Kingdom for the Radiological Safety Division of the Ministry of Agriculture, Fisheries and Food (MAFF; now the Food Standards Agency, FSA). The first version of SPADE was developed in 1979; since that time SPADE codes have been revised and improved extensively as part of an interactive process between model development and subsequent use.

SPADE is an interactive computer model which allows the user to predict the transfer of radionuclides from the environment to agricultural foodstuffs, for a wide range of user-specified agricultural scenarios. The soil, plant and animal models are linked by a number of transfer pathways. The transfer of radionuclides between compartments in SPADE is controlled by empirically derived rate coefficients, and radionuclide distribution at various times is calculated by references to the compartmental contents. Six types of seasons are include in SPADE: *Grow, Harvest, Fallow, Plough, Winter,* and *Cull*. A detailed description of SPADE is given in Annex II. A probabilistic version of SPADE called PRISM (PRobabilistic Improved SPADE Model) is being developed for FSA. Version 4.5 of the SPADE model was used in the Iput scenario exercise.

— **SENES model:** SENES is a research model, developed at SENES Oak Ridge, Inc., Tennessee, U.S.A., specifically for the Iput scenario exercise. Individual processes of transport and bioaccumulation of the contaminant in the environment were modelled starting from basic principles. Calculations were performed in EXCEL, and uncertainties were propagated using *Crystal Ball* software.

- **OSCAAR (Off-Site Consequence Analysis Code for Atmospheric Releases in reactor accidents):** OSCAAR has been developed within the research activities on probabilistic safety assessment (PSA) at the Japan Atomic Energy Research Institute. OSCAAR is primarily designed for use in Level 3 PSA of nuclear reactors in Japan. OSCAAR calculations, however, can be used for a wide variety of applications including siting, emergency planning, and development of design criteria, and in comparative risk studies of different energy systems.
- **LINDOZ model:** The LINDOZ model was developed after the Chernobyl accident as a dynamic compartmental radiological assessment model. It was initially calibrated with local data from Romania. It was then compared with Chernobyl data in the BIOMOVS programme (A4 Scenario) and further upgraded and used in VAMP and BIOMOVS II. The 1994 version of LINDOZ used for VAMP was used with an early version of the Iput scenario, and those 1994 results are presented in this report.
- **ECOMOD model:** ECOMOD is a research model, developed at SPA "Typhoon", Obninsk, Russia. A unified radioecological/ecological approach is used to simulate dynamic processes of radionuclide migration in ecosystems. ECOMOD includes a set of modules that are designed to simulate the radionuclide transfer in terrestrial (agricultural) or aquatic food chains. The first version of the ECOMOD model was developed in 1985 to simulate the impact of the Leningrad NPP on the shallow cooling waters of the Kopora bay of the Gulf of Finland. The modified ECOMOD model was used to assess the radioecological situation in the cooling pond of the Chernobyl NPP in 1986–1997 (under the BIOMOVS II programme). The ECOMOD model (both terrestrial and aquatic submodels) has also been used for calculations for Scenario S of the VAMP programme (1994–1996).

The Iput scenario was intended for modelling of the radioecological situation after a single accidental contamination of the area. Data were available by the end of the exercise to assess a 10-year period and practically all pathways of exposure (except for irrigation). It should be noted that the observed data for this area were seldom published in international journals; therefore, the modellers could not form judgments from reading papers. Special attention was given to modelling of agricultural countermeasures. Most assessment models have not provided the possibility of including countermeasures, and modellers experienced great difficulties in adapting the models to allow for countermeasures. Experience gained in this exercise showed that research models are most flexible, whereas commercial models, as a rule, are not as easy to adapt to nonstandard tasks, such as the description of countermeasures.

The test exercise was carried out more nearly in the spirit of a true dose reconstruction than a model testing exercise, in that model predictions were not all made blindly (without access to test data) and the information base (scenario description and test data) were revised during the course of the exercise. Ideally, for a model testing exercise, all participants make blind predictions (without access to test data), and when all predictions and documentation are submitted, only then are the test data released; the test data by this time have been thoroughly documented and finalized. In this exercise, due to various constraints of scheduling and funding, test data were released at several stages, final analysis and revision of the test data did not occur until most participants had submitted at least one set of predictions, and participants had access to various amounts of test data at different stages in their calculations (although not all participants took advantage of that).

A summary of the scenario history and the timing of submission of predictions by individual participants is shown in Table 2. The discussion in this report concentrates on the final set of predictions submitted by each participant. This exercise should be treated as a dose reconstruction exercise rather than a blind test of model predictions. In a dose reconstruction, models and calculations are based on the best information available, and these are revised as new information becomes available; this is essentially how the present test exercise has taken place. It must be pointed out, however, that the exercise cannot simply be a matter of fitting predictions to the data, but revisions to model structures, parameter values, or input assumptions must have a physical basis or an adequate rationale for their selection.

The following section presents a detailed analysis of the modelling approaches used by the participants. Of particular importance is the analysis of information sources on model parameters and selection of appropriate values for a specific region (Section 4).

TABLE 2. SUMMARY OF SCENARIO HISTORY AND TIMING OF SUBMISSION OF MODEL PREDICTIONS

Date	Event	Model predictions submitted								
		LIETDOS	RadCon	TAMDYN-UV	CLRP	SPADE	SENES	OSCAAR	LINDOZ	ECOMOD
April 1994	Initial draft of scenario released								X	
Oct. 1997	Revised scenario released to BIOMASS participants									
June 1998	Initial predictions submitted	X				X				X
Sept. 1998	Revised predictions submitted	X				X				X
May 1999	Initial or revised predictions submitted Test data for plants released	X	X		X	X				X
Oct. 1999	Initial or revised predictions submitted All test data released	X	X	X	X	X	X	X		X
Feb. 2000	Revised scenario description and test data released									
May–June 2000	Revised predictions submitted	X	X	X		X	X	X		X
Nov. 2000–Feb. 2001	Revised predictions submitted					X		X		

3. SUMMARY OF MODEL APPROACHES

In this section, the modelling approaches used for calculations for the Iput scenario are compared for each pathway of exposure. The input information necessary for calculations of the radionuclide transfer for each pathway is discussed in detail.

3.1. MODELLING OF ATMOSPHERIC RADIONUCLIDE DEPOSITION

Most of the models used in the Iput scenario started with calculations of radionuclide deposition from the atmosphere onto the soil surface. The modelling approaches used to predict atmospheric deposition are described below.

The most detailed descriptions of the atmospheric transport of radionuclides are incorporated in the LIETDOS and OSCAAR models. The current version of the OSCAAR model includes the atmospheric dispersion and deposition module ADD, based on a multi-puff trajectory approach. The OSCAAR-ADD module has two kinds of grid systems for input of meteorological information: the large system is a synoptic scale Eulerian grid, analysing wind data from the Japan Meteorological Agency; the second system is a mesoscale grid for surface wind and atmospheric stability information.

The LIETDOS model includes the atmospheric dispersion submodel LIETDOS-FILTSEG, which is based on the approach of segmental diffusion convectional radionuclide transfer in the atmospheric air. The LIETDOS-FILTSEG submodel can produce a detailed reconstruction of the radionuclide transfer with atmospheric processes and spatially non-uniform deposition on the soil of the area under consideration.

However, both models require sufficiently detailed input data on the source, meteorological data, and characteristics of the ground surface. In the absence of the required input data, the modelling results can have great uncertainties associated with them. For calculations on the Iput Scenario, the input data provided were not sufficient for detailed modelling of atmospheric transport of radionuclides (Section 6.1).

Radionuclide deposition onto the soil surface (dry and wet deposition) $DEP(t,t_0)$ during the cloud passage period $t\text{-}t_0$ was described by the following standard formula (LIETDOS, CLRP, ECOMOD, and TAMDYN-UV models):

$$C_s = DEP(t,t_0) = \int_{t_0}^{t} DEPI(\tau)d\tau \tag{3.1}$$

$$DEPI(t) = \{(1 - R_d(t)) \cdot V_d + (1 - R_w(t)) \cdot W_0 \cdot I_w(t)\} \cdot C_{air}(t)$$

where C_s is the soil surface contamination, Bq m^{-2}; $DEPI(t)$ is the intensity of deposition of ^{137}Cs, Bq m^{-2} d^{-1}; R_d and R_w are the dry and wet interception factors; V_d is the dry deposition velocity, m d^{-1}; W_0 is the washout ratio (Bq m^{-3} rain per Bq m^{-3} air); I_w is the precipitation rate, mm d^{-1}; and C_{air} is the activity of ^{137}Cs in air, Bq m^{-3}. The differences between the models consist only in the selected values of deposition parameters. The RadCon model accepts soil concentrations as generated by an atmospheric transport model or as measured data. The RadCon model describes the radionuclide concentrations due to direct deposition and interception on plants as in the ECOSYS-87 model (Müller and Pröhl, 1993).

3.2. EXPOSURE DUE TO GROUNDSHINE

External exposure was calculated by all participants using the following standard formula:

$$DR_{ground}(t) = DF_{ground} \times C_{dep} \times SF \times R(t) \times E(t) \tag{3.2}$$

where $DR_{ground}(t)$ is the dose rate from groundshine at time t after the radionuclide deposition on the ground (Sv y^{-1}); C_{dep} is the initial radionuclide deposition on the ground, Bq m^{-2} (it is assumed that the deposition occurred at time $t = 0$); DF_{ground} is the integrated dose-rate conversion factor for groundshine (Sv y^{-1} per Bq m^{-2}); SF is the integrated shielding factor for groundshine, $SF = \Sigma f_i SF_i$ (f_i is the fraction of time spent in different places, indoor, outdoor etc.; SF_i is the shielding factor for each place); $R(t)$ is a unitless factor taking into account the radioactive decay of the radionuclide deposited on the ground; and $E(t)$ is a unitless factor taking into account the decrease of groundshine due to environmental processes, such as radionuclide migration deeper into the soil, weathering, leaching, etc.

In calculations of exposure from groundshine, the main difference among the models consists in different descriptions of the factor $E(t)$ and different numerical values selected for the shielding factor SF and the dose conversion factor DF_{ground}. Most of the models used a single value of the dose conversion factor DF_{ground}. Several models (TAMDYN-UV, LIETDOS, and SENES) made more detailed assessments of groundshine. In the TAMDYN-UV and LIETDOS models, the total groundshine was integrated from the sum of several soil layers, according to the method described by Eckerman and Ryman (1993). Dose-rate conversion factors for the photon emitters in soil were taken from Kocher and Sjoreen (1985) and Eckerman and Ryman (1993). In the SENES model, the radionuclide was assumed to be distributed uniformly within a soil layer of depth z that changes with time since deposition.

3.3. EXPOSURE DUE TO CLOUDSHINE

External exposure from cloudshine was modelled by all participants with the following standard formula:

$$D_{cloud}(t_0,t) = DF_{cloud} \cdot SF_{cloud} \cdot \int_{t_0}^{t} C_{air}(\tau)d\tau \tag{3.3}$$

where $D_{cloud}(t_0,\ t)$ is the dose from cloudshine during the cloud passage period (t-t_0), Sv; DF_{cloud} is the dose conversion factor, Sv d^{-1} per Bq m^{-3}; SF_{cloud} is the shielding factor; and C_{air} is the radionuclide activity in the cloud at time τ during the cloud passage, Bq m^{-3}.

It was assumed that a person is immersed in the cloud; therefore the ground-level air concentration of the radionuclide was used in calculations. Differences between models are related only to dynamic calculations of the radionuclide concentration in air.

3.4. EXPOSURE DUE TO INHALATION

Internal exposure from inhalation of radionuclide with air was calculated by all participants with the following standard formula:

$$D_{inh}(t_0,t) = DF_{inh} \cdot V_{inh} \cdot F \cdot \int_{t_0}^{t} C_{air}(\tau)d\tau \tag{3.4}$$

where $D_{inh}(t_0,t)$ is the dose from inhalation of radioactive aerosols and resuspended particles from the air, Sv; V_{inh} is the breathing rate, m^3 h^{-1} (this parameter depends on the age, sex and physical activity of a person); DF_{inh} is the dose conversion factor for inhalation, Sv Bq^{-1}; F is the filtering/shielding factor, which indicates the difference between the radionuclide activity in the indoor/outdoor air, $F = \Sigma f_i F_i$ (f_i is the fraction of time spent indoors or outdoors; F_i is the filtering factor for indoor or outdoor air); and $C_{air}(\tau)$ is the radionuclide activity in outdoor air at time τ.

Differences between models consisted in the amount of detail used to describe the breathing rate and radionuclide concentrations in the indoor/outdoor air. The time-dependency of the radionuclide concentration in the surface air was either borrowed from the observed data (input data of the Iput scenario) or modelled using the atmospheric dispersion of the radionuclide, as well as a time-dependent resuspension factor (the OSCAAR and LIETDOS models).

3.5. MODELLING THE DYNAMICS OF ^{137}Cs ACTIVITY IN SOIL

An adequate description of the long term dynamics of the ^{137}Cs behavior in soil is the most important factor in the correct estimation of the radioactive contamination of local agricultural and forest products, which made a major contribution to the exposure of the local population. Since it was necessary to calculate the environmental behavior of ^{137}Cs over an extended period of time (10 years) in this scenario, much attention was given by the participants to modelling the dynamics of the ^{137}Cs activity in the root layer of the soil.

In the Iput scenario, determination of the concentration of ^{137}Cs in soil available for plants was a rather complicated task, owing to various agricultural countermeasures taken, including replowing and application of fertilizers and chemicals, which reduce the availability of ^{137}Cs to plants. All participants in the Iput scenario described an exponential decrease in the content of available ^{137}Cs in soil (without consideration for replowing). The amount of detail used to describe the processes that contributed to the redistribution of ^{137}Cs in soil varied considerably among models.

In the ECOMOD and SENES models, a reduction in the available ^{137}Cs in soil is described as a simple one-exponential function:

$$C(t) = C_0 e^{-\lambda_{decl} t} \tag{3.5}$$

where λ_{decl} is an empirical coefficient that reflects in a generalized form the action of all processes leading to soil self-purification, and C_0 is the concentration at time $t = 0$.

In the OSCAAR model, a reduction in the activity in soil due to environmental processes was divided into fast and slow components:

$$C(t) = C_0 e^{-\lambda_r t} \left[\alpha e^{-\lambda_{sf} t} + (1-\alpha) e^{-\lambda_{ss} t} \right] \tag{3.6}$$

where λ_r is the rate of radioactive decay, λ_{sf} and λ_{ss} are empirical factors describing the fast and slow components of environmental decay in soil; and α and $(1-\alpha)$ are the initial values of the components for fast and slow processes of soil self-purification of ^{137}Cs. In the OSCAAR final calculations, a simplified one-exponential function was used instead of formula (3.6).

In SPADE, the loss of radionuclides from external plant surfaces to the soil is modelled as two transfers from the external leaf compartment, one to the soil solution and one to the soil organic matter compartment in the surface layer of the soil model. The rate coefficients for the two transfers are specified by a function of the two model parameters 'washoff' and 'fractional washoff to soil solution'. The process of root uptake is modelled by the transfer of radionuclides from the soil solution to the plant root compartment. The transfer rate is assumed to vary with soil layer depth, as a function of the root distribution throughout the soil profile.

In the CLRP, RadCon, TAMDYN-UV, and LIETDOS models, the total activity of ^{137}Cs in soil was divided into a mobile fraction available to plants and a fraction fixed on soil particles (unavailable to plants). The ECOSYS-87 model (Müller and Pröhl, 1993) was the prototype for modelling the ^{137}Cs behavior in soil. The CLRP model used an algebraic formula of two-exponential radioactivity reduction in soil, which coincides in its form with the formula used in the OSCAAR model. While the RadCon model implements the equivalent of equation (3.6) for the activity in soil available for root uptake, for this application the equivalent of equation (3.5) was used, with λ_{decl} being the rate of activity decrease due to migration out of the root zone, radioactive decay, and fixation of the radionuclides in the soil.

The ^{137}Cs dynamics in soil are described most fully in the TAMDYN-UV and LIETDOS models as a set of linear differential equations. The soil compartment was divided into three layers: surface layer, root layer, and deep soil layer. The following soil processes were considered in the TAMDYN-UV and LIETDOS models:

— **Surface soil layer:** deposition; percolation into deeper layers; run off (TAMDYN only); weathering; resuspension (LIETDOS only);

$$\frac{dC_s}{dt} = DEPI(t) - (\lambda_r + \lambda_{runoff} + \lambda_{perc} + Res)C_s + \lambda_{weath} C_{plant} \tag{3.7}$$

— **Root soil layer:** transport from a mobile form of the radionuclide to a fixed form and back; uptake by plants; transfer to deep soil layer.

$$\begin{aligned} \frac{dC_{m,up}}{dt} &= -\left(\lambda_r + \lambda_{perc} + \lambda_{fix} + \frac{B_v}{L_s \rho_s} \cdot \frac{dY}{dt}\right) C_{m,up} + \lambda_{des} C_{fix,up} + \lambda_{perc} C_s \\ \frac{dC_{fix,up}}{dt} &= \lambda_{fix} C_{m,up} - \left(\lambda_r + \lambda_{fix,deep} + \lambda_{des}\right) C_{fix,up} \end{aligned} \tag{3.8}$$

where C_s is the contamination of the soil surface, Bq m^{-2}; $C_{m,up}$ is the activity of the mobile fraction of ^{137}Cs in the root zone, Bq m^{-2}; $C_{fix,up}$ is the activity of the fixed fraction of ^{137}Cs in the root zone, Bq m^{-2}; *DEPI(t)* is the intensity of deposition of ^{137}Cs (Equation 3.1); λ_r is the radioactive decay rate (d^{-1}); λ_{perc} is the percolation rate (d^{-1}); λ_{runoff} is the runoff from the soil surface (d^{-1}); *Res* is the resuspension rate, (d^{-1}); λ_{weath} is the loss rate due to weathering (d^{-1}); λ_{fix}, λ_{des} are the rates of fixation and desorption of ^{137}Cs (d^{-1}); $\lambda_{fix,deep}$ is the transfer of the fixed fraction to deeper soil layers (d^{-1}); C_{plant} is the activity of plants, Bq m^{-2}; B_V is the transfer factor from soil to plant, Bq kg^{-1}(f.w.) of plant per Bq kg^{-1} (d.w.) of soil; L_s is the depth of the root zone, m; ρ_s is the soil density, kg m^{-3}; and Y is the biomass of plants, kg m^{-2}.

3.6. MODELLING OF PLANT CONTAMINATION

Contamination of various species of plants in the test area determines directly or indirectly the intake by humans of the radionuclide in foodstuffs. Thus, for example, cereal crops, leafy vegetables and root crops are directly consumed by humans, whereas pasture makes its contribution to exposure of humans indirectly through contamination of the milk and meat of farm animals. Calculation of the contamination of various species of plants is therefore an important component of all models used for calculations on the Iput scenario.

Three of the models (SENES, RadCon, and CLRP) calculated the plant contamination using empirical “soil-to-plant” transfer factors:

$$C_{plant,i}(t) = B_{v,i} \cdot C_{soil}(t) \tag{3.9}$$

where $C_{plant,i}(t)$ is the concentration of ^{137}Cs in the i-th type of plant, Bq kg^{-1}; $C_{soil}(t)$ is the concentration of ^{137}Cs in soil (root zone), Bq kg^{-1}; and $B_{v,i}$ is the soil-to-plant transfer factor (i-th type of plant). In the RadCon model, $C_{soil}(t)$ is the bioavailable concentration in the soil. The OSCAAR model assumes a constant rate of radionuclide transfer from soil to plants per 1 m^2 of area and ignores seasonal variations of the vegetation growth rate. The RadCon and CLRP models also implement deposition and interception on plants.

In SPADE, the quantity of radionuclides reaching the above ground compartments of the plant from external (atmospheric) sources is determined according the interception fraction which takes account of changes in plant biomass with season. Depending on the model, plants or leaves are divided into external and internal components to allow particulate deposition to be distinguished from radioactive gases and vapours. Material lost from the plant by washoff is partitioned between either soil solution and organic matter, or 'soil available' and 'soil unavailable', as appropriate. The rate of radionuclide deposition to the plant from external (atmospheric) sources is calculated as a function of the total ground deposition rate, according to Chamberlain's interception fraction:

$$r = 1 - e^{-\mu W}$$

where r is the interception fraction, i.e., proportion of deposit retained initially; μ is the absorption coefficient, $m^2\ kg^{-1}$ (d.w.); and W is the dry weight herbage density, $kg\ m^{-2}$ (d.w.).

The LIETDOS, TAMDYN-UV and ECOMOD models use a detailed dynamic description of the plant contamination. These models consider the following plant contamination processes:

- surface contamination of plants with the radionuclide from atmospheric deposition with allowance for the interception factor;
- dynamics of the plant biomass growth during the vegetative season; and
- root uptake of the radionuclide to plants from soil.

The interception factor was calculated with one of the following formulas:

$$R(t) = R_{\max} \frac{m_{veg}(t)}{m_{v\max}} \quad \text{(TAMDYN-UV model)} \qquad (3.10a)$$

where R_{max} is the interception factor just before the harvesting; $m_{veg}(t)$ and m_{vmax} are the time dependent and maximal mass of vegetation, during seasonal growing ($kg\ m^{-2}$);

$$R(t) = 1 - e^{-\mu m_{veg} K} \quad \text{(LIETDOS model)} \qquad (3.10b)$$

where μ is the Chamberlain constant μ = 2.8 $m^2\ kg^{-1}$; K is the content of dry matter in biomass; or

$$R(t) = \frac{m_{veg}}{0.11 \cdot m_{v\max} + m_{veg}} \quad \text{(ECOMOD model)} \qquad (3.10c)$$

where the maximum value of R is assumed to be 0.9 at the time of harvesting.

The growth of vegetation was simulated by one of the following types of equations:

(1) Growth of biomass was interpolated linearly between the dates of sowing t_s and harvesting t_h:

$$m_{veg}(t) = m_s + (m_{\max} - m_s) \cdot \frac{t - t_s}{t_h - t_s} \quad \text{(LIETDOS model)} \qquad (3.11a)$$

(2) Growth of biomass was described as a non-linear function with saturation:

$$m_{veg}(t) = m_{\max}\left[1 - e^{-\beta(t - t_{harv})}\right] \text{for t > t}_\text{s} \text{ (TAMDYN-UV model)} \qquad (3.11\text{b})$$

or $$\frac{dm_{veg}(t)}{dt} = \alpha \cdot SOL(t)e^{0,065T^0} - \varepsilon \cdot m_{veg} \text{ (ECOMOD model)} \qquad (3.11\text{c})$$

where $m_{veg}(t)$ is the biomass of vegetation at time t (kg m^{-2}); m_s and m_{max} are the vegetation biomasses at time of sowing and harvesting (kg m^{-2}); β is an empirical parameter of biomass growth with time; $SOL(t)$ is the diurnal energy of photosynthetic solar radiation at a given latitude; T° is the air temperature, (°C); α is a growth factor; and ε is a metabolic loss factor.

The TAMDYN-UV and LIETDOS models describe the root uptake of the radionuclide by plants from soil, using the differential equation

$$\frac{dC_{veg}}{dt} = \frac{B_v}{L_s \rho_s} \cdot \frac{dY}{dt} \cdot C_{soil} - \lambda_r C_{veg} \qquad (3.12)$$

where B_v is the soil-to-plant transfer factor and $Y(t)$ is the biomass of plants, (kg m^{-2}). The LIETDOS model also considers radionuclide translocation from the plant surface to the internal parts of the plants; however, this process is not important for long term assessment. Here the main difference from the OSCAAR model consists in the fact that the growth rate dY/dt of plants is not constant and varies during the vegetative season.

From this comparison of the models for plant contamination it may be concluded that:

(1) For consideration of the early period following an accident or in the event of long term deposition, the differences between model assessments may be quite great, reflecting the extent to which surface contamination factors are taken into account;

(2) For consideration of the average contamination of the plant yield in succeeding years, the soil-to-plant transfer factor is the key parameter.

3.7. MODELLING OF AGRICULTURAL COUNTERMEASURES

As described in Annex I, various countermeasures were implemented in the 'Iput' test area. The main purpose of these countermeasures was to reduce the intake of dietary radiocesium by the local population. The main countermeasures were the following:

- elimination of the most highly contaminated lands from agricultural use;
- plowing of meadows;
- deep plowing of agricultural lands;
- liming, and fertilization of arable lands;
- restrictions in consumption of local agricultural and forest products.

Methodological approaches for simulation of countermeasures were discussed at several meetings of the Theme 2 Working Group of the BIOMASS Programme. In the Iput exercise, two main approaches were used to describe the agricultural countermeasures. One approach was based on calculation of the weighted average ^{137}Cs activity in the root zone of plants before and after countermeasures. This approach is appropriate for description of such countermeasures as elimination of the most contaminated lands from agricultural use, plowing of meadows, and deep plowing of arable lands. Another approach was based on changing the efficiency of root uptake of ^{137}Cs by plants as a result of countermeasures; this approach is appropriate to describe the effect of soil liming or fertilization. Other types of countermeasures may be described formally by changing the root uptake coefficients; however such an approach does not simulate the real processes of radionuclide downward migration.

Participants in the Iput exercise were faced with some difficulties in modelling the countermeasures. Before the Iput calculations the modellers had no experience in simulation of countermeasures, and computer codes had no special component for calculating the effect of the countermeasures. Participation in the Iput Scenario exercise provided modellers with a unique opportunity to gain experience in simulation of countermeasures.

The approach using weighted average ^{137}Cs activities in the root zone of plants was used in the CLRP and TAMDYN-UV models. The approach based on changing the root uptake transfer factors was used in the RadCon, OSCAAR, and SPADE models. Some modellers used both approaches for different countermeasures (LIETDOS, SENES, and ECOMOD models). All modellers except SENES took into account the restrictions in local foodstuff consumption as a specific countermeasure. Table 3 summarizes the various countermeasures in the Iput test area included by the participants in the exercise.

TABLE 3. SUMMARY OF COUNTERMEASURES CONSIDERED BY PARTICIPANTS IN THE IPUT SCENARIO EXERCISE

Model	Elimination of the most contaminated lands from agricultural use	Deep plowing of arable soils	Change of root uptake transfer coefficients	Restrictions in consumption of local foodstuffs
LIETDOS	X	X	X	X
RadCon		X*	X	X
TAMDYN-UV		X		X
CLRP	X	X		X
SPADE	X	X	X	X
SENES	X	X	X	
OSCAAR	X		X	X
ECOMOD	X		X	X

* RadCon accounted for deep plowing by incorporating the effect into the root uptake transfer coefficient.

3.8. MODELLING OF THE CONTAMINATION OF MILK AND BEEF WITH ^{137}Cs

The accuracy of predicted contamination of milk and beef with ^{137}Cs is strongly dependent on the correct determination of the ^{137}Cs content in pasture grass and other components of the fodder. A detailed account of the metabolic processes of ^{137}Cs uptake in the bodies of cows and its transfer to beef and milk makes it possible to describe seasonal variations in contamination of products; this is of particular importance in the first few years following a radiation accident. In the same manner as for the other assessment pathways, the description of the milk and beef contamination pathways varied in the models from simple algebraic equations, which assumed the presence of equilibrium in the “fodder-animal product” system, to sets of linear differential equations.

The LIETDOS model used the equilibrium transfer parameters “forage-beef” and “forage-milk”, following the simple formulas:

$$C_{beef}(t) = TF_{beef} \cdot Q(t) \tag{3.13}$$

and $$C_{milk}(t) = TF_{milk} \cdot Q(t)$$

where $Q = \Sigma M_{for,i} C_{for,i}$ represents daily intake of ^{137}Cs by the cow; $M_{for,i}$ is the daily consumption of the i-th forage category by the cow (kg day^{-1}); $C_{for,i}$ is ^{137}Cs concentration in the i-th forage category (Bq kg^{-1}); C_{beef} and C_{milk} are the activity of ^{137}Cs in milk (Bq L^{-1}), and beef (Bq kg^{-1}); and TF_{beef} and TF_{milk} are equilibrium transfer parameters from daily intake of ^{137}Cs to milk (d L^{-1}) and beef (d kg^{-1}).

The CLRP model provides a more complicated algebraic formula for the beef and milk contamination, taking into account the dynamics of radiocesium removal with respect to its uneven intake by farm animals with fodder.

$$C^i_{product}(t) = \sum_{j=1}^{k} Q(t_j) \cdot TF^i_{product} \cdot \left\{ \alpha^i e^{-\lambda_{i,fast} \cdot t_j} + (1-\alpha^i) \cdot e^{-\lambda_{i,slow} t_j} \right\} \tag{3.14}$$

where $i = 1$ refers to milk and $i = 2$ refers to beef; $Q(t_j)$ is the intake of radiocesium at the j-th day after the accident; and $\lambda_{i,fast}$ and $\lambda_{i,slow}$ are the fast and slow rate constants for the reduction of radionuclide concentration in an animal due to physiological processes.

SPADE deals with ingestion of pasture grass, other fodder crops, fodder, and soil associated with animal models. Inclusion of animal intakes of radionuclides via inhalation is an option which is available in SPADE. Radionuclide excretion from cattle is represented by several pathways in the models. Ingestion of feed containing radionuclides is represented by transfers to the upper gastro-intestinal tract compartment, from either the compartments in the plant module which represent above ground vegetation or external sources, depending on the pathway specified in the scenario. The rate of radionuclide uptake is determined differently for the two scenarios. Ingestion of soil with fodder is represented by compartmental transfers to the upper gastro-intestinal tract from each of the compartments in the surface soil layer. Equations used for these transfers are given in Annex II.

The ECOMOD and OSCAAR models use a similar approach in modelling the beef and milk contamination with radiocesium, based on differential balance equations:

$$\frac{dC_{beef}}{dt} = Q_m(t) \cdot TRF_{beef} - (\lambda_r + \lambda_{meta}) C_{beef} \tag{3.15}$$

and $$\frac{dC_{milk}}{dt} = Q_m(t) \cdot TRF_{milk} - (\lambda_r + \lambda_{milk}) C_{milk}$$

where C_{beef}, C_{milk} are concentrations of ^{137}Cs in beef and milk, Bq kg^{-1}; $Q_m(t)$ is the daily intake of radionuclide per kg of cow's body, Bq kg^{-1} d^{-1}, $Q_m(t) = Q(t)/m(t)_{cow}$ (m_{cow} is the cow's mass in kg); TRF_{beef} , TRF_{milk} are partitioning coefficients of bioassimilated ^{137}Cs between beef and milk; λ_{meta} is the removal rate of radionuclide due to metabolism; λ_{milk} is the milk production rate, d^{-1}; and λ_r is the radioactive decay rate, d^{-1}.

The metabolism of ^{137}Cs in the animal was described most fully in the TAMDYN-UV model, including radionuclide ingestion, assimilation in the gastrointestinal tract, and central circulation in blood, as well as transfer to the milk and muscles of the cow. The following set of linear differential equations describes these processes:

$$
\begin{aligned}
\frac{dC_{GIT}(t)}{dt} &= Q(t) - (\lambda_r + r_{exc} + r_{GIT-CC}) \cdot C_{GIT} \\
\frac{dC_{CC}(t)}{dt} &= r_{CC-GIT} C_{GIT} + r_{meta} C_{tis} - (\lambda_r + r_{exc} + r_{CC-tiss}) C_{CC} \\
\frac{dC_{tiss}(t)}{dt} &= -(\lambda_r + r_{meta} + r_{tiss-CC}) \cdot C_{tiss} + r_{CC-tiss} \cdot C_{CC}
\end{aligned}
\tag{3.16}
$$

where C_{GIT}, C_{CC}, *and* C_{tiss} are the activities of ^{137}Cs in the gastrointestinal tract, in the central circulation of the blood, and in tissues; r_{exc} is the rate of excretion (d^{-1}); and r_{GIT-CC}, r_{CC-GIT}, $r_{CC-tiss}$, $r_{tiss-CC}$, and r_{meta} are transfer rates between compartments in the animal's body (d^{-1}).

3.9. MODELLING OF THE RADIOACTIVE CONTAMINATION OF NATURAL PRODUCTS

3.9.1. Mushrooms and wild berries

In the test area described in the Iput scenario, the products of natural ecosystems traditionally occupy an important place in the diet of the population. In spite of the significance of the ^{137}Cs activity reconstruction in natural products, most of the modellers used a simple calculation approach (e.g. ECOMOD) based on the use of concentration factors. This reflects a general insufficient formalization of models describing ^{137}Cs behavior in forest ecosystems. In three models (TAMDYN-UV, CLRP, and RadCon), contamination of mushrooms and wild berries is estimated using the same equations as for farm crops (with the interception factor, the rate of radionuclide intake from soil, etc.). This makes it possible to estimate, if necessary, the primary contamination of mushrooms and wild berries in the early period of fallout. In the Iput scenario, however, it was necessary to calculate the ^{137}Cs dynamics in mushrooms and wild berries for an extended period of 10 years. Some of the models, such as the Japanese model OSCAAR, did not include the mushroom pathway. In the case of SPADE, calculations of mushroom contamination were made outside the main computer code.

3.9.2. River and lake fish

According to the observed data, consumption of lake fish and to a lesser degree of river fish makes a noticeable contribution to radiation doses to the population in the test area of the Iput scenario. On the whole, models for the transfer of ^{137}Cs in lake and river ecosystems are sufficiently well developed to predict the dynamics of ^{137}Cs accumulation by fish at different trophic levels. However, most radioecological models are specialized and describe in detail either terrestrial ecosystems (predominantly agricultural ones) or aquatic ecosystems, but not both.

For the most part, “terrestrial” models were used by participants in the Iput scenario exercise, and comparatively little attention was given to calculations of fish contamination with ^{137}Cs. Of eight modellers who made calculations, only three presented calculations for fish (SENES, TAMDYN-UV, OSCAAR; for the latter, calculations were made by T. Matunaga outside the main computer code). Simple assessments based on water-to-fish accumulation factors were used for the fish pathway. Other modellers did not consider the fish pathway at all; as a consequence, doses to the population in the test area could be underestimated.

3.10. THE INGESTION DOSE AND WHOLE BODY CONCENTRATION OF ^{137}CS

Internal exposure due to ingestion of contaminated food was evaluated by all models, using the equation:

$$D_{ing}(t_k) = DF_{ing} \sum_i \int_0^{t_k} M_i(t) C_i(t) dt \tag{3.17}$$

where DF_{ing} is the dose conversion factor for ingestion of ^{137}Cs; M_i is the daily consumption of the i-th food category by an adult representative of the local population (kg d^{-1} or L d^{-1}); and C_i is the activity of ^{137}Cs in the i-th food category (Bq kg^{-1} or Bq L^{-1}). The RadCon model also applies removal of contamination by food processing.

The whole body content of ^{137}Cs at time t [$WHB(t)$]due to consumption of contaminated food was calculated by means of the following equation (LIETDOS and CLRP models):

$$WHB(t) = \int_0^t Q_{\text{int}ake}(\tau) e^{-\lambda_r(t-\tau)} \{\alpha_{fast} e^{-\lambda_{fast}(t-\tau)} + \alpha_{slow} e^{-\lambda_{slow}(t-\tau)}\} d\tau \tag{3.18}$$

where $WHB(t) = M_{hum} \cdot C_{hum}$; C_{hum} is the activity concentration of ^{137}Cs in human body (Bq kg^{-1}); M_{hum} is the body mass (kg); Q_{intake} is the human daily intake of ^{137}Cs activity (Bq d^{-1}); λ_{fast} is a short term retention constant (d^{-1}); λ_{slow} is a long term retention constant; and λ_r is the radioactive decay rate. It is assumed that the radioactive contamination of the test area before the Chernobyl accident was negligible and that contamination occurred at the moment $t = 0$.

The authors of the Iput scenario (see Annex I, Section I–2) used the following simplified formula for calculating the expected average content of ^{137}Cs in the body of inhabitants of the Iput test area:

$$WHB = \int_0^{t_1} Q_{int\,ake}(\tau) \cdot R(t_1 - \tau) d\tau \tag{3.19}$$

where WHB is the activity of ^{137}Cs in the body of an adult representative of the local population (Bq kg^{-1}); $R(t) = \alpha_{slow} e^{-\lambda_{slow}(t-\tau)}$ (unitless) is the retention function for ^{137}Cs in the body of adult persons of both sexes; and the ^{137}Cs excretion half-period from the body of an adult person is assumed to be $T_{1/2} = \ln 2/\lambda_{slow}$. Equation (3.19) was used for calculating the radionuclide content in the body of inhabitants as of September 1986 (t_1 = 120 days). For later dates, it was assumed that ^{137}Cs intake and removal are balanced, and the calculation was performed according to the empirical formula

$$(WHB/M_{hum})_{av} = 1.67 * I_{137}(t) \tag{3.20}$$

where $I_{137}(t)$ is the average daily intake of ^{137}Cs by an adult member of the local population, Bq d^{-1}. In the absence of site specific data, it was assumed that M_{hum} = 70 kg.

4. SELECTION OF MODEL PARAMETERS

At the present state of radioecological modelling, selection of correct values for empirical parameters is the most important problem in determining the accuracy of calculations of ^{137}Cs dynamics in the ecosystem components, contamination of food products, and radiation doses to the local population. This section describes sources of information for values of the key radioecological parameters used in the exercise. The degree of uncertainty of the available information about the model parameters and the related uncertainty of model predictions are estimated. It should be noted that participants did not always use the same approaches to modelling a particular endpoint.

4.1. DOSE CONVERSION FACTORS FOR ^{137}Cs

The effective external and internal doses from ^{137}Cs to humans living in the contaminated area were calculated using the following set of dose conversion factors:

- Groundshine, DF_{ground};
- Cloudshine, DF_{cloud};
- Inhalation, DF_{inh}; and
- Ingestion, $DF_{ing.}$

Most radiological assessments use the same or similar dose conversion factors. The values of dose conversion factors used by participants in the Iput scenario exercise are described below, along with the sources from which those values were taken. Uncertainties in dose conversion factors were not considered by most participants.

- **Dose conversion factor for groundshine, DF_{ground}:** The values of DF_{ground} are given in Table 4. The most commonly used sources of information for this parameter are publications by Eckerman and Ryman (1993) and Jacob et al. (1990). One participant used the method of Kocher (1980) for calculations of DF_{ground}.
- **Dose conversion factor for cloudshine DF_{cloud}:** All modellers used similar values for this factor, ranging from 2.23×10^{-9} to 2.35×10^{-9} Sv d^{-1} per Bq m^{-3} (Table 5).
- **Dose conversion factor for inhalation DF_{inh}:** The values of DF_{inh} used by participants are given in Table 6. Most of the modellers used the value 8.6×10^{-9} Sv Bq^{-1}, although another value, 4.6×10^{-9} Sv Bq^{-1}, is adopted in the current International Basic Safety Standards (IAEA, 1996b).
- **Dose conversion factor for ingestion, DF_{ing}:** Participants used values for DF_{ing} ranging from 1.2×10^{-8} to 1.4×10^{-8} Sv Bq^{-1} (Table 7), based in most cases on ICRP publications (ICRP, 1979; 1993).

TABLE 4. VALUES OF DOSE CONVERSION FACTORS FOR ^{137}Cs GROUNDSHINE USED IN CALCULATIONS FOR THE IPUT SCENARIO

Model	Value of DF_{ground}, Sv d^{-1} per Bq m^{-2}	References
LIETDOS	2.87 × 10^{-11}. Influence of the downward migration of ^{137}Cs in soil was taken into account according to Kocher and Sjoreen (1985).	Eckerman and Ryman, 1993
SENES	Factor is calculated using dose rate factors for uniformly contaminated soil layers at different depths	Eckerman and Ryman, 1993; Apostoaei et al., 2000
RadCon	3.17 × 10^{-11}	Jacob et al., 1990
CLRP	3.17 × 10^{-11}	Jacob et al., 1990
SPADE	3.12 × 10^{-11}	Scenario description
TAMDYN-UV	Factor is calculated by summing dose rates from contaminated soil layers at different depths.	Jacob et al., 1990; MicroShield Version 3.0
OSCAAR	5.06 × 10^{-11}. Factor is calculated based on Kocher (1980).	Kocher, 1980
Authors' calculations	Calculated from measurements	

TABLE 5. VALUES OF DOSE CONVERSION FACTORS FOR ^{137}Cs CLOUDSHINE USED IN CALCULATIONS FOR THE IPUT SCENARIO

Model	Value of DF_{cloud}, Sv d^{-1} per Bq m^{-3}	References
CLRP	2.23 × 10^{-9}	ICRP, 1979
TAMDYN-UV	2.23 × 10^{-9}	
RadCon	2.23 × 10^{-9}	
SPADE	2.23 × 10^{-9}	
OSCAAR	2.49 × 10^{-9}. Factor is calculated based on Kocher (1980).	Kocher, 1980
LIETDOS	2.35 × 10^{-9}	Eckerman and Ryman, 1993
Authors' calculations	2.23 × 10^{-9}	Jacob et al., 1996

TABLE 6. VALUES OF DOSE CONVERSION FACTORS FOR ^{137}Cs INHALATION USED IN CALCULATIONS FOR THE IPUT SCENARIO

Model	Value of DF_{inh}, Sv Bq^{-1}	References
CLRP	8.6 × 10^{-9}	ICRP, 1979
RadCon	8.6 × 10^{-9}	
LIETDOS	8.6 × 10^{-9}	
TAMDYN-UV	8.6 × 10^{-9}	
SPADE	8.6 × 10^{-9}	
SENES	8.6 × 10^{-9} (GSD[a] = 1.8)	Eckerman et al., 1988
OSCAAR	8.63 × 10^{-9}. Factor is calculated by DOSDAC based on ICRP (1979).	ICRP, 1979
Authors' calculations	4.6 × 10^{-9}	IAEA, 1996b

[a] Geometric standard deviation.

TABLE 7. VALUES OF DOSE CONVERSION FACTORS FOR ^{137}Cs INGESTION USED IN CALCULATIONS FOR THE IPUT SCENARIO

Model	Value of DF_{ing}, Sv Bq^{-1}	References
CLRP	1.3 × 10^{-8}	ICRP, 1993
Authors' calculations	1.3 × 10^{-8}	
RadCon	1.4 × 10^{-8}	ICRP, 1979
TAMDYN-UV	1.4 × 10^{-8}	
LIETDOS	1.4 × 10^{-8}	
SPADE	1.4 × 10^{-8}	
SENES	1.2 × 10^{-8} (GSD[a] = 1.2)	Apostoaei et al., 1998

[a] Geometric standard deviation.

4.2. PARAMETERS OF ^{137}Cs MIGRATION IN SOIL

The following information on ^{137}Cs behavior in soil is necessary for radiological assessment:

- total inventory of ^{137}Cs on soil (Bq m^{-2}) as a starting point for calculations;
- the dynamics of mobile ^{137}Cs in the root zone, available for plant uptake (for calculation of plant contamination); and
- the dynamics of ^{137}Cs activity in the root zone (both mobile and fixed fractions) and the rate of radionuclide migration into the deeper soil layers (for groundshine exposure calculations).

4.2.1. Total inventory of ^{137}Cs in soil

The scenario description included data on the inventory of ^{137}Cs in each particular subarea of the test area (see Table I–XLI in Annex I), from which it is possible to estimate the average inventory in the test area (Bq m^{-2}). Some participants (e.g. LIETDOS in preliminary calculations) preferred to estimate the ^{137}Cs inventory from available data on air contamination during the radioactive cloud passage through the test area in 1986; however, due to the incompleteness of the air concentration data, these attempts were not successful and resulted in mispredictions of ^{137}Cs inventory. The values of the ^{137}Cs inventory in the Iput test area, calculated by participants in the test exercise, are summarized in Table 8. The incorrect estimation of ^{137}Cs inventory in the test area made by some participants was a basic cause of model misprediction for the whole set of exposure pathways.

4.2.2. Dynamics of mobile ^{137}Cs in the root zone of plants

Modelling the dynamics of the mobile ^{137}Cs concentration in soil, or the fraction of ^{137}Cs available for plant uptake, is a difficult task for modellers. Up to now, the physical-chemical processes of ^{137}Cs behavior in soil have not been well studied, and only a few experimental estimates of the kinetic rates were available for modellers in the Iput scenario calculations.

Following the recommendations of the IAEA (1994) and data on parameter values presented in the ECOSYS-87 model (Müller and Pröhl, 1993), some modellers (SENES, ECOMOD, OSCAAR) used a simple one-exponential formula (Equation 3.5) to describe the decrease of available ^{137}Cs in the root zone (arable land). The value of the exponential decrease parameter used in calculations was within the range λ_{decl} = 0.1–0.15 y^{-1} for the first 3–5 years after the accident. For the later period, the λ_{decl} was rather uncertain; it should be less than 0.1 y^{-1}, but greater than the radioactive decay rate, 0.023 y^{-1}.

TABLE 8. CALCULATED VALUES OF ^{137}Cs INVENTORY IN THE IPUT SCENARIO TEST AREA (AGRICULTURAL LANDS) IN 1986

Model	Average inventory, kBq m^{-2}
LIETDOS	796
OSCAAR	821
CLRP	811
RadCon	724
TAMDYN-UV	695
SPADE	773
SENES	741
ECOMOD	710
LINDOZ	507
Authors' calculations	790 ± 360 (arithmetic mean ± standard deviation) 710 (geometric mean; GSD[a] = 1.55)

[a] Geometric standard deviation.

The CLRP model used a two-exponential decrease formula (Equation 3.6) for calculation of the total bioavailable concentration of ^{137}Cs in the soil root zone. It was assumed that the activity of the mobile fraction of ^{137}Cs decreased more rapidly in the upper soil layer (because of percolation, runoff, etc.) than the activity of the fixed fraction of ^{137}Cs. The parameter of the fast exponential decrease used in these models varied in the range of 0.35–1.13 y^{-1}; the parameter of slow exponential decrease varied from 0.0073 up to 0.014 y^{-1} (without consideration of radioactive decay).

Two models (LIETDOS and TAMDYN-UV) used a set of differential equations to calculate ^{137}Cs dynamics in soil (mobile and fixed fractions separately, Equations 3.7 and 3.8). For the downward migration of ^{137}Cs in soil, only the soluble form was taken into consideration in the TAMDYN-UV model. The TAMDYN-UV model considered the soil layers as connected compartments with the downward migration rate proportional to the thickness of the layer. Despite a detailed description of the processes responsible for ^{137}Cs migration, modellers had no site specific information on the parameter values, so they used default values from the literature (mostly from ECOSYS-87), or some modifications of default values, according to the modeller's judgement. Complicated formulas from differential equations 3.7 and 3.8 may be approximated by a simple one-exponential formula with the following values of the decrease parameter:

- LIETDOS, $\lambda_{decl} \approx 0.14$ y^{-1} for the first 1–5 years after the accident; $\lambda_{decl} \approx 0.05$ y^{-1} for the later period; and
- TAMDYN-UV, $\lambda_{decl,\ \mathrm{soluble}} \approx 5.5$ y^{-1} for the soluble fraction of ^{137}Cs in soil (20 cm layer). Due to $K_d \approx 1000$ L kg^{-1}, the global value (both soluble and fixed ^{137}Cs) could be assessed as $\lambda_{decl} \approx 0.006$ y^{-1}.

Table 9 presents a summary of the parameter values used in the Iput scenario exercise for simulation of the ^{137}Cs dynamics in soil. The calculated values of ^{137}Cs activity in the root zone of soil in the test area are summarized in Table 10 for several participants.

TABLE 9. PARAMETER VALUES FOR ^{137}CS MIGRATION IN SOIL

Model	Parameter values
$C(t) = C_0 e^{-\lambda_{decl} t}$	
SENES	$\lambda_{decl} = 0.15$ y^{-1} (most endpoints); $\lambda_{decl} = 0.023$ y^{-1} (>5 years, radioactive decay only, for predictions of concentrations in rye)
ECOMOD	$\lambda_{decl} = 0.1$ y^{-1}
LIETDOS (approximation of the complex formula)	$\lambda_{decl} = 0.14$ y^{-1} (1–5 years after the accident); $\lambda_{decl} = 0.05$ y^{-1} (>5 years)
RadCon	$\lambda_{decl} = 0.11$ y^{-1}
ECOSYS-87 (for comparison)	$\lambda_{decl} = 0.1058$ y^{-1}
$C(t) = C_0 e^{-\lambda_r t} \left[\alpha e^{-\lambda_f t} + (1-\alpha) e^{-\lambda_s t} \right]$	
CLRP	$\alpha = 0.6$; $\lambda_f = 0.35$–0.99 y^{-1}; $\lambda_s = 0.069$ y^{-1}
OSCAAR	$\lambda_{decl} = 0.11$ y^{-1}
Authors' estimates (Fesenko & Sanzharova)	$\alpha = 0.7$–0.8; $\lambda_f = 0.23$–$0.46 y^{-1}$; $\lambda_s = 0.04$–0.09 y^{-1}

TABLE 10. PREDICTED VALUES OF ^{137}CS ACTIVITY IN THE ARABLE SOIL OF THE IPUT SCENARIO TEST AREA

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
LIETDOS											
Total ^{137}Cs, kBq m^{-2}	796	780	765	751	737	723	710	697	684	671	
Bioavailable ^{137}Cs, kBq m^{-2}	682	546	438	363	311	275	249	230	216	206	
OSCAAR											
Total ^{137}Cs, kBq m^{-2}	821	790	760	731	703	676	651	626	603	580	558
Bioavailable ^{137}Cs, kBq m^{-2}	821	729	647	574	510	453	402	357	317	281	250
SENES (upper 10-cm of soil)											
Total ^{137}Cs, kBq m^{-2}	740	720	590	530	480	440	430	420	411	401	
Bioavailable ^{137}Cs, kBq m^{-2}	740	620	430	330	250	200	160	135	112	93	
RadCon (without countermeasures)											
Total ^{137}Cs, kBq m^{-2}	724	707	690	673	657	642	627	616	597	573	
Bioavailable ^{137}Cs, kBq m^{-2}	724	647	570	518	463	414	310	331	296	265	
SPADE (agricultural soil, 0-30 cm)											
Total ^{137}Cs, kBq m^{-2}	776	746	716	656	597	567	537	507	507	477	
Bioavailable ^{137}Cs, kBq m^{-2}	567	418	298	218	128	78	48	27	17	12	
TAMDYN-UV (uncultivated soil, 0-20 cm)											
Total ^{137}Cs, kBq m^{-2}	695	690	670	650	630	600	580	560	540	530	
ECOMOD (effective average contamination of the test area with countermeasures)											
Bioavailable ^{137}Cs, kBq m^{-2}	710	410	310	240	190	170	150	135	121	110	

4.3. SELECTION OF SOIL-TO-PLANT TRANSFER FACTORS

Iput scenario calculations include the long term assessment of ^{137}Cs concentrations in the most important types of agricultural plants and in pasture grass. In this context the root uptake of ^{137}Cs by plants is more important than surface plant contamination. Most of the participants in the Iput exercise used Equation (3.9) and default values of soil-to-plant transfer factors (Bq kg^{-1} d.w. plant per Bq kg^{-1} d.w. soil) taken from the following publications: IAEA (1994), Nisbet et al. (1998), or Müller and Pröhl (1993). In the ECOMOD and SENES models, some site specific data on the soil-to-plant transfer factors were taken from Shutov (1992) or Fesenko et al. (1995; 1997). The differences among default values of the transfer factors used by different participants are attributable mostly to the participant's assessment of the soil type in the test area: the CLRP model assumed sandy soil (pH = 5); the RadCon and SENES models assumed mixtures of loam and sandy soils; some models assumed loam soil with pH = 6. A summary of soil-to-plant transfer factors used by participants in the Iput scenario calculations is presented in Table 11. Several models (LIETDOS, SPADE, OSCAAR and TAMDYN-UV) used transfer rates of ^{137}Cs for root uptake instead of transfer factors. Corresponding values of transfer factors, calculated from differential equations for plant contamination, are included in Table 11.

The accuracy of predictions was determined mainly by two factors: accuracy in the prediction of radiocesium dynamics in the root zone of the soil, and selection of appropriate values for the soil-to-plant transfer factor. If the dynamic behavior of ^{137}Cs in soil was calculated correctly, use of default values for soil-to-plant transfer factors (e.g. IAEA, 1994) for sandy loam soil produced results that were in good agreement with the observed data.

TABLE 11. VALUES OF THE SOIL-TO-PLANT TRANSFER FACTORS USED IN THE "IPUT" SCENARIO CALCULATIONS, Bq kg^{-1} d.w. per Bq kg^{-1} soil d.w.

Model	Potatoes	Cereals	Leafy vegetables	Pasture vegetation (hay)
RadCon	0.056	0.017	0.159	0.5
CLRP	0.17	0.06	0.4	2
LIETDOS	0.02	0.02	0.02	0.05
OSCAAR*	0.017–1.7*	0.0026–0.26*	0.046–4.6*	0.024–2.4
TAMDYN-UV**	~0.018**	~0.027**	~0.031**	~0.12**
SENES	0.0015-0.15*	0.0037, 0.037, 0.37 (wheat)***	-	-
ECOMOD	0.02	0.07	0.1	0.37

* Range of log-uniform distribution.

** Transfer factors were calculated by integrating the system of differential equations for an equilibrium situation. The TAMDYN-UV model uses a three-compartment approach for each type of vegetation with dynamic transfer rates between compartments. Transfer factors refer to the soluble fraction of ^{137}Cs in soil. SPADE uses transfer coefficients (s^{-1}).

*** Minimum, mode, and maximum of a log-triangular distribution.

4.4. SELECTION OF PARAMETER VALUES FOR ^{137}Cs TRANSFER FROM FEED TO ANIMAL PRODUCTS (BEEF, MILK, PORK)

The requested endpoints in the Iput scenario exercise are the year-by-year ^{137}Cs concentrations in the main types of agricultural animal products, such as cow's milk, beef, and pork. Two types of approach (equilibrium and dynamic) were used to calculate the ^{137}Cs transfer from contaminated pasture and fodder to animal products.

Equilibrium transfer factors were used by the LIETDOS and CLRP models, assuming a fixed proportion between daily intake of ^{137}Cs by an animal and the resulting radionuclide concentration in its tissues and milk. Use of equilibrium values of transfer factors was reasonable for long term assessment, given a test area contaminated with long lived ^{137}Cs. The equilibrium approach, however, cannot give very accurate predictions for the first year after the accident, when the dynamic processes are of great importance; also, this approach cannot give a detailed description of the seasonal dynamics of milk and meat contamination.

Sources of default values for the transfer factors included IAEA (1994), Köhler et al. (1991), and Müller and Pröhl (1993). The values of feed-to-animal products transfer factors used in the Iput scenario exercise are summarized in Table 12. Each participant used his or her own judgment in selecting values of transfer factors from a wide range of recommended values. As a result, default values for the same transfer factor, taken from the same publication, may differ by one or two orders of magnitude; for example, the feed-to-beef transfer factor selected was 0.02 d kg^{-1} in the LIETDOS model and 0.2 d kg^{-1} (veal) in RadCon model.

The RadCon model used a modification (Equation 3.14) of the equilibrium approach for the ^{137}Cs accumulation in the animal's body, as recommended in the ECOSYS-87 model (Müller and Pröhl, 1993). This modification is intended to take into account the biological half-lives of the ^{137}Cs in the cow's (or pig's) body in case of uneven daily intake of radionuclide. In the RadCon model, the values of the ^{137}Cs biological half-lives were taken from Müller and Pröhl (1993): $T_{f,milk}$ = 1.5 days (fraction α = 0.8); $T_{s,milk}$ = 15 days (fraction α = 0.2); T_{beef} = 30 days; T_{pork} = 35 days. In case of chronic contamination of animal feed (daily intake of ^{137}Cs is constant), Equation 3.14 gives the same result as the equilibrium approach (Equation 3.13).

The OSCAAR and ECOMOD models used simplified differential equations (Equation 3.15) for ^{137}Cs transfer in the trophic chain “feed–cow (milk and beef)” or “feed-pork”. To make possible a direct comparison between different models, the integrated transfer factors were calculated from differential equations (Equation 3.15) for the case of a quasi-equilibrium radioecological situation. The values of integrated transfer factors for the OSCAAR and ECOMOD models are given in Table 12.

The TAMDYN-UV and SPADE models used a full set of differential equations (Equations 3.16) to describe in detail the metabolic processes of ^{137}Cs bioassimilation in the cow’s body. Integrated values of "feed-animal products" transfer factors for these models (quasi-equilibrium state) are given in Table 12.

TABLE 12. VALUES OF THE FEED-TO-ANIMAL PRODUCTS TRANSFER FACTORS USED IN THE IPUT SCENARIO EXERCISE

Model	Feed-to-milk transfer factor, d L^{-1}	Feed-to-beef transfer factor, d kg^{-1}	Feed-to-pork transfer factor, d kg^{-1}	References
LIETDOS	0.007	0.02	0.24	Köhler et al., 1991
CLRP	0.0053	0.01	0.36	
RadCon	0.0079	0.2	0.24	Müller and Pröhl, 1993; IAEA, 1994
OSCAAR*	0.0079	0.20	0.24	IAEA, 1994
ECOMOD (authors' calculations)	0.01	0.055	0.12	Romanov, 1993
SPADE	0.014	0.054	0.043	Mouchel Consulting, 1999

* Indicates mean of distribution used.

5. DISCUSSION OF RESULTS

5.1. CONTAMINATION OF PASTURE AND AGRICULTURAL PLANTS

The dynamics of contamination of pasture and the most important agricultural plants were determined by several factors:

- External contamination was important only in 1986. The contribution of interception in the test area was less important than that of resuspension because the accident-derived deposition took place before the sowing time, with the exception of winter rye.
- During the period 1987–1996, the contamination of plants was determined by the root uptake of ^{137}Cs. The decrease of ^{137}Cs concentration in plants over time was dependent on the rate of downward migration of the radionuclide in arable soils and meadows, as well as the decrease of the radionuclide bioavailability for plants. Both processes included natural factors and the effects of various countermeasures. The dynamics of ^{137}Cs activity in plants completely repeated the dynamics of the bioavailable radionuclide in the root zone of the soil.
- After 1994, the intensity of application of countermeasures decreased due to a general economic depression in Russia. The result of this was a considerable increase of ^{137}Cs activity in agricultural plants.

5.1.1. Leafy vegetables

Maximum levels of ^{137}Cs activity in leafy vegetables were observed in 1986 (average value, 607 Bq kg^{-1} f.w., 95% confidence interval, 466–748 Bq kg^{-1} f.w.; Annex I). By 1991, the overall decrease in contamination of leafy vegetables was about one order of magnitude; for the later period of observation (1992–1996), the decontamination rate was much slower, less than 10% per year.

The revised predictions of the modellers were generally in good agreement with the test data over the 10-year period of observations (Figure 2). Some models (CLRP, ECOMOD) overestimated the ^{137}Cs activity in leafy vegetables in 1986. These mispredictions were caused by using an incorrect sowing date for vegetation that resulted in an error in the value of the interception factor.

The LIETDOS, RadCon, TAMDYN-UV, and ECOMOD models were in general agreement with the test data for leafy vegetables and described adequately the decrease of ^{137}Cs activity in this product. The OSCAAR model also was in general agreement with the test data, but underestimated for the early period after the accident, when the interception was not accounted for. The SPADE model underpredicted contamination of leafy vegetables, as a result of assuming a fast decrease of ^{137}Cs bioavailability in soil.

The CLRP model adequately described the dynamics of ^{137}Cs activity in leafy vegetables, but all results for the period after 1987 were underestimated by a factor of about 5. The reason was the incorrect choice of soil type in the test region and underestimation of the soil-to-plant transfer coefficient.

5.1.2. Potatoes

Maximum levels of ^{137}Cs activity in potatoes were observed in 1986 (average value, 256 Bq kg^{-1} f.w., 95% confidence interval, 187–326 Bq kg^{-1} f.w.; Annex I). By the end of 1988, the average contamination of potatoes had decreased by a factor of two. From 1989 to 1992 the decontamination was negligible; in 1993, due to application of countermeasures, the average ^{137}Cs activity in potatoes dropped down to about 30 Bq kg^{-1}.

The RadCon, TAMDYN-UV, and SENES models produced good results for ^{137}Cs activity in potatoes for the whole 10-year period of observations (Figure 3). The CLRP, LIETDOS, and ECOMOD models gave underestimates of the contamination in potatoes. At the same time, the predicted time dependence of ^{137}Cs activity in potatoes closely correlated with the dynamics of the test values (both curves have similar shapes). This means that the models have a good predictive capacity, and the underestimation in the results was caused by an incorrect choice of soil-to-plant transfer factors.

Initial predictions by the SENES model gave a very rapid decrease in contamination with time, which did not correlate with the test data. The main reason for such misprediction was the assumption of a rapid decrease in ^{137}Cs bioavailability for plants. The revised results are in rather good agreement with the test data. The SPADE and OSCAAR models produced good results for the period 1986–1988, but predictions for the later period were progressively underestimated (SPADE) or overestimated (OSCAAR) in comparison to the test data.

5.1.3. Cereals

The dynamics of ^{137}Cs activity in cereals was complicated in the test area, as it depended strongly on the intensity of applied countermeasures. The maximum level of contamination was observed in 1986 (average value, 670 Bq kg^{-1} d.w., 95% confidence interval, 568–772 Bq kg^{-1} d.w.). During 1986–1989, the annual decrease in ^{137}Cs activity in cereals was about 30%. In 1991–1994, due to intensive countermeasures, the contamination of cereals decreased considerably, to as low as 30–40 Bq kg^{-1} d.w. During the last years of the observation period, 1995–1996, many of the countermeasures were stopped, resulting in an increase of ^{137}Cs activity in cereals.

The SENES and SPADE models adequately reconstructed the long term decrease of ^{137}Cs activity in cereals for most of the years (Figure 4). The LIETDOS model adequately described the contamination of cereals in the first four years after the accident, but gave overestimates for the later period because it underestimated the effectiveness of agricultural countermeasures in this period. Several models overestimated the contamination of cereals in 1986 due to the use of high interception values; however, for the period 1987–1990, the predictions by several models were lower than the test data. For the last years of observation, 1991–1996, more adequate agreement with the test data was obtained by most models; however, none of participants described the increase in contamination of cereals in 1994–1996, when application of countermeasures was stopped.

5.1.4. Pasture (hay)

The activity of ^{137}Cs in pasture grass or hay was an intermediate endpoint in the Iput calculations; results were submitted by six modellers (Figure 5). The LIETDOS model predictions were in good agreement with the test data for the whole period of observations. The RadCon and ECOMOD models were in good agreement with the test data for the contamination of hay in the first year after the accident. For the period 1987–1991, the RadCon and CLRP models underestimated the contamination levels of ^{137}Cs activity in hay, similar to the underestimation these models gave for other agricultural plants (leafy vegetables, cereals). For the later period (1992–1996), their calculations satisfactorily described the observed levels of ^{137}Cs activity in hay. The TAMDYN-UV model overestimated hay contamination in the first two years mainly due to overestimation of interception, while results for the other eight years were in good agreement with the test data.

5.2. CONTAMINATION OF MILK, BEEF AND PORK

5.2.1. Milk

The dynamics of milk contamination in the Iput test area in 1986–1996 were rather complicated. During the first year after the accident, ^{137}Cs activity in milk was high; the maximum value was in May 1986 (average value, 9600 Bq L^{-1}). In 1987–1992 the milk contamination gradually decreased. Substantial (factor of 2–3) seasonal variations of ^{137}Cs activity were observed. In 1993–1996, the activity in milk remained at the level of 1992 and even increased in the later years, due to the reduction in the application of agricultural countermeasures.

Several models underpredicted the ^{137}Cs activity in cow's milk (Figure 6), due either to underestimation of the pasture–to-vegetation–to-milk transfer coefficients or to underestimation of the pasture contamination values. Models developed for the European climatic zone were able to reconstruct the seasonal variations of ^{137}Cs activity in milk. Models developed for warm climatic zones (OSCAAR, RadCon) were not designed for seasonality calculations, and therefore they were not able to adequately reconstruct annual variations of ^{137}Cs activity in milk. The TAMDYN-UV, LINDOZ, and ECOMOD models correctly reconstructed seasonal dynamics as well as long term dynamics of ^{137}Cs activity in milk, although TAMDYN-UV overestimated the concentration in the first year due to overestimation of the interception. SPADE produced underestimates of milk contamination for the first several years after the accident, with better values for subsequent years.

5.2.2. Beef

The dynamics of ^{137}Cs activity in beef in general repeated the dynamics of ^{137}Cs activity in milk, but the self-clearance (loss) processes occurred much more slowly. For a period of 10 years of observations, the activity of ^{137}Cs in milk decreased 2 orders of magnitude from the maximum value, whereas ^{137}Cs activity in beef for this period decreased only 1 order of magnitude (from 8200 to 500 Bq kg^{-1}). In general, model results for the ^{137}Cs activity in beef were in good agreement with the test data.

The RadCon and ECOMOD models provided good results for the reconstruction of ^{137}Cs dynamics in beef during the whole 10-year period of observations, while other models reproduced parts of the observation period (Figure 7). The CLRP and TAMDYN-UV models were in good agreement with the test data except for the first 2 years after the accident. TAMDYN-UV produced overestimates for the early period due to overestimation of the interception; CLRP produced underestimates due to underestimation of ^{137}Cs concentrations in hay and an underestimate in the metabolic model for the transfer into muscle. The LIETDOS model presented results that correlated with the test data, but all predicted numerical values were slightly underestimated. The LINDOZ results for the period 1986–1992 were slightly overestimated. The SPADE model produced good results for the period 1986–1987, although the predictions show rather large seasonal variations that exceed those for the observed concentrations.

5.2.3. Pork

The levels of ^{137}Cs activity in pork in the Iput test area were lower than those for beef (Annex I). The maximum value of ^{137}Cs activity in pork was observed in 1986 (4000 Bq kg^{-1}); the minimum values were observed in 1993 (110–130 Bq kg^{-1}). Seasonal variations of ^{137}Cs activity in pork were observed along with a general trend of long term decrease. The levels of ^{137}Cs activity in pork were higher in summer than in winter.

In general, the models used in this exercise adequately described the ^{137}Cs dynamics in pork (Figure 8). The predictions of the LIETDOS and ECOMOD models were in agreement with the test data in the range of uncertainty of the test data for the whole 10-year period of observations. The LINDOZ model produced correct results for the period 1986–1993. The CLRP and SPADE models strongly overestimated the seasonal variations of ^{137}Cs activity in pork. For CLRP, the main reason was the assumption of a large amount of green legumes in the summer diet of pigs. In the case of SPADE, it was assumed for the sake of simplicity that pigs were grazing on pasture in the summer, but in the winter, were kept indoors and fed on grass cut straight from pasture. The RadCon model slightly underestimated the contamination of pork for the time period 1987–1990, but it was in good agreement with the test data for

1986 and for 1991–1996. The reason for the mispredictions was the use of a step function in the soil-to-plant transfer factors, which caused, in turn, a step-shaped decrease in the contamination of the fodder used for the pigs.

The OSCAAR model predictions were in sufficiently good agreement with the test data for the first five years; for the later period, predicted values were higher than the test data. The TAMDYN-UV model overestimated (by almost 1 order of magnitude) the contamination of pork with ^{137}Cs in the early period after the accident (1986–1988) due to overestimation of the interception on fodder. For the later period, this model predicted practically a constant ^{137}Cs activity in pork, which did not agree with the test data.

5.3. EFFECTIVENESS OF AGRICULTURAL COUNTERMEASURES

In the Iput scenario, detailed comparison of the ^{137}Cs activity levels in agricultural products with and without the application of countermeasures was not specifically requested; nevertheless such comparative analysis is extremely important for understanding the practical usefulness of particular countermeasures to decrease the doses received by the local population.

Special calculations on the effectiveness of different countermeasures were performed for several endpoints using the LIETDOS model (Figures 9 and 10) and for wheat using the SENES model (Figure 4). Figure 9 compares the ^{137}Cs activities in leafy vegetables, cereals, hay (grass) and potatoes, both with applied protective measures and without protective measures, as well as the test data and changes in provisional limits (regulatory limits). Figure 10 shows the ^{137}Cs activity levels in animal products (beef, milk, and pork) predicted without countermeasures in comparison with results based on different countermeasures assumed to have been applied in the test area. Both sets of predictions are compared with test data. It follows from the graphs, that countermeasures applied directly to animals may be potentially very effective (for instance, keeping cattle on clean forage before slaughtering); however as seen from the test data, such countermeasures were not applied actively in the Iput test area, probably because of economic reasons.

The modelling of countermeasures intended to decrease the radioactive contamination of agricultural products is a very important, but insufficiently developed, part of radioecological assessment. The Iput scenario (Annex I, Section I–1.3.5) contains much information on countermeasures that was not fully used by this group of participants, but which may be useful to later modellers. The difficulties in the modeling of countermeasures are discussed in Section 6.2.

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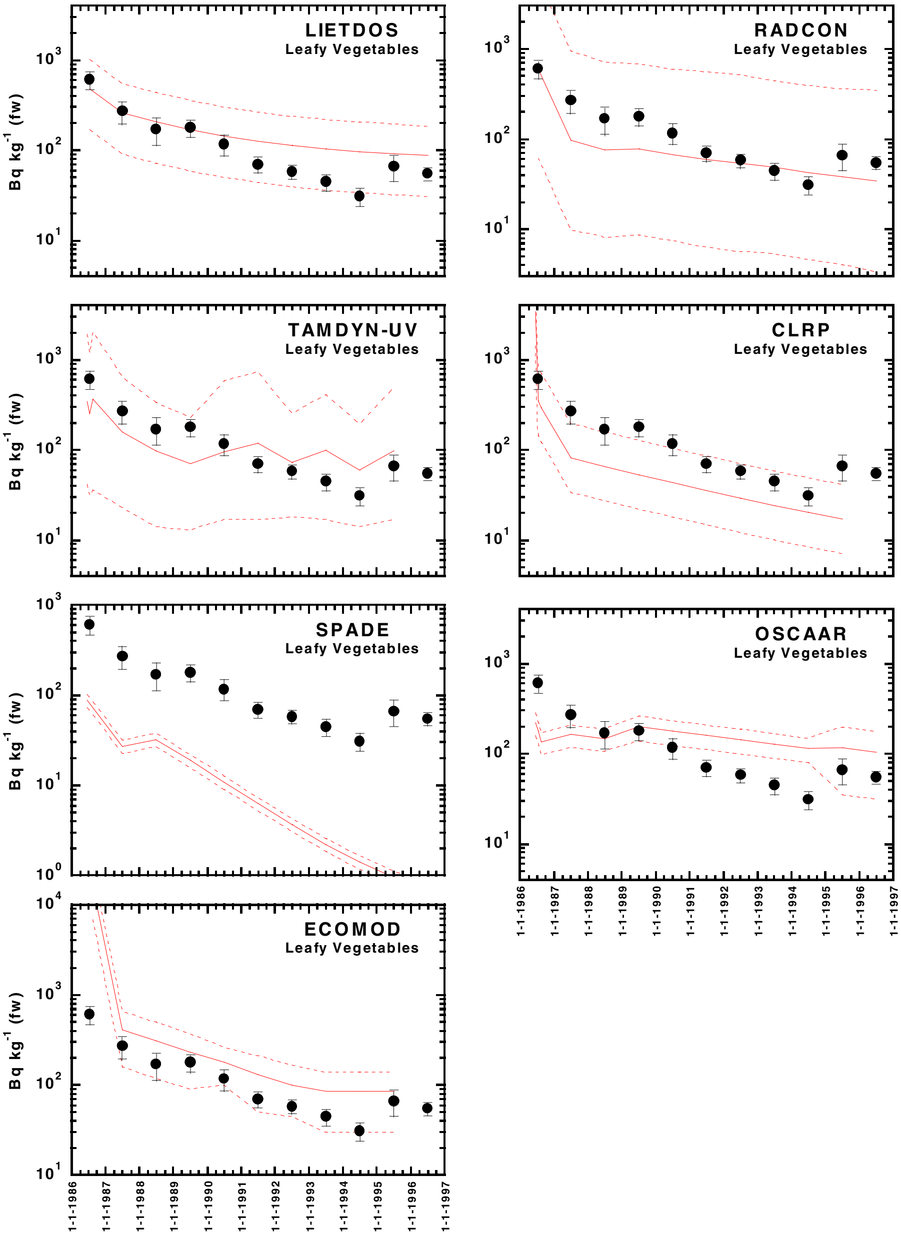


FIG. 2. Comparison of model predictions with measurements for ^{137}Cs concentrations in leafy vegetables. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means.

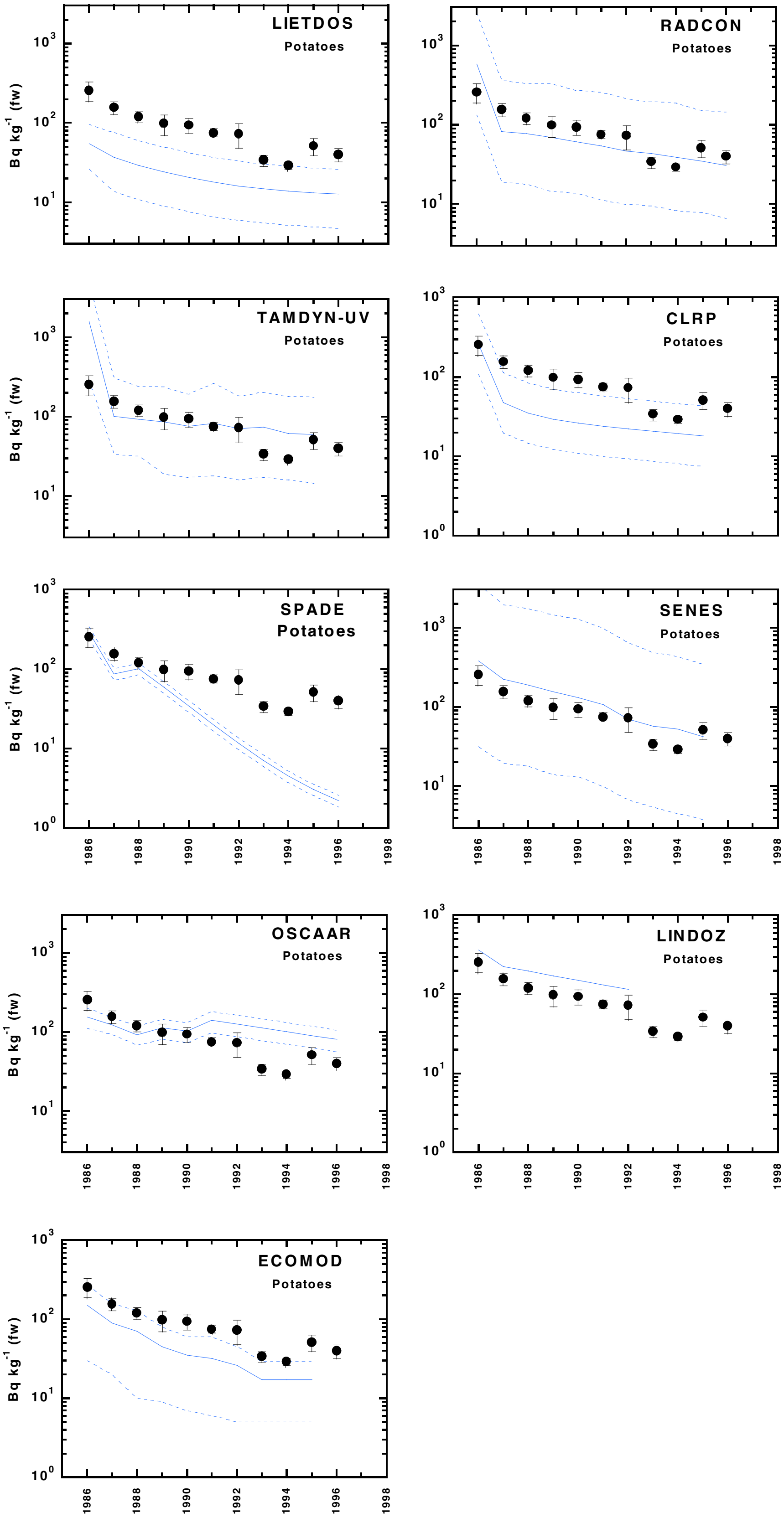


FIG. 3. Comparison of model predictions with measurements for ^{137}Cs concentrations in potatoes. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means.

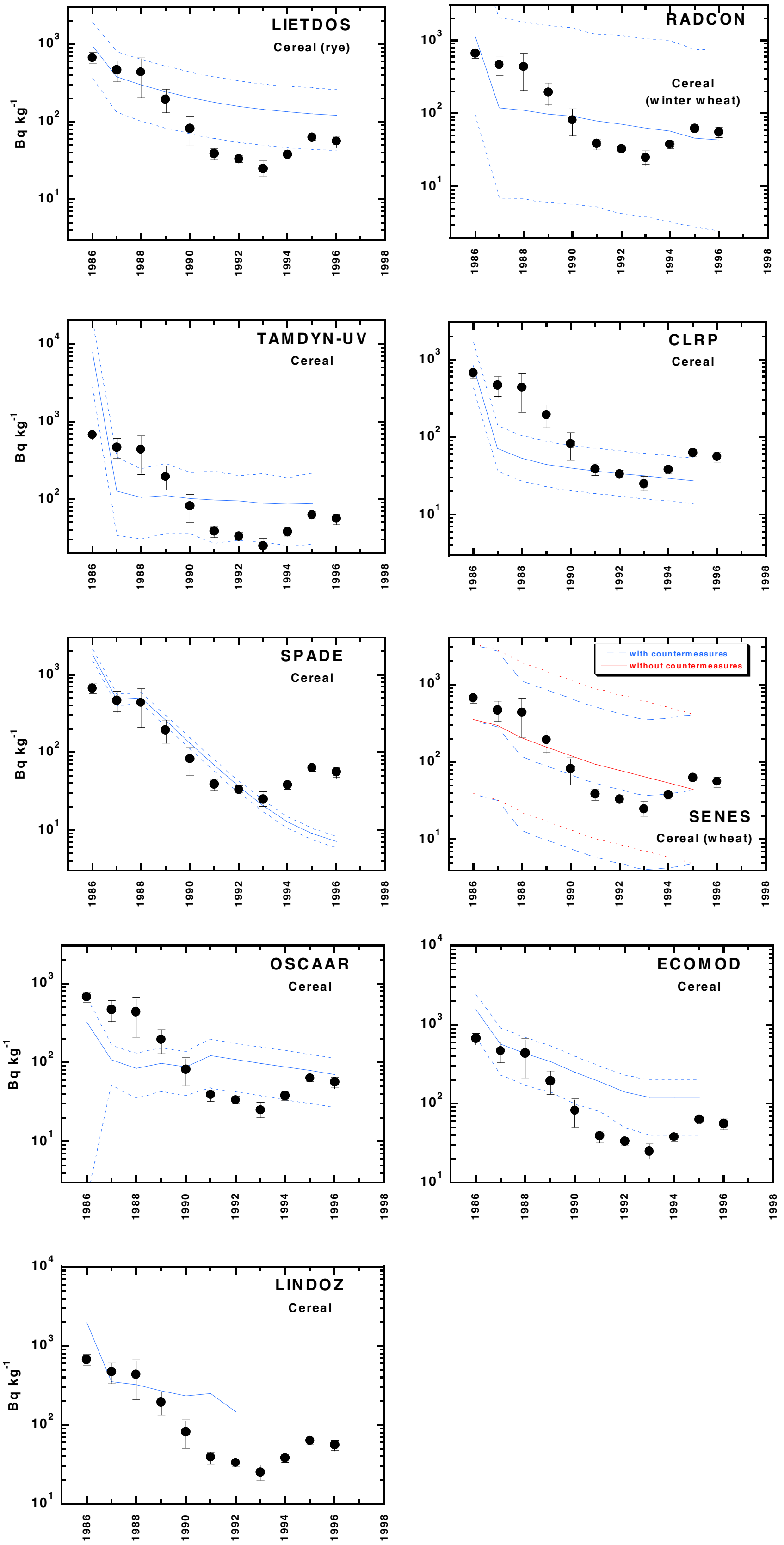


FIG. 4. Comparison of model predictions with measurements for ^{137}Cs concentrations in cereals. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means.

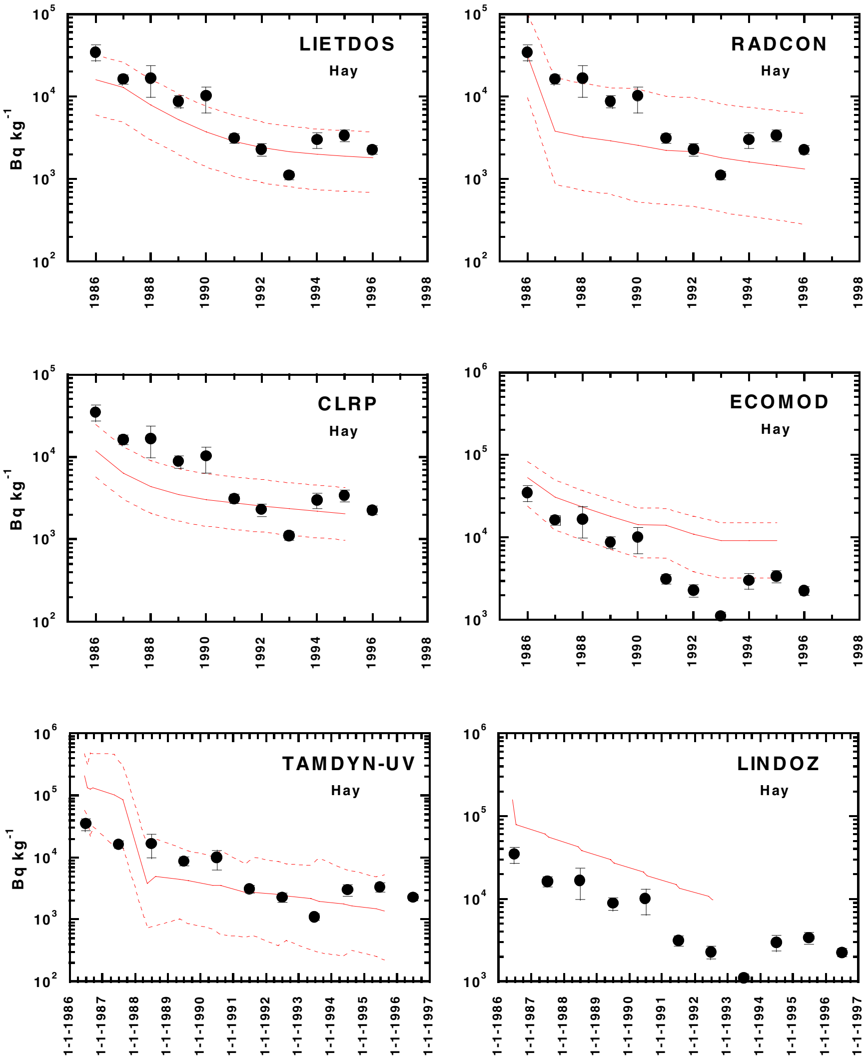


FIG. 5. Comparison of model predictions with measurements for ^{137}Cs concentrations in hay. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the mean. LIETDOS reported values for pasture grass; these were converted to values for hay based on a wet-to-dry weight conversion factor of 5.

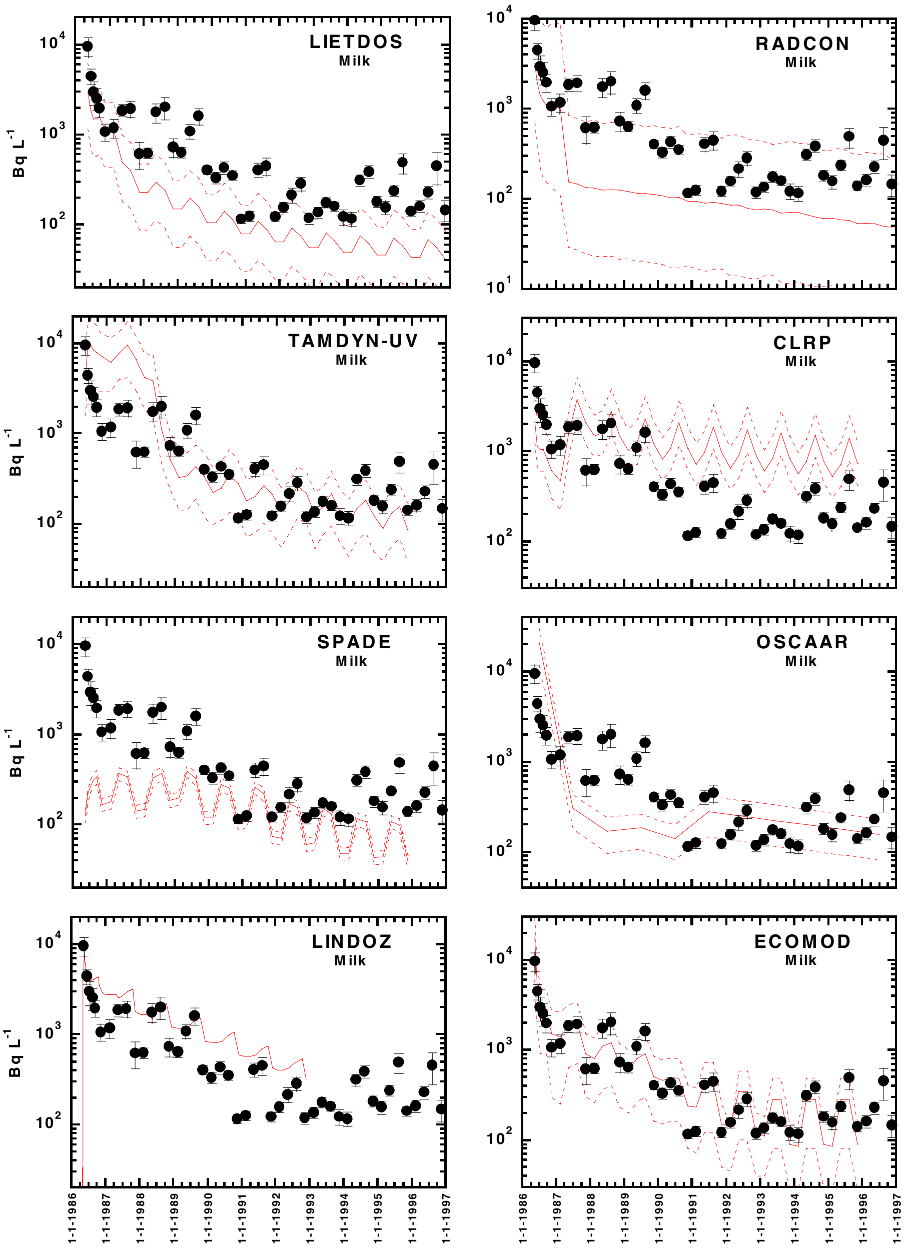


FIG. 6. Comparison of model predictions with measurements for ^{137}*Cs concentrations in milk. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means.*

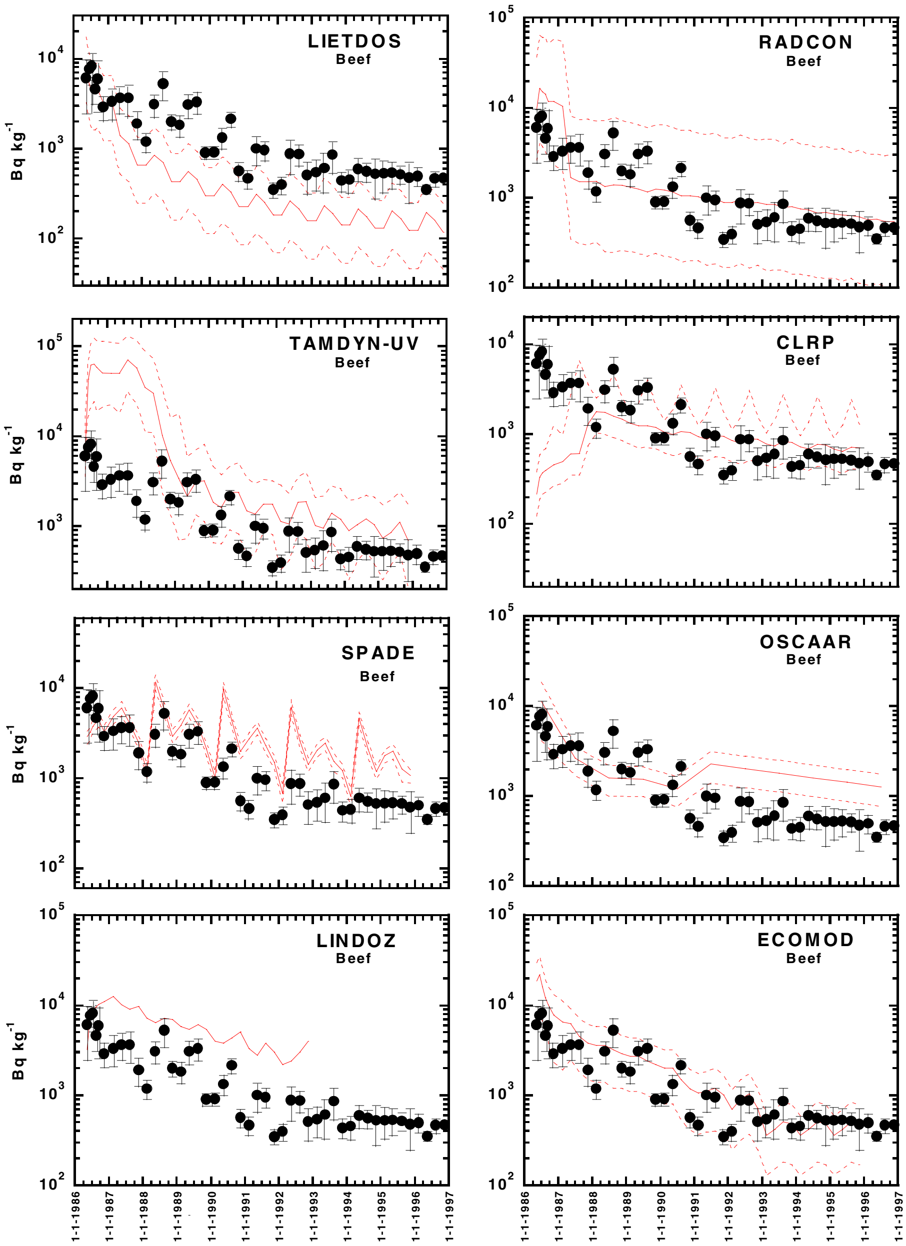


FIG. 7. Comparison of model predictions with measurements for ^{137}Cs concentrations in beef. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means.

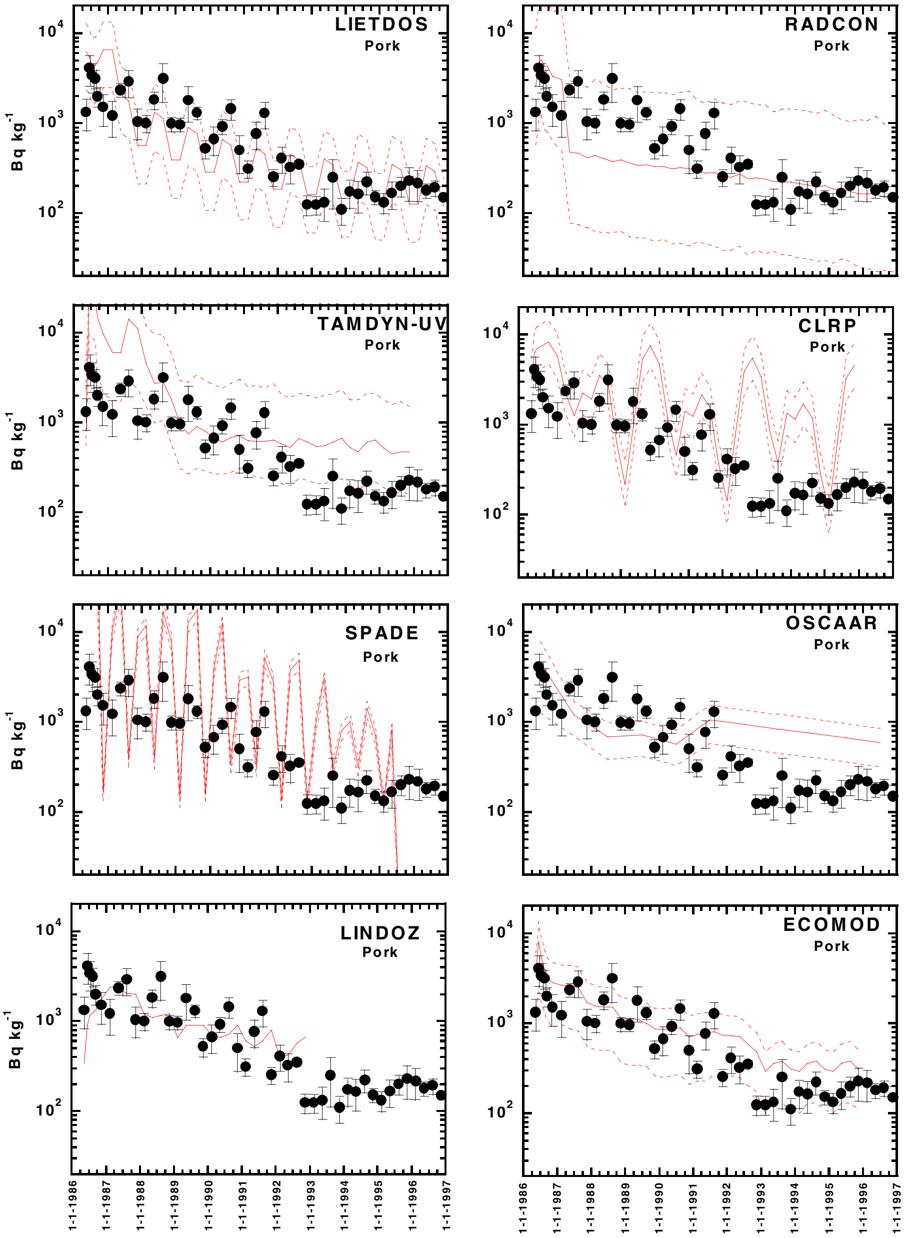


FIG. 8. Comparison of model predictions with measurements for ^{137}Cs concentrations in pork. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means.

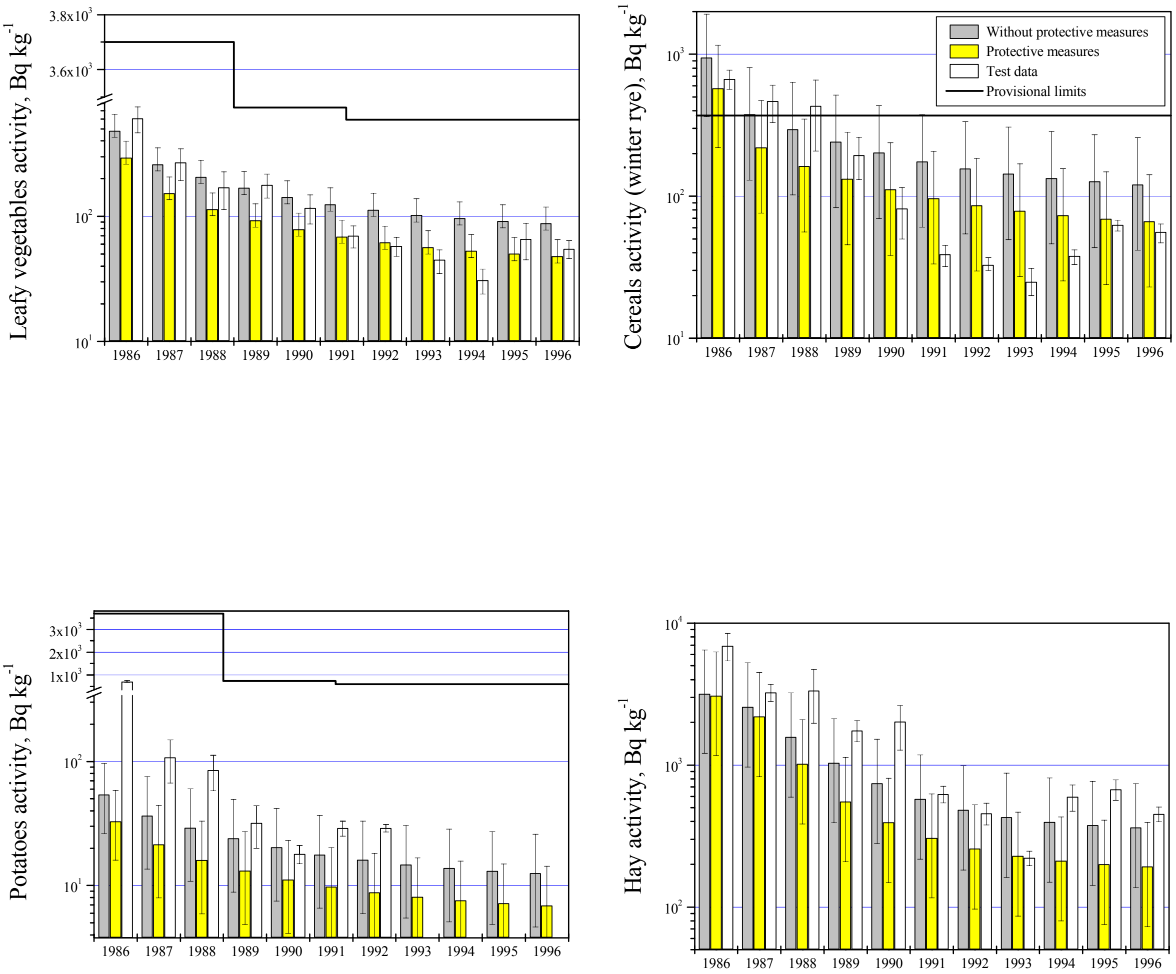


FIG. 9. Comparison of ^{137}Cs activities in leafy vegetables, cereals, potatoes, and hay, with and without applied protective measures (LIETDOS model calculations).

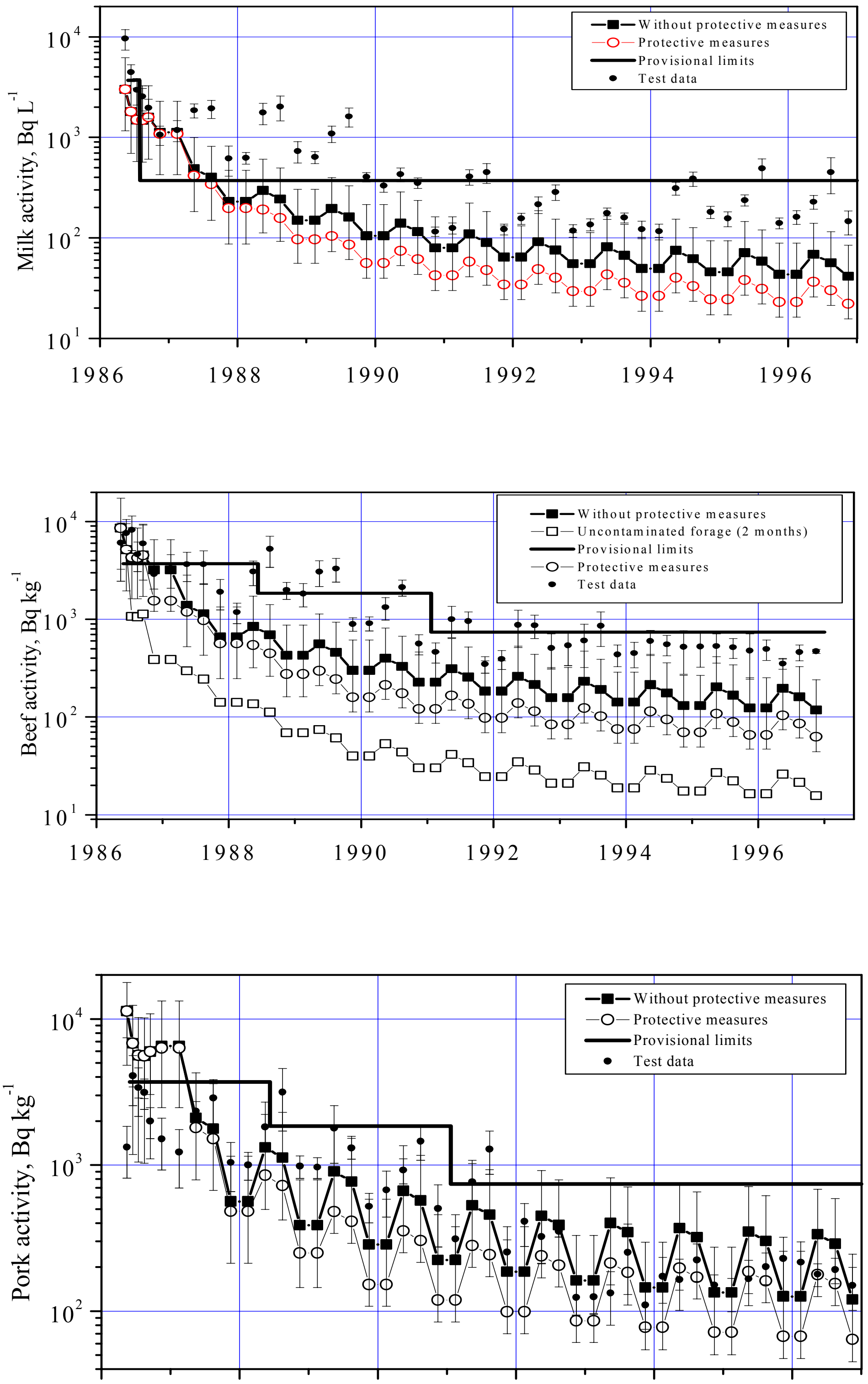


FIG. 10. Temporal changes of predicted milk, beef and pork contamination with and without inclusion of protection measures. For beef, the additional measure of feeding uncontaminated forage for 2 months before slaughter is also shown. Calculations were performed with the LIETDOS model.

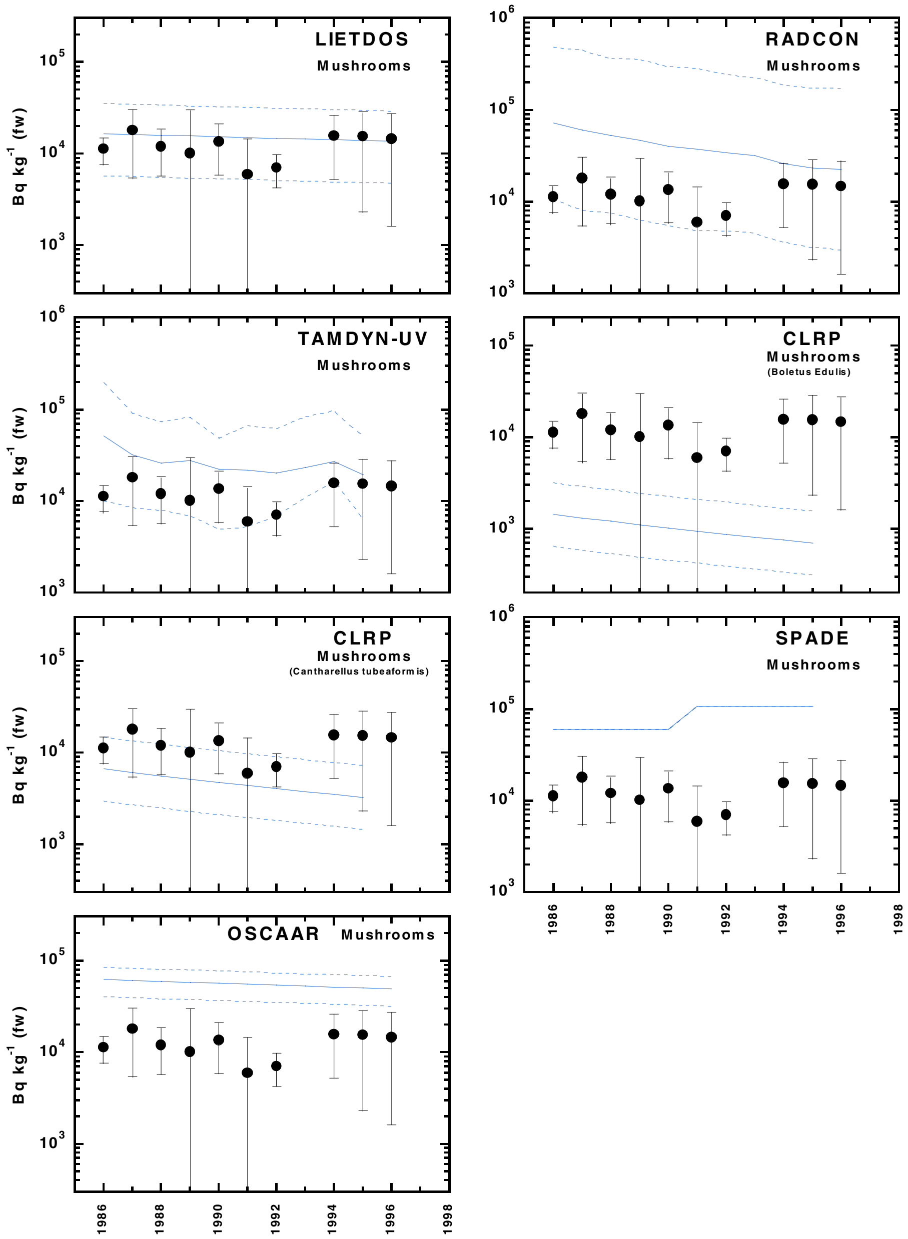


FIG. 11. Comparison of model predictions with measurements for ^{137}*Cs concentrations in mushrooms. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means. Predictions for SPADE were made outside the main code.*

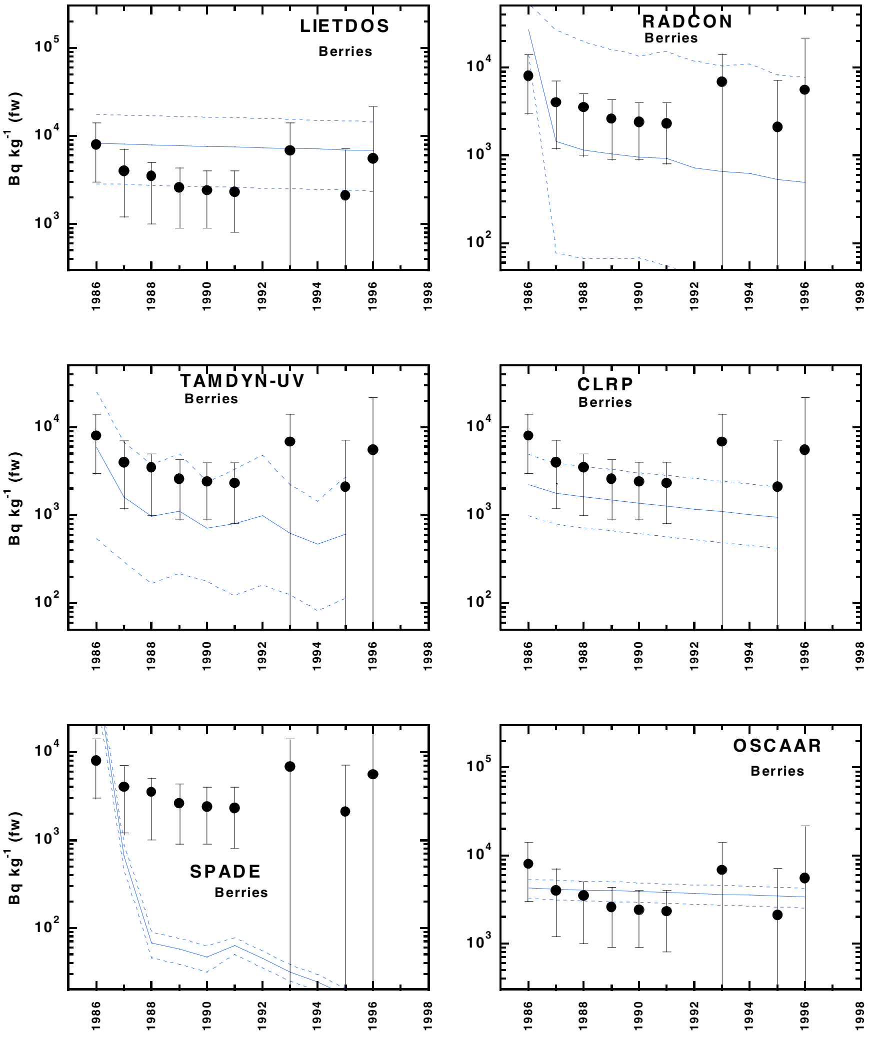


FIG. 12. *Comparison of model predictions with measurements for* ^{137}*Cs concentrations in berries. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means.*

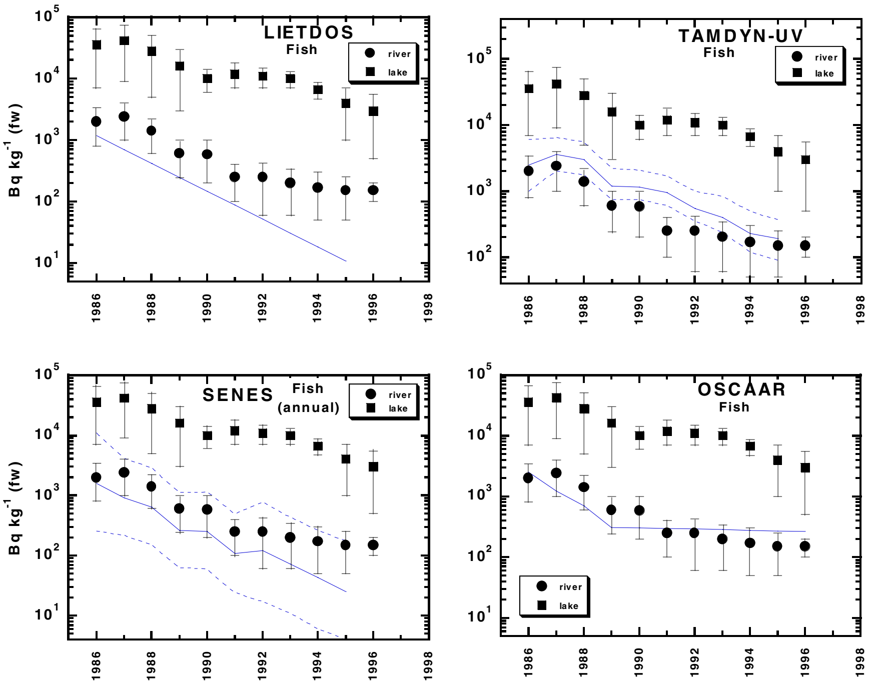


FIG. 13. Comparison of model predictions with measurements for ^{137}Cs concentrations in fish. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles and squares indicate the mean value of the measurements, and the vertical lines indicate the 95% confidence intervals on the means. Predictions for OSCAAR were made outside the main code.

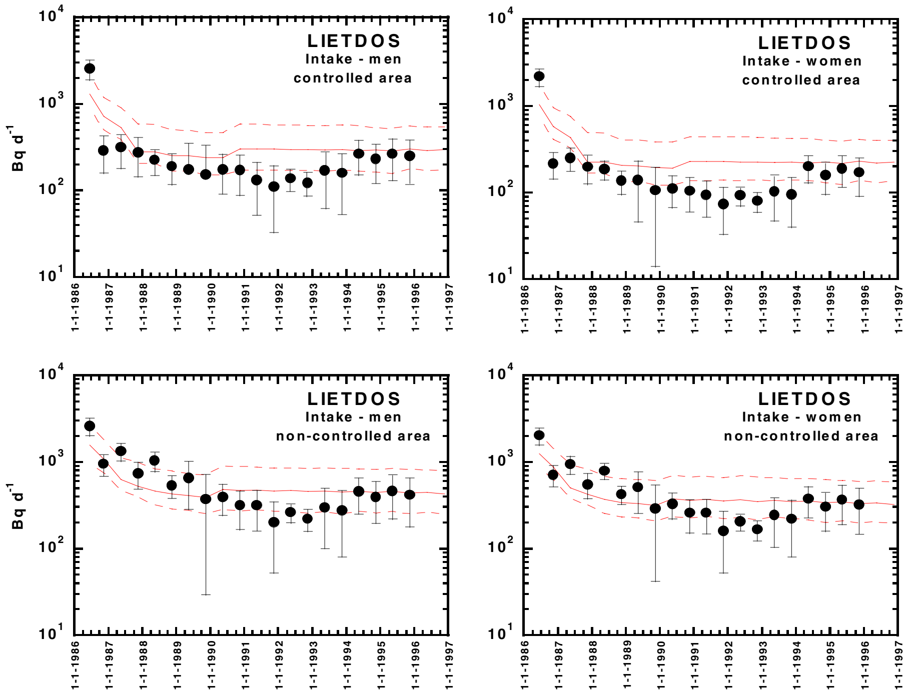


FIG. 14. Comparison of predictions made using the LIETDOS model with authors' calculations for average daily intake of ^{137}Cs by men and women in the controlled or non-controlled areas, as indicated. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values calculated by the scenario authors, and the vertical lines indicate the 95% confidence intervals on the means.

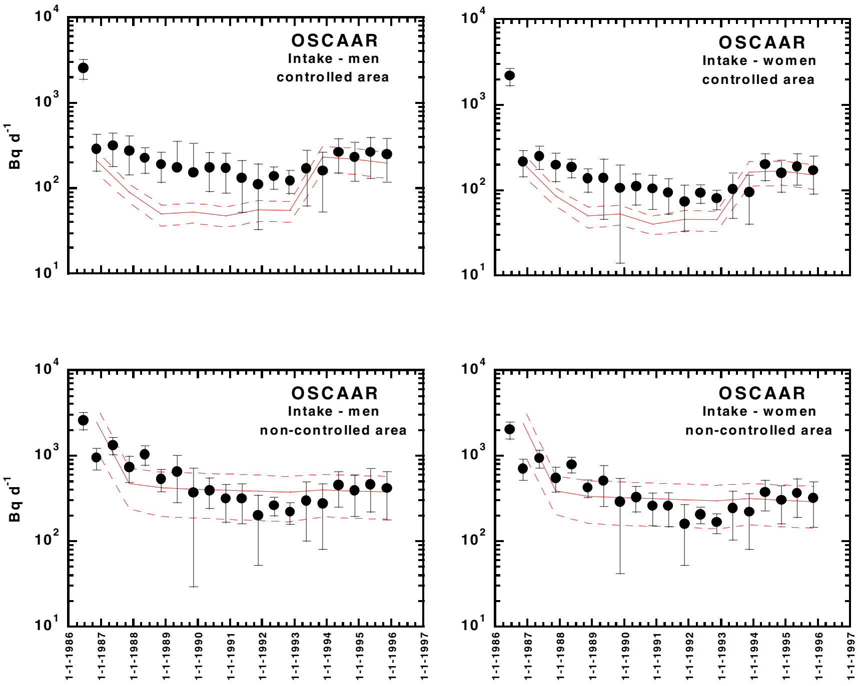


FIG. 15. Comparison of predictions made using the OSCAAR model with authors' calculations for average daily intake of ^{137}Cs by men and women in the controlled or non-controlled areas, as indicated. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values calculated by the scenario authors, and the vertical lines indicate the 95% confidence intervals on the means.

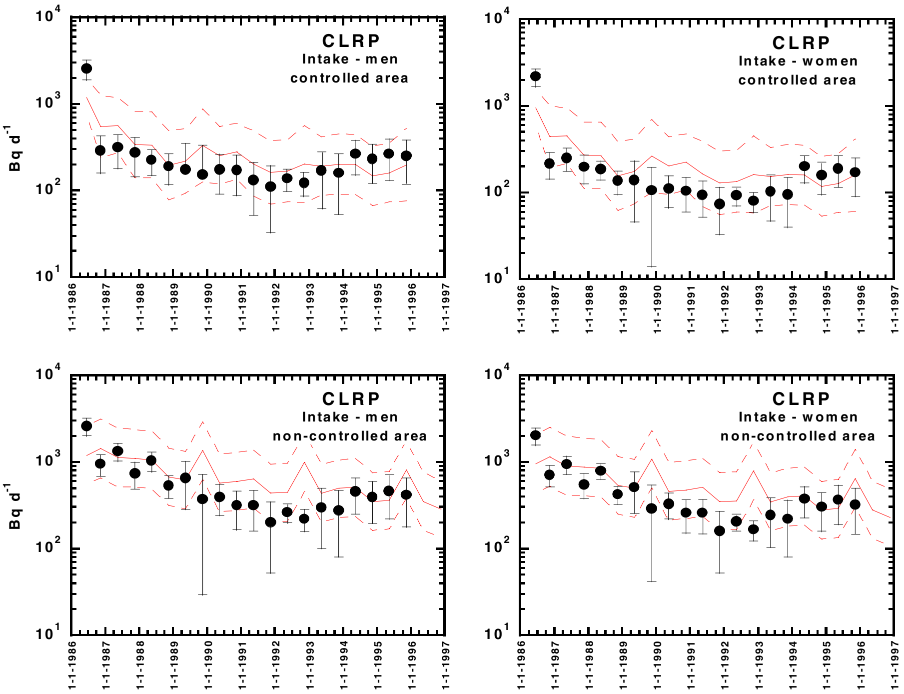


FIG. 16. Comparison of predictions made using the CLRP model with authors' calculations for average daily intake of ^{137}Cs by men and women in the controlled or non-controlled areas, as indicated. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values calculated by the scenario authors, and the vertical lines indicate the 95% confidence intervals on the means.

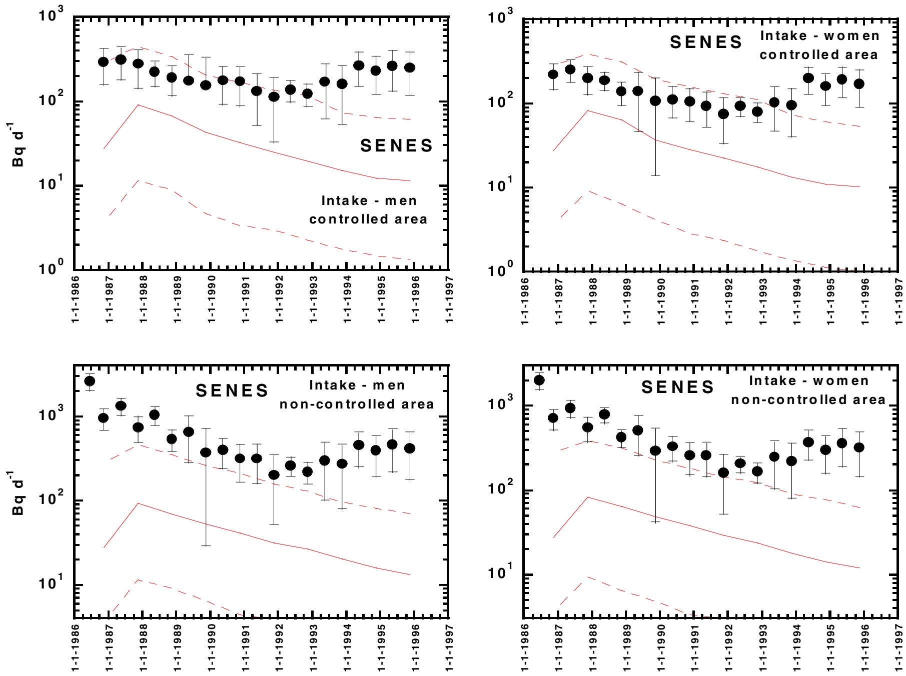


FIG. 17. Comparison of predictions made using the SENES model with authors' calculations for average daily intake of ^{137}Cs by men and women in the controlled or non-controlled areas, as indicated. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values calculated by the scenario authors, and the vertical lines indicate the 95% confidence intervals on the means. Predictions for SENES include only the contributions from grains, potatoes, and fish.

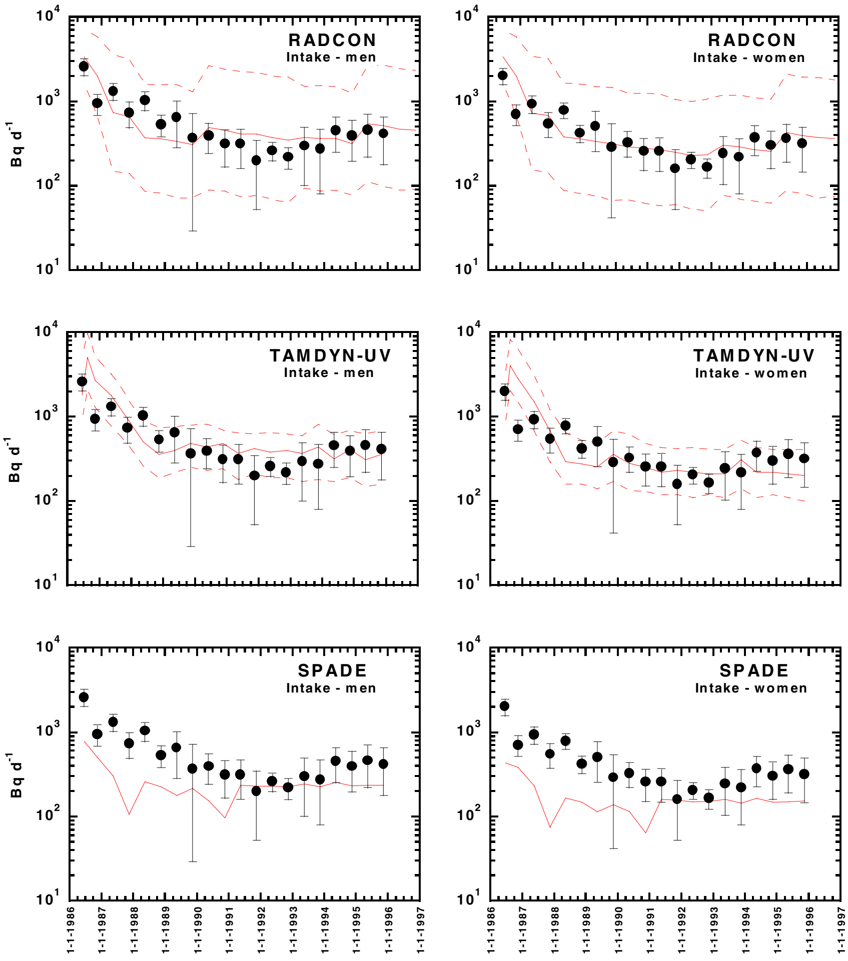


FIG. 18. Predictions for average daily intake of ^{137}Cs by men and women in the entire test area made using the RadCon, TAMDYN-UV, and SPADE models, compared with the authors' calculations for men and women in the non-controlled area. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values calculated by the scenario authors, and the vertical lines indicate the 95% confidence intervals on the means. Predictions labelled SPADE were made outside the main computer code.

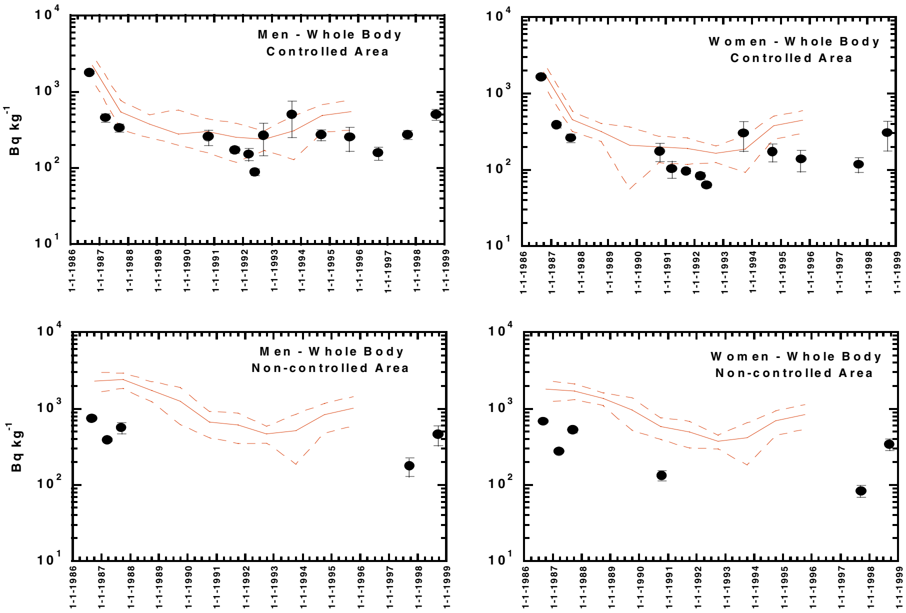


FIG. 19. Comparison of measured whole body concentrations of ^{137}Cs in men and women in the controlled and non-controlled areas with authors' calculations based on measured concentrations of ^{137}Cs in foodstuffs and estimated intakes. The solid lines indicate the central values of the authors' calculations; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values of the measured specific activities of ^{137}Cs in the human whole body (men and women, controlled and non-controlled areas, as indicated), normalized to a soil deposition of 1 MBq m^{-2} of ^{137}Cs, and multiplied by the mean soil contamination for the controlled or non-controlled area (0.87 MBq m^{-2} and 0.40 MBq m^{-2}, respectively). The vertical lines (not visible in some cases) indicate 1 standard error above and below the normalized means.

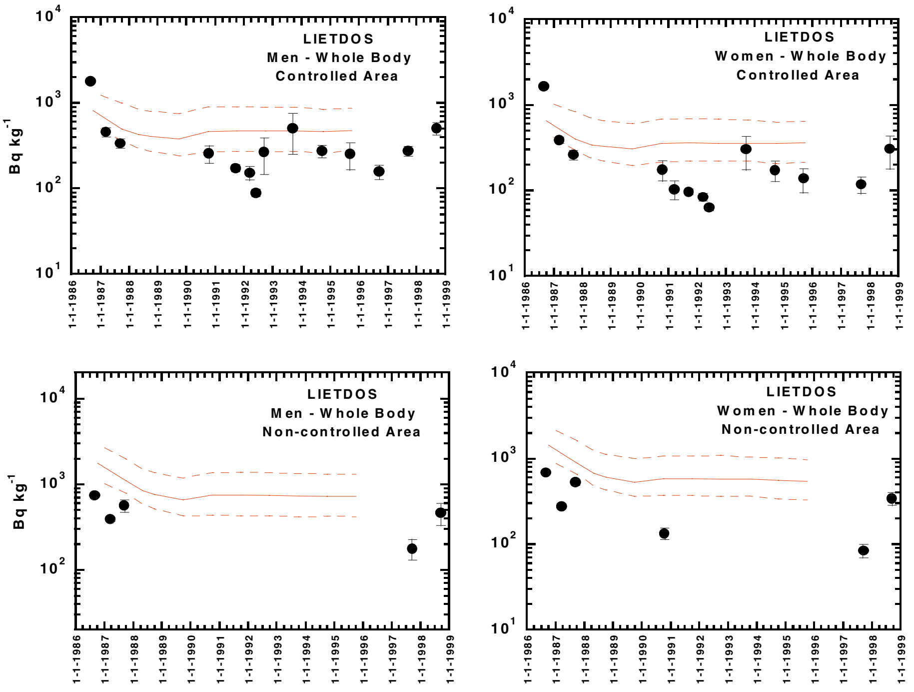


FIG. 20. Comparison of predictions made using the LIETDOS model with measurements of mean whole body concentrations of ^{137}Cs in men and women in the controlled and non-controlled areas. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values of the measurements, and the vertical lines indicate 1 standard error above and below the means (see Figure 19 for more detail).

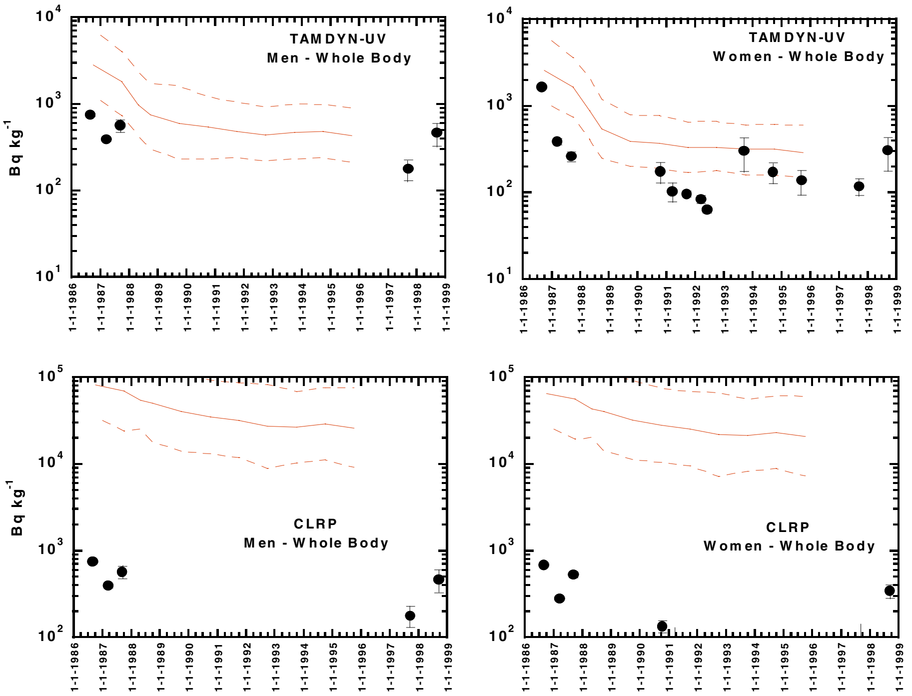


FIG 21. Predictions for mean whole body concentrations of ^{137}Cs in men and women in the entire test area made using the TAMDYN-UV and CLRP models, compared with measurements for men and women in the non-controlled area. The solid lines indicate the central values of the predictions; the dashed lines indicate the 95% subjective confidence intervals. The dark circles indicate the mean values of the measurements for the non-controlled area, and the vertical lines indicate 1 standard error above and below the means (see Figure 19 for more detail).

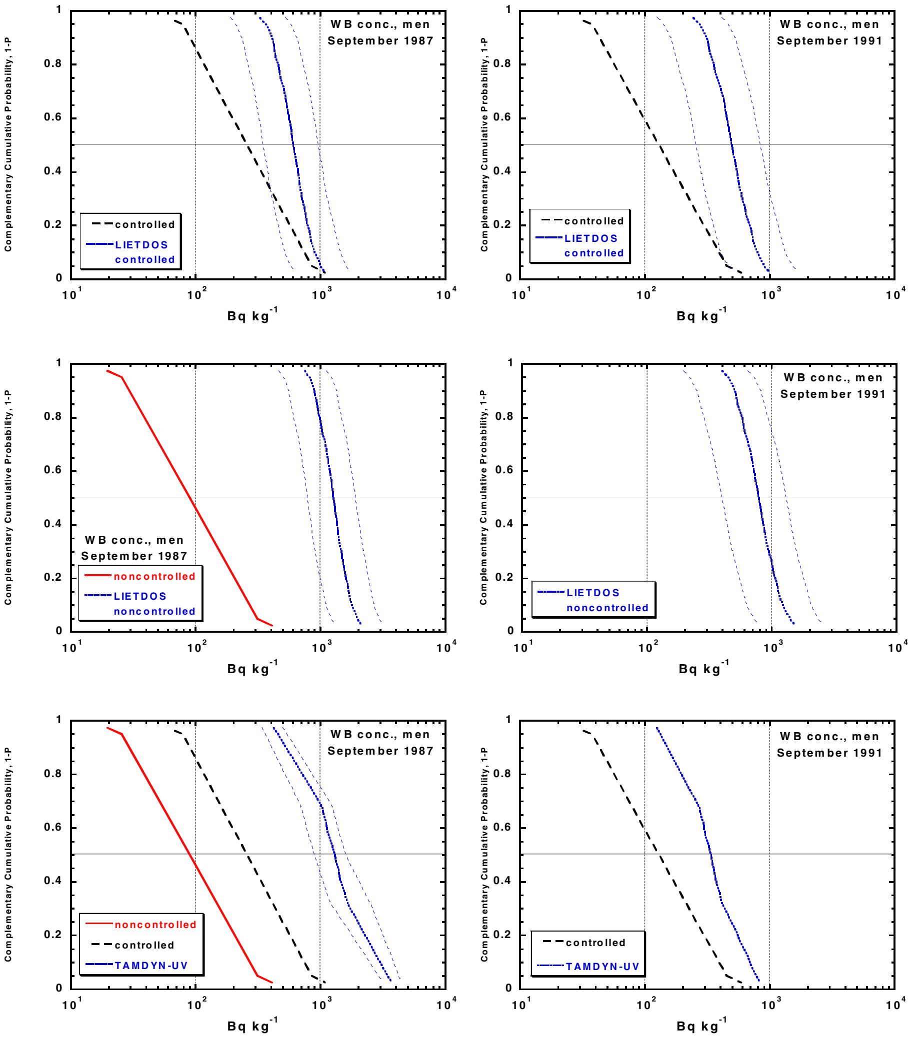


FIG. 22. Predicted distributions of whole body concentrations of ^{137}Cs in men at two time points, compared with observed distributions for the controlled and non-controlled areas, as indicated. Predictions for LIETDOS were made separately for the controlled and non-controlled areas, as indicated; predictions for TAMDYN-UV were made for the entire test area. No measurements were available for September 1991 for the non-controlled area. The thin dashed lines on most of the predictions indicate 95% subjective confidence intervals on the central values.

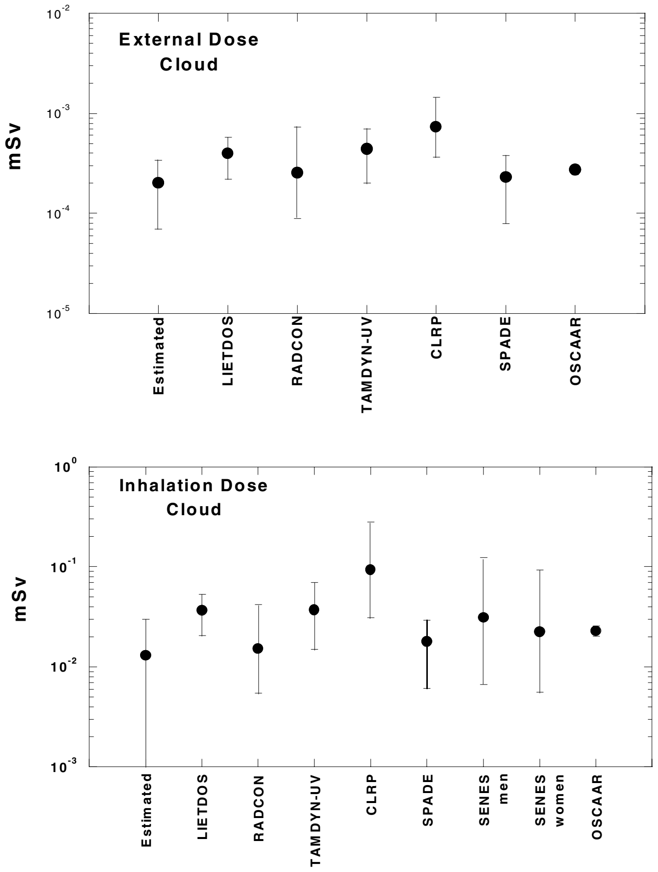
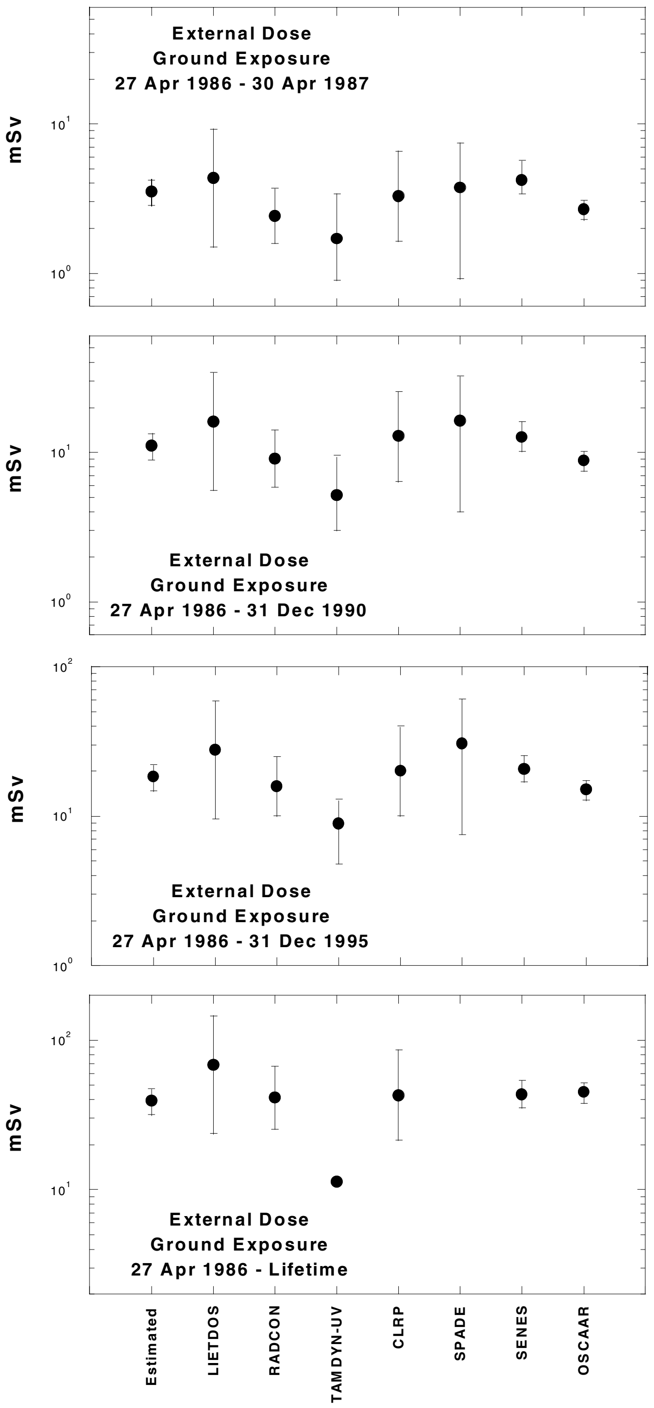


FIG. 23. Comparison of predicted mean external (top) and inhalation (bottom) doses from passage of the Chernobyl cloud with doses estimated by the scenario authors. The dark circles indicate the central values of the predicted or estimated doses, and the vertical lines indicate the 95% subjective confidence intervals.


External Dose Ground Exposure 27 Apr 1986 - 30 Apr 1987

External Dose Ground Exposure 27 Apr 1986 - 31 Dec 1990

External Dose Ground Exposure 27 Apr 1986 - 31 Dec 1995

External Dose Ground Exposure 27 Apr 1986 - Lifetime

FIG. 24. Comparison of predicted mean external doses from ground exposure (groundshine) with doses estimated by the scenario authors, for four time intervals after the accident. The dark circles indicate the central values of the predicted or estimated doses, and the vertical lines indicate the 95% subjective confidence intervals.

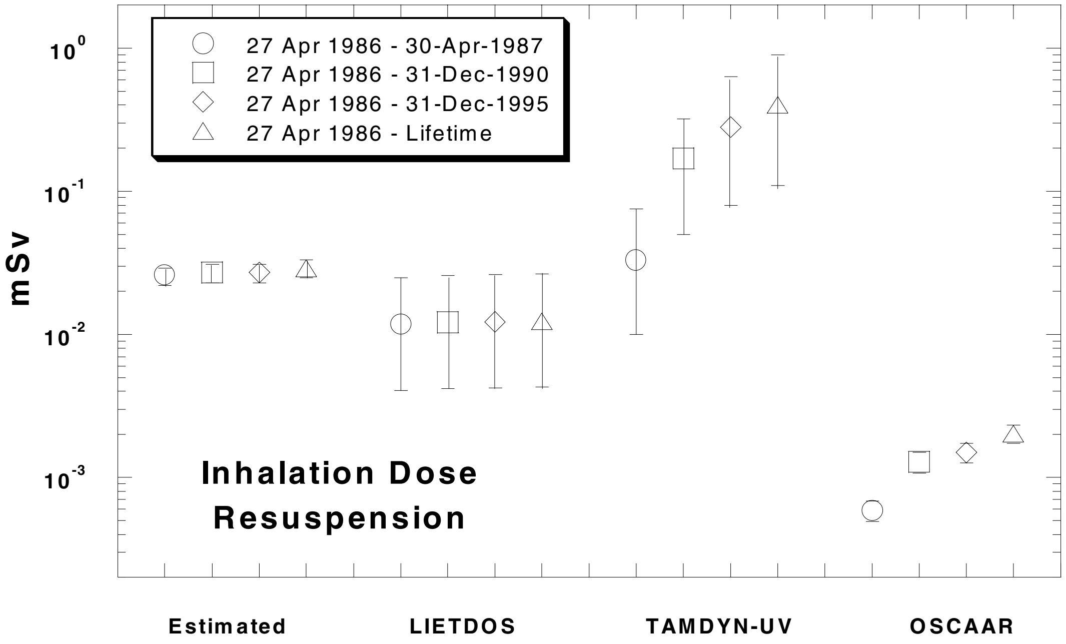


FIG. 25. Comparison of predicted mean doses from inhalation of resuspended material with doses estimated by the scenario authors, for four time intervals after the accident. The open shapes indicate the central values of the estimated or predicted doses, and the vertical lines indicate the 95% subjective confidence intervals.

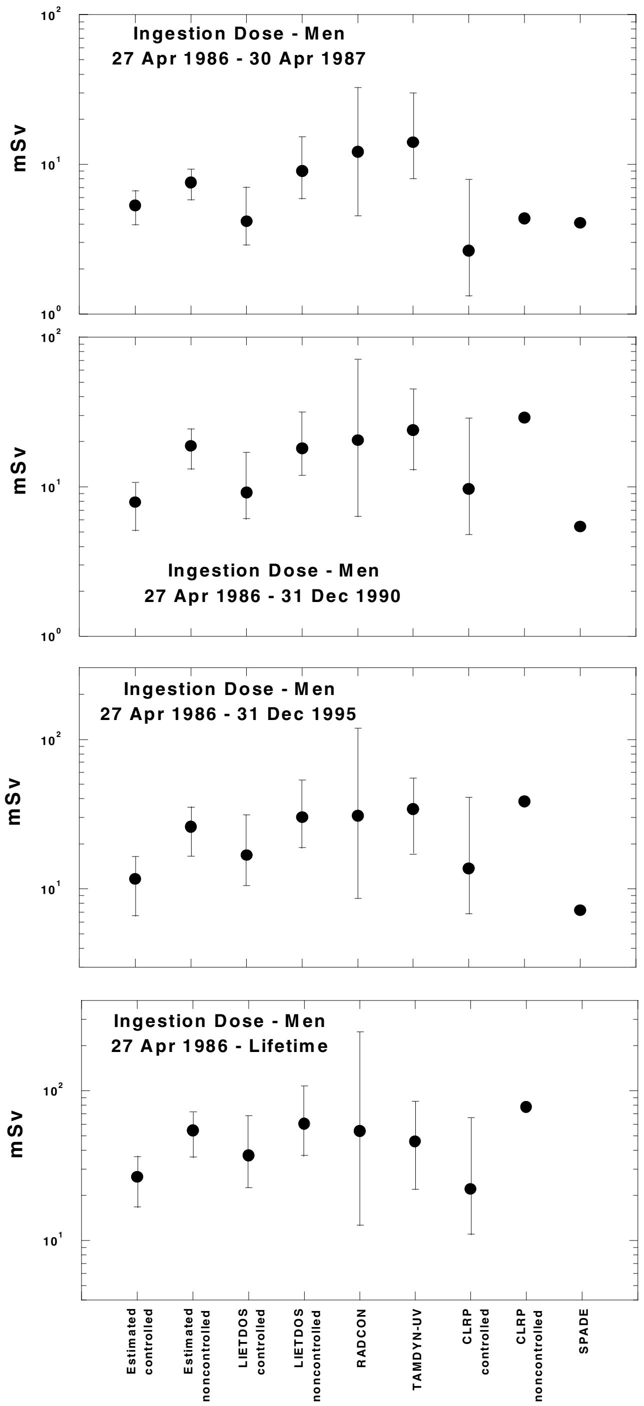


FIG. 26. Comparison of predicted mean doses to men (adult for TAMDYN-UV) from ingestion of contaminated foodstuffs with doses estimated by the scenario authors for four time intervals after the accident. The dark circles indicate the central values of the estimated or predicted doses, and the vertical lines indicate the 95% subjective confidence intervals. Predictions for SPADE were made outside the main code.

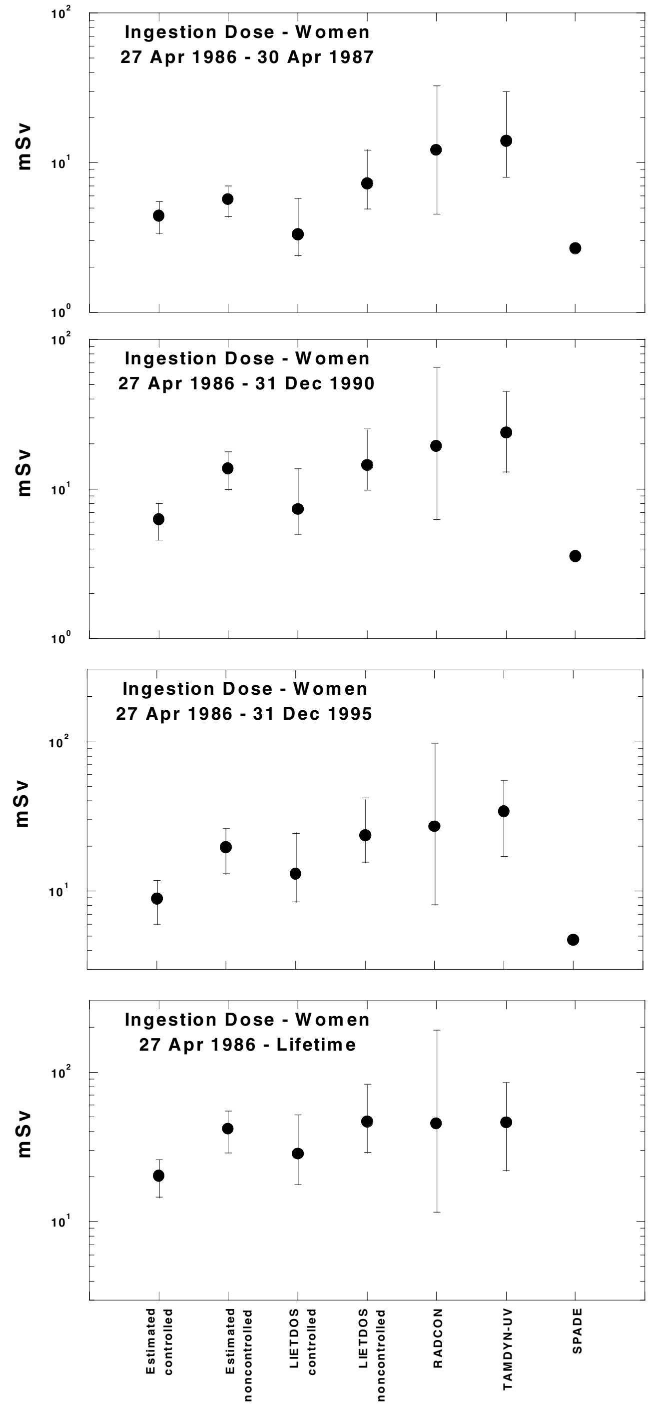


FIG. 27. Comparison of predicted mean doses to women (adult for TAMDYN-UV), from ingestion of contaminated foodstuffs with doses estimated by the scenario authors for four time intervals after the accident. The dark circles indicate the central values of the estimated or predicted doses, and the vertical lines indicate the 95% subjective confidence intervals. Predictions for SPADE were made outside the main code.

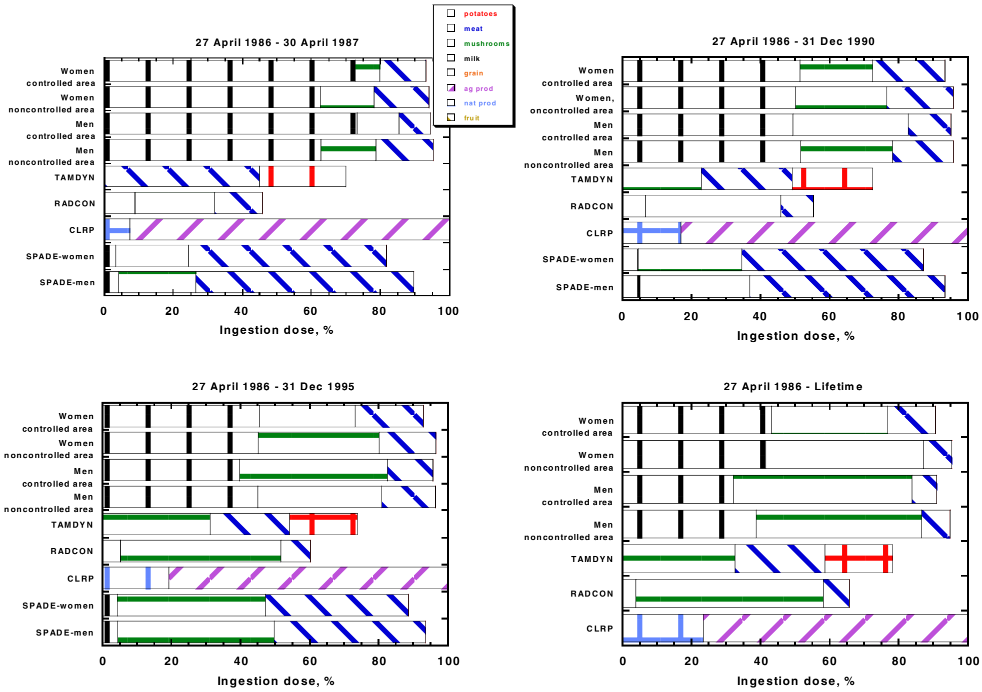


FIG. 28. Comparison of the major contributors (food types) to the estimated or predicted ingestion for men and women, expressed as a percentage of the estimated or predicted dose.

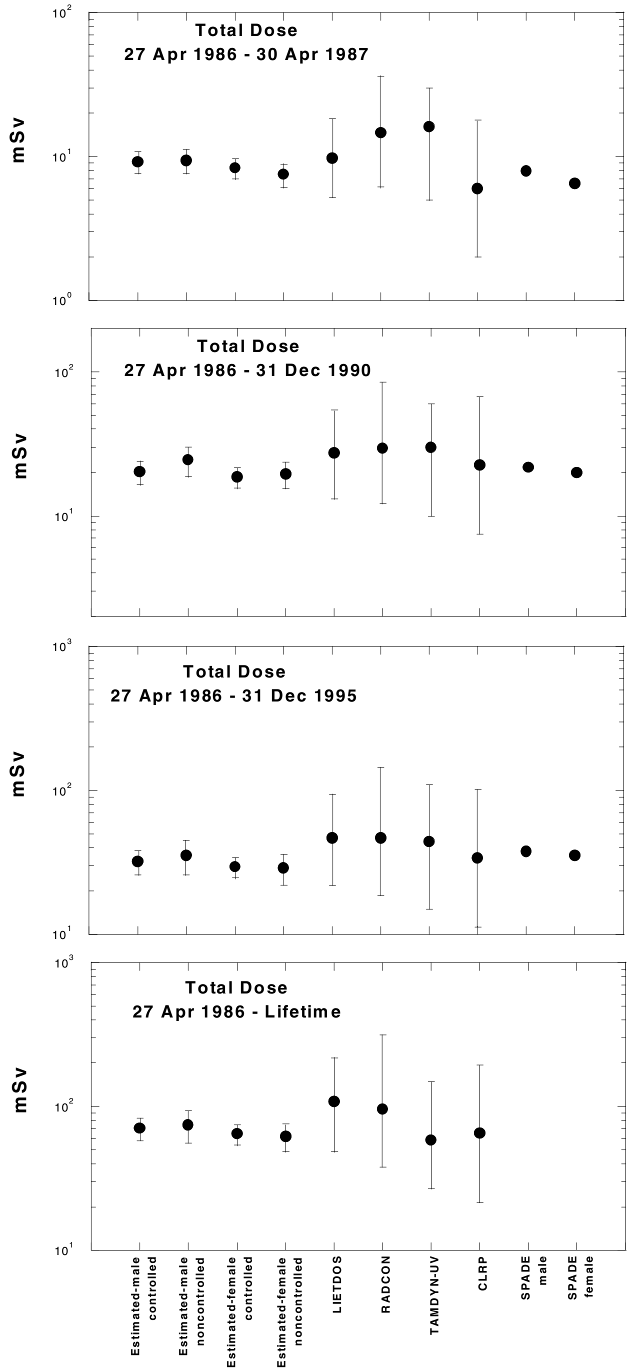


FIG. 29. Comparison of predicted mean doses to men (men and women for SPADE) from all pathways (total doses) with doses estimated by the scenario authors, for four time intervals after the accident. The dark circles indicate the central values of the estimated or predicted doses, and the vertical lines indicate the 95% subjective confidence intervals.

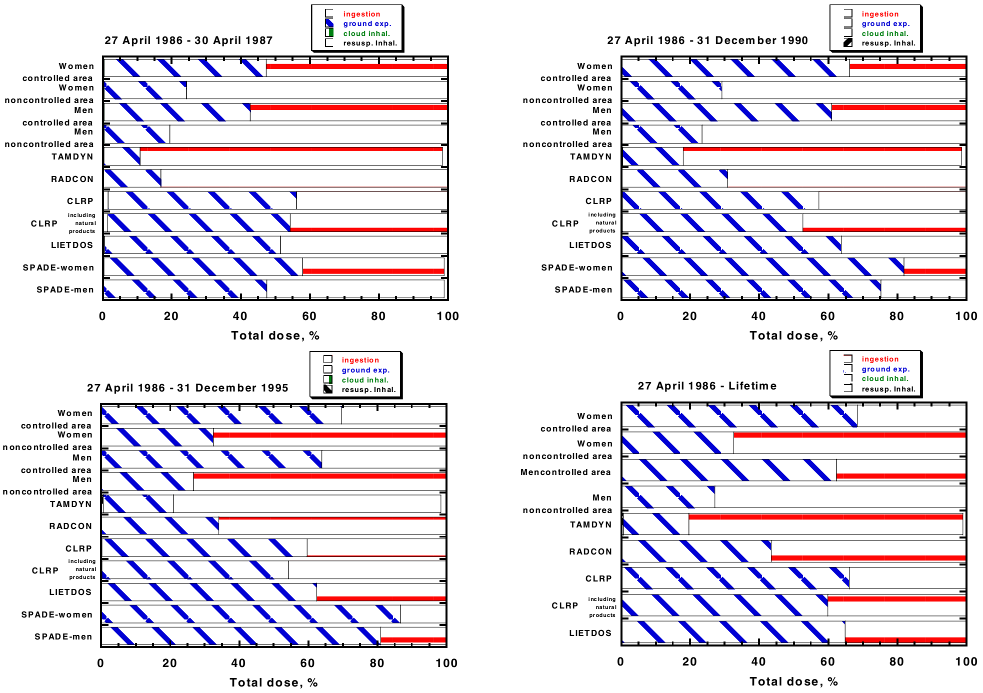


FIG. 30. Comparison of the major exposure pathways contributing to the estimated or predicted total doses for men, expressed as a percentage of the estimated or predicted dose.

5.4. CONTAMINATION OF PRODUCTS FROM THE NATURAL ECOSYSTEM

5.4.1. Mushrooms

The activity of ^{137}Cs in forest mushrooms remained stable during the whole 10-year period of observations, with the average value about 12 ± 4 kBq kg^{-1} f.w. (Annex I). The test data for mushrooms represent a weighted average across several species, calculated on the basis of aggregated transfer factors (Section I–2.2.1). The best results were obtained with the LIETDOS model, using a simple transfer factor approach (Figure 11). Attempts made by some modellers (RadCon, CLRP) to simulate the dynamics of ^{137}Cs activity in forest mushrooms were not as successful, resulting in either overestimation or underestimation of ^{137}Cs activity in mushrooms by as much as an order of magnitude.

5.4.2. Berries

The activity of ^{137}Cs in wild berries gradually decreased over the period of 1986–1991 from 8 to 2.3 kBq kg^{-1} (Annex I). During the later period, some fluctuations around an average contamination level were observed. The test data for ^{137}Cs activity in wild berries since 1992 have a large range of uncertainty. The test data for berries represent a weighted average across several species, calculated on the basis of aggregated transfer factors (Section I–2.2.1).

Model predictions of ^{137}Cs activity in wild berries ranged from good general agreement with the test data (OSCAAR, LIETDOS, CLRP) to deviations from the test data of an order of magnitude or more (Figure 12).

5.4.3. River and lake fish

The dynamics and values of ^{137}Cs activity for fish from the Iput River were different from those for fish dwelling in the lakes located in the Iput test area. In flowing water (Iput River), the maximum values of fish contamination with ^{137}Cs were observed in 1986–1987 (2000 Bq kg^{-1} f.w.). In 1988–1991, ^{137}Cs activity in the river fish gradually decreased; since 1991, the radioecological situation in the river ecosystem has been stable, with the activity of ^{137}Cs in the river fish about 200 Bq kg^{-1} (Annex I).

The activities of ^{137}Cs in fish taken from the small lakes in the test area were considerably higher than the activities of the river fish for the whole 10-year period of observations. The maximum ^{137}Cs activities in lake fish were observed in 1986–1987 (36–42 kBq kg^{-1} f.w.). The higher levels of contamination in lake fish in comparison with river fish may be explained by the slower decrease of ^{137}Cs activity in water in lakes and resuspension of radionuclide from the bottom sediments to lake water.

Four modellers presented calculations for fish contamination (LIETDOS, TAMDYN-UV, SENES, OSCAAR; Figure 13). All results concerned the contamination of river fish. The predictions of the OSCAAR, SENES and TAMDYN-UV models were in general agreement with the test data within the range of uncertainty of the test data. The predictions of the LIETDOS model were in agreement with the test data only for the first year after the accident, substantially underestimating the ^{137}Cs activity in river fish for the years after 1991.

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

The average daily intake of ^{137}Cs by humans (Bq d^{-1}) was calculated separately by the scenario authors for the controlled area (where countermeasures were applied) and the non-controlled or observed area (where countermeasures were not applied). Intake was calculated from the measured concentrations in foodstuffs and survey data on the population’s dietary habits; separate estimates were made for men and women. The “controlled area” corresponds to the most contaminated parts of the test area, in which the various countermeasures were applied to decrease the radiation doses received by the inhabitants. The “non-controlled” or “observed” area corresponds to the remaining parts of the test area, in which the countermeasures were not applied.

The calculated daily intake for men in the controlled area decreased from about 2500 Bq d^{-1} (central value) in 1986 to 100–200 Bq d^{-1} from 1989–1993, and then increased to around 250 Bq d^{-1} (Annex I). For men in the non-controlled area, the lowest values were around 200 Bq d^{-1} in 1991–1992, increasing to 400 Bq d^{-1} by 1995. In other words, the implementation of countermeasures in the controlled area was expected to have reduced intakes below those received in the non-controlled area. Calculated intakes for women showed similar trends, but overall values were lower due to the smaller amounts of food ingested.

Participants in the exercise used their modelled concentrations of ^{137}Cs in foodstuffs to estimate the average daily intakes. Four participants (LIETDOS, OSCAAR, CLRP, and SENES) provided separate estimates for the controlled and non-controlled areas (Figures 14–17). Three additional participants (RadCon, TAMDYN-UV, and SPADE) made predictions for human intake for the test area in general (Figure 18). Their predictions are shown in comparison to the authors' calculations for the non-controlled area. The predictions labelled SPADE were actually made outside the main computer code.

LIETDOS, OSCAAR, and CLRP provided generally good predictions for the non-controlled area, in comparison to the authors' calculations; CLRP also gave good predictions for the controlled area, while LIETDOS and OSCAAR overestimated and underestimated, respectively, for some time periods for the controlled area. The SENES predictions include only the contributions from grains, potatoes, and fish, and thus are expected to be substantially lower than estimates made using additional important contributors to intake such as milk and meat. RadCon, TAMDYN-UV, and SPADE gave reasonably good predictions in comparison to the authors' calculations for the non-controlled area and therefore would be expected to give overestimates for the controlled area, in comparison to the authors' calculations.

5.6. AVERAGE ^{137}Cs CONCENTRATIONS IN HUMANS

Average whole body concentrations of ^{137}Cs in adult men and women (Bq kg^{-1}) were calculated by the scenario authors for the controlled area (where countermeasures were applied) and the non-controlled or observed area (where countermeasures were not applied), based on the calculated intakes described in Section 5.5. In addition, measurements were made at various time points of actual whole body concentrations of ^{137}Cs in men and women in these areas. The measurements are reported in terms of the measured specific activities in each area, normalized to a soil deposition of 1 MBq m^{-2} of ^{137}Cs (Annex I). For comparison with the calculated values (Figure 19), the normalized concentrations were multiplied by the mean soil contamination in the controlled and non-controlled areas (0.87 MBq m^{-2} and 0.40 MBq m^{-2}, respectively). For the controlled area, the calculated concentrations are close to the measured concentrations, with a tendency toward overestimation (Figure 19). For the non-controlled area, there are fewer measurements available, but where comparisons can be made, the calculated values appear to overestimate the actual concentrations (Figure 19).

Predictions submitted by three modellers were compared to the measured whole body concentrations (Figures 20 and 21). The predictions for LIETDOS were made separately for the controlled and non-controlled areas (Figure 20); predictions from TAMDYN-UV and CLRP for the whole test area were compared to the measurements for the non-controlled area (Figure 21). In general, the model predictions overestimated the whole body concentrations, as did the authors' calculations. This suggests that actual ingestion rates may have been less than the reported ingestion rates used in the model predictions and authors' calculations.

Predicted distributions of whole body concentrations were provided by two participants, using the TAMDYN-UV and LIETDOS models. Comparisons were made between these model predictions and the observed distributions for September 1987 and September 1991 (Figure 22). The same tendency toward overprediction is seen in the predicted distributions at these time points as was seen in the time-dependent predictions of mean whole body concentrations.

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

Multiple-pathways dose assessment was requested in the Iput scenario to obtain dose estimates for average members of the local rural population, living in the contaminated test area. Dose assessment includes the estimation of doses from the following pathways:

exposure from the initial radioactive cloud, exposure from groundshine, inhalation of resuspended material, and ingestion of contaminated food. The total dose from all pathways was also requested. Test estimates of effective doses from different pathways (committed effective dose for inhalation and ingestion) were prepared by the authors of the Iput scenario, based on observed data.

5.7.1. Exposure to the initial radioactive cloud from Chernobyl

The authors' estimate of the mean effective dose from external exposure to the initial radioactive cloud was 2×10^{-4} mSv (95% confidence interval, 0.7–3.4×10^{-4} mSv; Annex I). The authors' estimate of the effective dose from inhalation of ^{137}Cs in the initial radioactive cloud was 0.013 mSv (95% confidence interval, 0–0.03 mSv; Annex I).

Those modellers (e.g. RadCon) who based calculations on the recommended values of ^{137}Cs concentrations in air produced results for the inhalation and exposure doses that were very close to the test estimates (Figure 23). Those modellers (e.g. LIETDOS, CLRP) who based calculations on a model reconstruction of atmospheric dispersion of the radionuclide tended to overpredict both the external and inhalation doses from the radioactive cloud (Figure 23). An additional reason for differences in results was the use of different values of the dose conversion factor for inhalation of ^{137}Cs from the cloud (Section 4.1). It should be noted that doses from ^{137}Cs in the initial radioactive cloud from Chernobyl were relatively small in comparison with other exposure pathways, so mispredictions in doses from the cloud did not have any significant impact on the total doses predicted for the local population.

5.7.2. Effective doses from groundshine

Predictions for the effective external dose from groundshine were requested for several time intervals after the Chernobyl accident. The following mean effective external doses from groundshine in the Iput test area were estimated by the scenario authors (Annex I): 3.53 mSv (27 April 1986–30 April 1987); 11.1 mSv (27 April 1986–31 December 1990); 18.4 mSv (27 April 1986–31 December 1995); and 39.6 mSv (27 April 1986–lifetime). The external exposure from groundshine was an important contributor to the total dose received by members of the local population.

Four models (CLRP, RadCon, OSCAAR, and SENES; also SPADE for the first year) produced good estimates of doses from groundshine for each requested time period (Figure 24). In spite of detailed descriptions of groundshine from different soil layers, two models produced either underestimates (TAMDYN-UV) or overestimates (LIETDOS; also SPADE for the longer periods) of doses, especially for the longer time intervals; possible reasons for the mispredictions include a lack of detailed data on the parameter values for the downward migration of ^{137}Cs in soil and incorrect assumptions about the amount of shielding provided by the soil. The predictions labelled SPADE were actually made outside the main computer code.

5.7.3. Inhalation dose from resuspension

Inhalation doses from resuspension in the Iput test area estimated for different time periods were rather small: 0.026 mSv for the first year after the Chernobyl accident (27 April 1986–30 April 1987) and 0.029 mSv for the lifetime period (28 April 1986–lifetime; Annex I). Three modellers made calculations for the dose from resuspension (Figure 25). In general, the final predictions by LIETDOS and OSCAAR were underestimates and those by TAMDYN-UV, overestimates, in comparison to the doses estimated by the authors. The upper bounds of the LIETDOS predictions and the TAMDYN-UV prediction for the first year overlapped the authors' estimates. All three models correctly predicted that the major contribution to the inhalation dose occurred during the first year after the accident.

5.7.4. Effective doses from ingestion

Calculation of ingestion doses (effective dose equivalents from ingestion) was the central task for participants in the Iput scenario exercise.

The authors' estimates of ingestion doses were based on the dietary intake of ^{137}Cs by representatives of the local rural population (adult man and adult woman). Estimates were made for representatives of two parts of the Iput test area: the controlled area and the non-controlled (observed) area. The controlled area included farms with high levels of initial ^{137}Cs deposition; this area was subjected to intensive countermeasures. The non-controlled area included farms with lower levels of initial contamination; application of countermeasures was not intensive in this area.

According to the authors' estimates, the mean effective doses from ingestion to an average adult man or woman in the controlled area increased with time after the Chernobyl accident as follows (Figures 26 and 27; Annex I):

- 5.3 mSv (women, 4.4 mSv) for the period 27 April 1986–30 April 1987;
- 7.9 mSv (women, 6.3 mSv) for the period 27 April 1986–31 December 1990;
- 11.6 mSv (women, 8.9 mSv) for the period 27 April 1986–31 December 1995;
- 26.5 mSv (women, 20.3 mSv) for the period 27 April 1986 –lifetime.

Estimated mean ingestion doses to an adult man or woman living in the non-controlled (observed) area increased more rapidly with time (Figures 26 and 27):

- 7.6 mSv (women, 5.7 mSv) for the period 27 April 1986–30 April 1987;
- 18.7 mSv (women, 13.8 mSv) for the period 27 April 1986–31 December 1990;
- 26.0 mSv (women, 19.6 mSv) for the period 27 April 1986–31 December 1995;
- 54.1 mSv (women, 41.7 mSv) for the period 27 April 1986–lifetime.

Due to consideration of the intensive application of countermeasures, the estimated ingestion doses in the controlled area were lower than the estimated doses for the non-controlled area, in spite of the higher initial contamination of the controlled area. In actuality, the estimated whole body concentrations of ^{137}Cs in the non-controlled area were greater than the observed concentrations (Section 5.6), suggesting that the true doses in the non-controlled area were lower than those estimated here. During the post-accidental period 1986–1990, the dominant contributor to the ingestion dose was milk consumption; later on the consumption of mushrooms became the dominant contributor to the ingestion dose (Figure 28).

Participants in the Iput scenario exercise calculated ingestion doses using their model predictions of ^{137}Cs concentrations in local food products and data on consumption rates taken from the Iput scenario (Figures 26 and 27). Two models (LIETDOS and CLRP) generated calculations separately for the controlled and non-controlled areas of the test area. Other modellers (RadCon, TAMDYN-UV and SPADE) calculated average ingestion doses for the whole test area. (Ingestion doses labelled SPADE were calculated outside the main computer code.) In general, the LIETDOS and CLRP predictions for the controlled and non-controlled areas corresponded reasonably well to the authors' estimates for the respective areas (Figures 26 and 27). The RadCon and TAMDYN-UV predictions agreed generally with the authors' estimates for the non-controlled area, while the SPADE predictions agreed generally with the authors' estimates for the controlled area. The major contributors to the predicted ingestion doses are shown in Figure 28.

5.7.5. Total doses

Predicted total doses to men in the entire test area are shown in comparison to the authors' estimated total doses, listed separately for men and women and for the controlled and non-controlled areas (Figure 29). Differences in the authors' estimates are small, reflecting the importance of external doses, which were not influenced as much by the countermeasures or by male–female differences as were the ingestion doses. The predicted total doses are in good general agreement with the authors' estimates, although the uncertainties are somewhat larger. The percent contributions of the major contributors to total dose (primarily the ingestion dose and the external dose from ground exposure) are shown in Figure 30. Both the scenario authors and the participants in the exercise show an increasing importance of external dose at the later time periods, but the estimated percentage contributions vary considerably.

6. REASONS FOR MISPREDICTIONS AND REVISED RESULTS

6.1. ESTIMATION OF SOIL CONTAMINATION IN THE TEST AREA FROM DATA ON ATMOSPHERIC DEPOSITION

The radioactive contamination of the Iput test area was caused by the short term passage of the Chernobyl radioactive cloud from 27 to 30 April 1986. The first task for the modellers that participated in the Iput scenario exercise was the reconstruction of the ^{137}Cs fallout onto soils of the test area. Two methods can be employed for the reconstruction of radioactive fallout:

- Estimation of the total fallout from data on atmospheric deposition; and
- Estimation of total fallout in the test area, using data on soil contamination with ^{137}Cs.

Taking into account the availability of detailed data on soil contamination, the authors of the Iput scenario recommended estimating the total ^{137}Cs fallout from the soil contamination measurements. The values of average ^{137}Cs contamination density, calculated by modellers from soil data, were within the range of 710–820 kBq m^{-2} in the Iput test area.

However, for theoretical and practical reasons it was also important to check the possibility of reconstructing fallout from the available, albeit scarce, information on air contamination in the test area. It was also important to estimate the scale of potential mispredictions caused by the lack of detailed meteorological data on rain intensity in the area during the period of radioactive cloud passage, as well as the lack of information about values of dry and wet deposition rates of radiocesium.

Calculations of ^{137}Cs fallout from atmospheric deposition were performed with the LIETDOS and CLRP models. The following data were requested for the standard procedure of fallout calculation:

- ^{137}Cs activity in above ground air during the passage of the radioactive cloud;
- daily rainfall data; and
- site specific dry and wet deposition rates.

Data on ^{137}Cs activity in air for the period of the radioactive cloud passage (28–30 April 1986) were presented in the Iput Scenario description (see Annex I, Table I–I); the air contamination was 60 ± 40 Bq m^{-3}. These concentrations were reconstructed from measurements made in neighboring regions.

Data on daily rainfall intensity were given in the Iput Scenario description (see Annex I, Table I–XIII). Data from five neighboring rainfall stations were available: Bryansk (N. 26898), Roslavl (N. 26882), Krasnaya Gora (N. 26976), Zlynka (N. 33042), and Chechersk (N. 26974). Of these five stations, Chechersk, Krasnaya Gora, and Zlynka are situated closest to the Iput test area, and the other two stations (Bryansk and Roslavl) are more distant (see Figure I–1 in Annex I). For the critical 3-day period of the radioactive cloud passage, rainfall data were available only for some stations (Table 13).

TABLE 13. AVAILABLE RAINFALL DATA FOR THE PERIOD OF RADIOACTIVE CLOUD PASSAGE THROUGH THE IPUT TEST AREA (EXTRACTED FROM TABLE I–XIII, ANNEX I)

Station	Rainfall intensity, mm d^{-1}		
	28 April 1986	29 April 1986	30 April 1986
Chechersk	11.9	0.4	No data
Krasnaya Gora	1.6	No data	0.6
Bryansk (remote station)	No rain	No rain	No rain

Modellers faced serious difficulties in analyzing the rainfall data. The character of the heavy contamination of the local Iput test area clearly indicated the dominant role of wet deposition due to intensive local rains. Heavy rains were observed at the Chechersk rainfall station on the first day of the radioactive cloud passage; however, for the next two days, the rainfall data are very uncertain. Here modellers could use the following approaches in averaging rainfall data, resulting in different estimated values of total ^{137}Cs deposition in the Iput test area:

- Very conservative estimations based only on rainfall data from the Chechersk station (average rain intensity, 6.2 mm d^{-1}) produce a value of ^{137}Cs total deposition on the soil surface of about 700 kBq m^{-2}, which is very close to the measured data on soil contamination (700–800 kBq m^{-2}).
- By averaging available data on the closest stations, Chechersk and Krasnaya Gora, a modeller would calculate an average rainfall intensity of 3.6 mm d^{-1}, which results in a predicted fallout density of about 400 kBq m^{-2} (this value is about two times lower than the measured data);
- By averaging all available data, including the remote station in Bryansk, a modeller would calculate an average rainfall intensity of 2.1 mm d^{-1}; this low value of rain intensity results in considerable underestimation of the total deposition density (about three times).

The estimates described above were obtained using the most conservative assumptions on the deposition rate values (LIETDOS model): dry deposition velocity, 173 m d^{-1}, and washout ratio, 6.2×10^5 [Bq m^{-3}]$_{rain}$ / [Bq m^{-3}]$_{air}$. In the CLRP model, the value of the washout ratio was chosen to be $(1.4 \pm 0.6) \times 10^5$, which is lower than the most conservative assumption made in the LIETDOS model; thus the CLRP model produced greater mispredictions in the fallout estimations. The lack of site specific measurements on deposition rates leads to additional uncertainty in the results of fallout calculations based on meteorological data. Eventually, all modellers considered their attempts at fallout reconstruction from air deposition as unsuccessful and used fallout values calculated from measured data on soil contamination.

The general conclusions from the fallout reconstruction exercise, based on the Iput scenario data, are as follows:

- Correct estimation of the radioactive fallout to soil from air contamination data is possible when detailed meteorological information is available;
- If rainfall data for the deposition period are scarce, predictions of fallout are strongly dependent on the modeller's judgment and the method of rainfall data analysis; and
- For long lived radionuclides such as ^{137}Cs, data on soil contamination may be considered more reliable than data on air contamination.

6.2. MODELLING THE EFFECTIVENESS OF COUNTERMEASURES

In the CB and S scenarios of the VAMP programme, no attention was given to modelling agricultural countermeasures. The Iput scenario provided a unique opportunity to consider countermeasures in the radioecological models and to evaluate the effectiveness of different protective actions. However, the lack of experience in modelling countermeasures was in some cases associated with a misunderstanding of scenario information, as well as with mispredictions in the evaluation of the effectiveness of the countermeasures.

Agricultural countermeasures considered by participants in the Iput test exercise were mainly of two types:

- mechanical countermeasures (deep plowing, radical amelioration of pastures, removal of highly contaminated lands from agricultural production); and
- chemical countermeasures (fertilization, liming of lands).

The effectiveness of a particular countermeasure was evaluated in terms of a reduction factor, which was calculated as a ratio between the ^{137}Cs concentration in an agricultural plant before and after the countermeasure action. The Iput scenario description contains data on the effectiveness of agrotechnical (mechanical) countermeasures, as well as chemical countermeasures (Tables I–LIV, and I–LV of Annex I). Also, information was provided on the intensity of application of countermeasures in different years.

Most of the participants in the Iput exercise had no difficulties in using reduction factors to simulate the effectiveness of the countermeasures in their models. However, it was not clearly understood that any countermeasure action is characterized not only by the value of the reduction factor, but also by the duration of the effect. As a rule, mechanical countermeasures are effective for long periods of time, and the reduction factor for mechanical countermeasures is essentially constant. On the contrary, agrochemical countermeasures are effective for restricted periods after their application: fertilization is effective for one vegetation season, liming for two or three vegetation seasons. So, in the case of a single chemical countermeasure action, the reduction factor gradually decreases with time from its maximum to its minimum value. In case of systematic application of agrochemical countermeasures, based on the optimal time schedule, the reduction factor is kept at its maximal level. All modellers participating in the Iput exercise correctly estimated the effectiveness of mechanical countermeasures, using constant values of reduction factors.

In modelling agrochemical countermeasures, the following mispredictions were observed:

- In early calculations with one model, it was assumed that any single chemical countermeasure action is effective for a long period of time. Following this assumption, the total effectiveness of the countermeasure actions accumulated over time. If chemical countermeasures were applied every year, the resulting value of the reduction factor was calculated as a power function: a reduction factor obtained in a single action, R, was raised to the power equal to the total number of actions, N (R^N); i.e., the reduction factor was equal to R in the first year, R^2 in the second year, R^3 in the third year, etc. As a result of such assumption, the effectiveness of the countermeasures was progressively overestimated in time, predicted bioavailability of ^{137}Cs in soil rapidly decreased, and the calculated values of activity in agricultural plants were progressively underestimated.
- Most of the modellers used constant values for reduction factors associated with systematic application of chemical countermeasures. However, in the scenario description, it was mentioned that since 1993, application of countermeasures was considerably decreased due to economic difficulties in the area. The test data for the period 1993–1996, after countermeasures were stopped, clearly demonstrate the gradual increase in the contamination of agricultural plants. Only one of the modellers (SENES) simulated this effect; therefore, most model predictions do not fit well with the test data for the period 1993–1996 (e.g. Figure 4).

Thus, the Iput exercise provided a good lesson in understanding the nature of countermeasures, as well as some useful ideas about the treatment of countermeasures in radioecological models.

6.3. ASSUMPTIONS ABOUT THE DYNAMICS OF ^{137}Cs BIOAVAILABILITY AND DOWNWARD MIGRATION IN SOIL

Some of the most important endpoints in the Iput exercise were the predictions of the long term dynamics of ^{137}Cs concentrations in the main types of agricultural plants. To perform such an assessment, it was necessary to know the long term dynamics of ^{137}Cs concentrations in the root zone of the soil. The Iput Scenario does not contain detailed information on ^{137}Cs behavior in soil. Common data on total radionuclide contamination per unit area (Bq m^{-2}) are available, and also the vertical distribution of ^{137}Cs in the soil (soil profile) several years after the Chernobyl accident (see Tables I–XLI and I–XLII in Annex I). So, computer modelling was the only way to reconstruct ^{137}Cs behavior in soils of the Iput test area; an additional problem for modellers was the scarcity of data for validating the model parameters.

Participants in the Iput scenario exercise paid serious attention to the modelling of ^{137}Cs migration in soil; the models employed varied from simple empirical models to complicated dynamic ones. The model approaches are summarized in Section 3.5 of this report. The models differed from each other by the number of physico-chemical processes considered, as well as by the number of model parameters used for the calculations. In the simple models, one or two empirical parameters were used; numerical values of these parameters were taken from the literature or estimated from available data on the vertical distribution of radiocesium in the soil (Table I–XLII in Annex I).

Dynamic models can provide a more detailed description of ^{137}Cs behavior in soil, including bioavailable and fixed forms of the radionuclide. Parameters used in dynamic models are the specific rates of sorption-desorption processes, downward migration, uptake by plants, etc. For the Iput test area, site specific values of these parameters were not available; modellers used default values taken from scientific publications. It should be noted that estimation of site specific values for dynamic processes of radionuclide migration in soil is a difficult task, requiring the results of special experiments; such data are not available for most radioecological assessments.

The predicted dynamics of ^{137}Cs concentrations in soil, presented in Figure 31 (see also Table 10), clearly demonstrate the great variability of predictions obtained with different assumptions about the values of key parameters. The lack of data on site specific values of key parameters responsible for ^{137}Cs behavior in soils may be considered as the main source of misprediction in calculations of ^{137}Cs activity in the root zone of plants, which, in turn, results in misprediction of agricultural plant contamination.

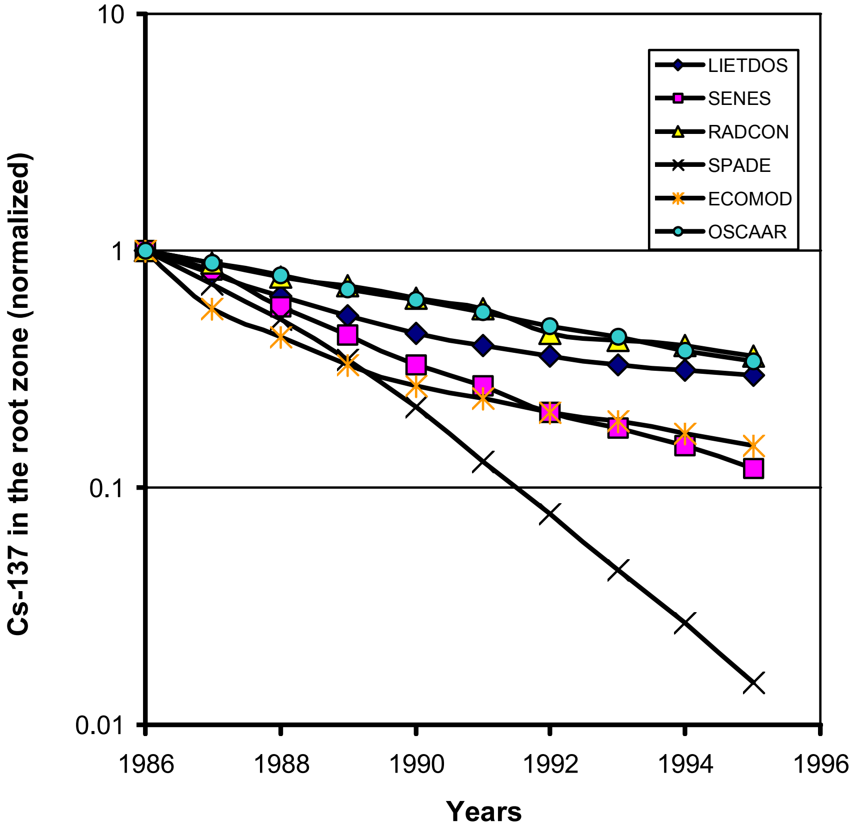


FIG. 31. Predicted dynamics of the decrease of bioavailable CS-137 in the Iput test area (arable soils, root zone). Data area normalized to the predicted values of the initial contamination.

7. SUMMARY AND CONCLUSIONS FROM THE IPUT SCENARIO EXERCISE

The Iput Scenario is based on a unique data collection from 10 years of local monitoring in the test area, which was highly contaminated with ^{137}Cs from Chernobyl fallout. The Iput scenario provides data on ^{137}Cs behavior in practically all agricultural components, as well as natural ecosystems typical of a moderate climatic zone. A unique feature of the scenario is a detailed description of countermeasures applied to decrease doses to the local population.

The modellers who participated in the Iput scenario exercise are from different parts of the world, such as Europe, Australia, the U.S., and Japan, and represent various geographic and climatic zones. Some of the models used by participants were commercial or official models, used by national authorities for assessment and decision making for radiological situations; other models were developed for research purposes (Table 1). The great diversity of models, as well as the specific individual or national judgment of specialists participating in the Iput scenario exercise, provided a unique opportunity to discuss the problems of radioecological assessment from many points of view. The text of the Iput scenario, as well as the results of model predictions, were discussed in detail at several working meetings of the Dose Reconstruction Working Group (1997–2000) within the framework of the BIOMASS Programme.

The Iput scenario is the most complicated one among the existing multiple pathways scenarios from the VAMP, BIOMOVS, and BIOMASS programmes. The spotty character of the radioactive contamination within the test area, numerous exposure pathways, and application of various countermeasures, all caused serious difficulties for modellers. In general, radioecological assessment for the Iput test area was performed successfully by all participants. Final model predictions are in good agreement with the test data. In most cases, individual predicted values are within a factor of two or three of the observations. Most of the modellers successfully reconstructed the whole 10-year time course of ^{137}Cs activity concentrations in all requested types of agricultural products and components of natural ecosystems. The authors of the Iput scenario also performed independent model estimations for each of the scenario endpoints; the purposes of such calculations were to check the completeness of the input information provided in the scenario and to select optimal values of model parameters.

The most difficult problems to arise in the course of the Iput calculations were the following: data averaging to account for the spotty contamination of the test area; simulating the downward migration and bioavailability of ^{137}Cs in soil (root zone); and modelling the effectiveness of countermeasures. All these problems were actively discussed at the working meetings of the Dose Reconstruction Working Group; the exchange of ideas was very useful and helped participants to make good progress in improving their models and revising their initial results.

Along with model predictions, each participant in the Iput exercise prepared a detailed description of his or her model, including documentation of the values of model parameters (Annex II). Based on these materials, a detailed analysis of model approaches was performed for each exposure pathway (Section 3). A comparison of parameter values used by participants was also prepared (Section 4), with special consideration of the sources of information where the default values of key parameters were found. The major reasons for misprediction revealed in the course of Iput calculations have also been summarized (Section 6). The comparison of model approaches provided modellers with the opportunity to see more clearly the weak or strong points of particular models, to define the situations where a model does not work correctly, or to evaluate the range of mispredictions resulting from the great uncertainty about key model parameter values. Of great importance was the discussion of the reliability of default values of radionuclide transfer factors taken from available publications.

Calculations for the Iput scenario were made in several stages. Initial calculations were performed by participants as a blind test. From analysis of these initial results, modellers were able to identify some mispredictions in results or misinterpretation of input information; necessary corrections were made in the model predictions. Later on, test data for a few midpoints (e.g. hay, cereals) were made available to participants; these data helped modellers to correct the values selected for key parameters, such as soil-to-plant and fodder-to-milk transfer factors. For the final stage of calculations, all test data were made available, thus giving modellers the opportunity to check all the endpoints of their calculations and to find reasons for any systematic over- or underestimation in their predictions.

The work on the Iput scenario gave participants valuable experience in assessment of the long term radioecological situation for a local area highly contaminated with a long lived and biologically active radionuclide, ^{137}Cs. Several major conclusions can be drawn from the exercise.

- As a rule, complicated models with detailed descriptions of processes need a great volume of high quality input information, which in many cases is either not available or difficult to obtain. In cases where the necessary input information is available, a complicated model can produce very accurate and detailed predictions; the predictive power of such a model is normally much higher than that of a simple empirical model. However, when the input information is absent or scarce, complicated models produce unreliable results, which may be even worse than predictions obtained with simple models. Thus, the complexity of a model employed in radioecological assessment should be in accordance with the availability of input information. Use of complicated models with insufficient input information is fruitless for the purpose of radioecological assessment.
- Some radioecological computer codes have only one starting point for calculations, for example, the atmospheric dispersion and deposition of a radionuclide. Such a rigid structure for the computer code creates many difficulties in cases where the preferred input data are not available and calculations must be started from another point, for instance, from data on soil contamination. Ideally, commercial codes for radioecological assessment should be highly flexible, providing users the capability to omit some program sub-blocks or to start calculations from the most appropriate starting point.
- Participation in the Iput scenario exercise gave modellers a unique experience in modelling agricultural countermeasures. Modellers learned that agricultural countermeasures (especially agrochemical measures) are complex actions characterized by several important factors: the effect on radionuclide bioavailability for plants and animals, duration of the effect in time, saturation effect, and indirect effects on the fertility of agricultural lands. Neglect of the above mentioned factors may result in serious mispredictions in the resulting radionuclide concentrations.
- The summary of model approaches presented in Section 3 demonstrates the current state of radioecological modelling: some specific processes are described completely and are well documented, whereas other processes are described empirically or are poorly documented. Well-developed models include those for atmospheric deposition of radionuclides, initial interception on plant surfaces, exposure from a radioactive cloud,

and radionuclide transfer in cows. Models of ^{137}Cs downward migration in soils are still incomplete; formally, all processes responsible for ^{137}Cs bioavailability and migration in soil can be described as a set of differential equations, but documentation for default values of key parameters for different soil types is scarce. An inadequate knowledge of ^{137}Cs dynamics in soil is probably one reason for inaccuracy in estimation of the soil-to-plant transfer factors in this exercise. For instance, some modellers considered soil-to-plant transfer factors in relation to the total ^{137}Cs activity concentration in the root zone of the soil, whereas other modellers referred to the bioavailable fraction of ^{137}Cs in soil.

- Model predictions may be strongly dependent on the judgment of the modeller in selection of parameter values or interpretation of input information, especially for a dose reconstruction situation, where data are incomplete. Existing publications provide a considerable amount of information on default values of many parameters, e.g. transfer factors for many agricultural plants. However, data for other parameter values are scarce, e.g. transfer factors for natural food products (mushrooms, wild berries), site specific values for many parameters.
- Uncertainty analysis in radioecological models may be based on different assumptions, varying from the personal judgment of a specialist to complex Monte Carlo simulations. In general, use of standard procedures for uncertainty assessment is very helpful in the comparison of modellers' predictions and test data.
- Detailed models of some specific pathways (e.g. fruit, forest, and lake pathways) could be incorporated into multiple pathway models as the specific pathway models are developed.

Detailed, high quality data sets for the Iput test area are now available for present and future generations of modellers, to test radioecological models, decision making systems, and national computer codes for assessment of the radiation exposure from environmental releases of ^{137}Cs. Some of these data may also be useful for derivation of parameter values for radioecological models. The Iput scenario also contains a great volume of information on some specific exposure pathways, such as forest pathways (mushrooms, wild berries) and aquatic pathways (lake and river fish), which may be used for testing specialized models of biospheric transport of radionuclides.

Among the issues that arose during the exercise are several that may be appropriate subjects for future investigation:

- Inclusion of a wide variety of radionuclides in radioecological assessment;
- Development of models based on scientific understanding of physico-chemical, as well as biological, processes, rather than empirical models alone; and
- Analysis of interactions or combined action between radioactive contaminants and non-radioactive substances in terrestrial and aquatic environments.

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Annex I

SCENARIO DESCRIPTION AND DOCUMENTATION OF DATA FOR THE IPUT RIVER SCENARIO

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I–1. SCENARIO DESCRIPTION

I–1.1. INTRODUCTION

This scenario involves the assessment of ^{137}Cs body content in humans, concentrations in environmental materials, and the total radiation dose[1] to humans due to ^{137}Cs in the environment affected by the Chernobyl accident. In this scenario, models are tested against data for the rural population living in the Iput River catchment area of the Bryansk Region, Russia. The most contaminated part of the Iput catchment area, the Novozybkov district of the Bryansk region, is considered as the test area.

The scenario can be considered in two parts:

(1) a model test in which predictions of ^{137}Cs concentrations in environmental materials and body content can be compared with observed values in the test area; and

(2) a model comparison in which the total doses to the local population from ^{137}Cs in the test environment are predicted by different models and compared with each other and with estimates made by the authors of the scenario. The authors' estimates of external dose are based on the results of hundreds of individual thermoluminescent dose measurements, and the estimates of internal dose are based on the results of thousands of whole body measurements of cesium radionuclides.

Pathways contributing to dose may include those from both terrestrial and aquatic environments. The region of Scenario I is shown in Figures I-1 and I-2.

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[1] 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.

I–1.2. ASSESSMENT TASKS

I–1.2.1. General description

The following subsections contain descriptions of the calculation endpoints required in this test scenario. The quantities to be predicted are separated into two groups: quantities for which measurements exist and against which model predictions can be tested, and quantities which can only be predicted but not tested (e.g., radiation doses). The latter are included because they are the most common and useful endpoints in radiological assessments. For all quantities, a 95% confidence interval about the arithmetic mean was requested to quantify the expected uncertainty in the result.

For the quantities requested in Sections I–1.2.2 and I–1.2.3, an estimate of the arithmetic mean is required for the time periods specified and for the entire region or for the “controlled area” (^{137}Cs soil contamination density above 555 kBq m^{-2}) and the “non-controlled area” (“observed area,” ^{137}Cs soil contamination density below 555 kBq m^{-2}). The 95% confidence intervals for the means are also required.

I–1.2.2. Calculations for model testing

The calculations in the model testing part were to be performed for two average representatives of the rural population of the test area, i.e., an adult woman and an adult man. The term "test persons" refers to these two categories.

I–1.2.2.1. ^{137}Cs concentrations in food products

Estimate the mean ^{137}Cs contamination of food products produced and consumed in the test area for the time periods specified:

- Leafy vegetables (Bq kg^{-1} f.w.) for the harvests of 1986 to 1996.
- Potatoes (Bq kg^{-1} f.w.) for the harvests of 1986 to 1996.
- Cereals (wheat and rye) (Bq kg^{-1} f.w.) for the harvests of 1986 to 1996.
- Milk (Bq L^{-1}) monthly for May–September 1986 and quarterly for IV.1986 to 1996.
- Beef (Bq kg^{-1}) monthly for May–September 1986 and quarterly for IV.1986 to 1996.
- Pork (Bq kg^{-1}) monthly for May–September 1986 and quarterly for IV.1986 to 1996.
- Mushrooms (Bq kg^{-1} f.w.) for the picking seasons of 1986 to 1996.
- Wild berries (Bq kg^{-1} f.w.) for the picking seasons of 1986 to 1996.
- Freshwater fish (river and lake) (Bq kg^{-1} f.w.) for the second half of 1986 and the annual catches of 1987 to 1996.

I–1.2.2.2. Human intake

Estimate the mean ^{137}Cs intake per day (Bq d^{-1}) of the test persons (women and men, averaged over the “controlled area” and “non-controlled area”) for June 1986, the fourth quarter (IV) of 1986; and the second and fourth quarters (II and IV) for the years 1987 to 1996.

I–1.2.2.3. Whole body content

Estimate the mean ^{137}Cs concentration (Bq kg^{-1}) in the body of the test persons in the "controlled area" and "non-controlled area" on 30 September of each year from 1986 to 1996.

I–1.2.3. Calculations for comparison of dose predictions

I–1.2.3.1. External dose

Estimate the mean dose to the test persons from external exposure due to ^{137}Cs from the Chernobyl cloud (mSv). Estimate the mean dose to the test persons from ^{137}Cs ground deposits (mSv) for the periods 28 April 1986 to 30 April 1987, 28 April 1986 to 31 December 1990, 28 April 1986 to 31 December 1995, and 28 April 1986 to 30 April 2036 (lifetime dose).

I–1.2.3.2. Inhalation dose

Estimate the mean dose to the test persons from inhalation from the Chernobyl cloud (mSv). Estimate the mean inhalation dose to the test persons (mSv) from resuspended ^{137}Cs for the periods 28 April 1986 to 30 April 1987, 28 April 1986 to 31 December 1990, 28 April 1986 to 31 December 1995, and 28 April 1986 to 30 April 2036.

I–1.2.3.3. Ingestion dose

Estimate the mean dose to the test persons (mSv) in the "controlled area" and "non-controlled area" from ingestion for the periods 28 April 1986 to 30 April 1987, 28 April 1986 to 31 December 1990, 28 April 1986 to 31 December 1995, and 28 April 1986 to 30 April 2036. For each time period show the percentage contributions of the three main food items contributing to the ingestion dose.

I–1.2.3.4. Total dose

Estimate the mean dose to the test persons (mSv) from all pathways for the periods 28 April 1986 to 30 April 1987, 28 April 1986 to 31 December 1990, 28 April 1986 to 31 December 1995, and 28 April 1986 to 30 April 2036. For each time period show the percentage contributions of the three main exposure pathways contributing to the total dose.

I–1.2.3.5. Dosimetry

For models not designed with a fixed set of dose conversion factors, the use of the factors from the International Basic Safety Standards is recommended.

I–1.3. INPUT INFORMATION

I–1.3.1. Environmental ^{137}Cs in the test area

I–1.3.1.1. Air concentrations

Practically no experimental data on the ^{137}Cs concentrations in the air of the region are available for the early period after the accident. These concentrations were reconstructed from the data of measurements taken in neighbouring regions and from the air radiation monitoring in Novozybkov region during the ensuing years (Table I-I).

I–1.3.1.2. Soil contamination

The radioactive contamination of the test area was caused by the radioactive "Chernobyl cloud" passage from 28 to 30 April 1986. The radionuclide composition of soil contamination in the early period after the accident is presented in Table I-II. Measured ^{137}Cs concentrations in the soil in the settlements of the test area are listed in Table I-III (see also Figure I-3). The vertical distribution of ^{137}Cs in the soil surface layer was determined for different soils in the test area (Table I-IV).

The Chernobyl fallout in the Bryansk Region of Russia was represented by aerosol particles of condensation type. In contrast, the fallout in the near zone of the Chernobyl NPP was represented mostly by particles with contamination of fuel type. Because of the condensed aerosol nature of the deposition, the share of exchangeable, soluble fractions of ^{137}Cs in soils of the Bryansk Region was rather high in 1987 — about 5–6 times higher than that in the Chernobyl near zone. The dominant types of soils in the most contaminated Novozybkov district of the Bryansk Region are soddy podzolic of light mechanical composition (sandy and sandy loam), with a relatively large content of small fractions (the percentage of soil fractions with particle sizes less than 0.05 mm is about 55%). The distribution of ^{137}Cs activity on soil particles of different sizes is given in Table I-V.

On the contaminated territory of the Novozybkov district, the values of soil-to-plant transfer coefficients (SPTC) in 1987–1988 were higher than transfer coefficients in the Chernobyl near zone. The maximum values of SPTC were estimated in 1987; they were stabilized in 1988 and became close to the values estimated for global fallout. Since 1988, the SPTC values were rather stable with slow decrease in time due to the fixation of ^{137}Cs in soil ("ageing" process).

I–1.3.1.3. Water contamination

The Iput river area is shown in Figure I-2. Tables I-VI and I-VII show concentrations of ^{137}Cs in the Iput river water (both in solution and in suspension) during both a flooding period and a low-water period in 1991. Table I-VIII presents average concentrations of ^{137}Cs in the lake water of the test area. The common properties of these lakes are as follows: depth, about 2 m; area, 0.1 to 0.2 km^2; potassium concentration, 1 to 2 mg L^{-1}; fish productivity, 2 to 5 g m^{-2}. The vertical distribution and specific activity of ^{137}Cs in the upper 20-cm soil layer of the Iput river flood plain and bottom sediments are given in Tables I-IX and I-X.

The characteristics of the Iput watershed contaminated with ^{137}Cs are presented in Table I-XI. The coefficient of ^{137}Cs wash-off from the Iput river watershed was estimated to be equal to 1.9×10^{-3} y^{-1} in 1987 and decreased to the value 1.1×10^{-3} y^{-1} in 1988. (The wash-off coefficient is defined as the share of the total activity of a watershed that is washed to a river during one year). The normalized coefficient of ^{137}Cs wash-off from the Iput river watershed was estimated to be equal to 0.8×10^{-5} mm^{-1} y^{-1} in 1987, and decreased to the value 0.6×10^{-5} mm^{-1} y^{-1} in 1988. (The normalized wash-off coefficient is defined as the share of the total activity of a watershed that is washed to the river by each millimeter of the run-off. The annual run-off layer for the Iput river is about 160–175 mm).

The ^{137}Cs activity in the Iput river water (for each hydrometric post) is correlated closely with the contamination of the particular watershed. The average annual activity of ^{137}Cs in water (near the inflow of the Iput river into the Sozh river) is given in Table I-XII.

I–1.3.2. Environmental information

I–1.3.2.1. Meteorological characteristics

The observations for rainfall in the test area and neighboring regions are given for 5 stations for the period 20 April to 20 May 1986. The total rainfall amounts were measured from 06.00 a.m. on the given day to 06.00 a.m. on the following day and are given in Table I-XIII in mm d^{-1} for the period 20 April to 20 May. The regional location of the stations is shown in Figure I-1.

The wind direction is unstable in spring: south-westerlies give way to north-westerlies and south-easterlies. The wind speed changes from month to month. In winter, it is insignificant, the maximum occurring in February and being 4 to 5 m s^{-1} on exposed places. In spring and summer it decreases to 2.5 to 3 m s^{-1}. The average annual wind speed in exposed places is 3.5 to 4 m s^{-1}.

I–1.3.2.2. Topographical description

The Iput basin lies in the lowest part of the Pridneprovye lowland. In the upper reaches, the catchment area is a hill plain of 150 to 278 m absolute heights. Rivers and ravines cross the plain. In the middle, the river plain has a few hills of 134 to 233 m absolute heights and is cut by rather shallow river valleys. In the lower reaches, the terrain is plain with prevailing heights of 120 to 150 m (maximum, 188 m). The hills of 20 m have rounded tops and gentle slopes.

The type of soil is primarily loamy sand and sand of 80 to 110 cm in depth. In the lower reaches, it is sand and pebble, loam, and loamy sand; in the river plain it is clay sands. The ground water occurs at a depth of 1 to 3 m and on the slopes of hills, to 10 m.

I–1.3.2.3. Hydrological characteristics of the Iput Basin

The Iput river is 437 km long, with a catchment area of 10,900 km^2. The average slope of the water surface is 0.19%, and the coefficient of river sinuosity is 2.82. Swamps, about 7%, occur largely on the lowland. The lakes are few, most of them on the flood plain. The sand and pebble deposits effectively filtrate precipitation. The predominantly flat relief weakens the intensity of surface run-off and erosion of the Iput river. Most sediments are formed by soil wash-off with down slope snowmelt and rainfall water. The flood plain is mostly two-sided, of 1.5 to 3 km in width. The river bed is meandering, made of sand and silted in pools (Table I-XIV).

The major hydrological characteristics of the Iput river are presented in Table I-XV. Table I-XVI shows the water balance of the test region. Month-to-month distributions of discharges of water and suspended sediments on the Iput river are given in Table I-XVII. The fish productivity of the Iput river is about 0.3 g m^{-2}.

I–1.3.2.4. Climatic conditions

The snow cover on the Iput river plain varies significantly. In the coldest time of winter, the air temperature is below –5° C, and stable snow cover is formed. The winter starts early in December and lasts for 3 to 4.5 months. The maximum height of snow cover occurs from the second decade of February to the first decade of March and reaches 30 cm. The snow cover comes off in late March to early April. The daily average temperature increases from 0 to 13 or 14° C during the spring. Given the general tendency of warming, however, spells of cold weather with frosts and snow sometimes occur. The ranges of the average monthly temperatures in the test region are given in Tables I-XVIII and I-XIX.

The test region is distinguished by considerable humidity. The annual amount of precipitation varies from 650 to 790 mm. About 70 to 75% of the total annual precipitation falls during the warm period from April to October. The precipitation is less than 1 mm d^{-1} for about 40% of all precipitation days. Precipitation above 30 mm d^{-1} occurs, on average, once a year; above 20 mm d^{-1}, three times a year; and above 10 mm d^{-1}, 12 to 15 times a year.

I–1.3.2.5. Soil cover

Soddy and soddy-podzolic soils of different bedrock textures predominate. Soils are developed on sands, in some places on loam. The water storage in the soil is directly dependent on its texture. The water storage within the 1-m soil layer is least in sandy and loamy-sandy soils, ranging from 70 to 200 mm. In dry years the water supply can decrease to 20 mm on sands and loamy sands. In spring the formation of run-off is largely dependent on water permeability of frozen soil. The soil freezes down to 40 to 150 cm.

The soils are well described agrochemically. The content of humus in sands and loamy sands is rather low, to 30–40 t ha^{-1} in the 0 to 50 cm layer. The nitrogen content is 4 to 5 t ha^{-1}. About 70% of arable lands have a low to extremely low content of exchangeable potassium, and only 5% have a high content. Soils of medium and strong acidity make up about half the area of the cultivated lands; the rest of the soils have low acidity. Neutral soils make up approximately one-fourth of the cultivated lands, which are located on the drier weak podzolic soil. The primary agrochemical measures are enrichment of light soil with organic matter, application of lime and fertilisers, and reclamation of marshlands.

I–1.3.2.6. Forests

The area covered by forest amounts to 2293 km^2 (i.e., 24 % of the total area of the district). Average age of the predominant trees, consisting mainly of pine and birch, varies from 37–57 years. The forest is primarily mixed (birch, aspen-spruce). In elevated places, it is coniferous. On low and flooded lands, the undergrowth (hazel) is dense and may be up to 3 m high.

The average level of forest contamination is about 980 kBq m^{-2}. The forests on the territory of the test area can be divided into 15 forest units characterised by definite forest type and ^{137}Cs contamination density. The information on the forests related to these forest units is summarised in Table I-XX. Data on the population living in rural settlements surrounded by forests are also shown in this Table.

The most popular mushrooms species sampled by the population are *Boletus edulis, Leccinum scabrum, Leccinum aurantiacum, Suillus luteus, Russula sp, Cantharellus cibarius, Lactarius necator, Lactarius terminuses, Tricholoma flavovirens, and Xerocomus badius.* The berries are represented mainly by *Vaccinium myrtillus, Vaccinium vitisidala, Rubus idalus* and *Fragaria vesca*. The data on potential yield of the most important species of mushrooms and berries are given in Tables I-XXI to I-XXII.

I–1.3.3. Agriculture

I–1.3.3.1. General characteristics

The test area includes territory of the Novozybkov district of the Bryansk region (Figure I-3). The agricultural area (AGRO1) totals about 840 km^2; nineteen farms and 115 inhabited localities are on this territory, with 12,000 inhabitants (Tables I-III and I-XXIII). The arable lands occupy about 65% of the agricultural areas, the hay and grazing lands about 35% (Table I-XXIV). Each subarea of AGRO1 (Figure I-3) is the territory of one collective farm, including agricultural lands, pasture, meadows, and one or more settlements. Table I-XXV presents a list of those farms, and Table I-XXVI shows land use on the territory of subareas.

I–1.3.3.2. Cultivated soils

The test area belongs to the Bryansk woodland territory. Topsoil area is generally poor turf-podzolic soils with light land, the soil solution of which is of acidic reaction and has a low absorbing capacity and a poor humus content (Table I-XXVII). Agrochemical characteristics for most of the soils are presented in Tables I-XXVIII, I-XXIX, and I-XXX. The soil types for cereal cultivation are usually chosen as follows:

- Winter rye: all mineral soil types are possible;
- Winter wheat: light grey forest intermediate loam soil and grey forest light loam soil are the best;
- Spring barley: all soils except for peaty swamped and flooded;
- Oats: all soil except for peaty ones;
- Maize for silage): all mineral soil types, light grey forest and grey forest soil are the best;
- Potatoes: all mineral soil types;
- Root crops: all mineral soil types;
- Vegetables: all mineral soil types except for those with low pH;
- Grasses: all soil types.

I–1.3.3.3. Practices by season

Winter and spring grain crops are grown in the region. The sowing of winter crops lasts from August (3rd decade) to September (1st decade). Usually, autumn vegetation is stopped in the middle of October. Its renewal occurs during the first half of April. Generally, harvesting of winter crops is done in July (3rd decade). The sowing of spring grain crops is performed in the second half of April, and harvesting during the last decade of August. Potatoes are planted early in May and harvested at the end of September or early in October. The planting and harvesting of root crops are done 10 days earlier than for potatoes (Table I-XXXI).

The major individual types of vegetables include potatoes, beetroots, carrot, marrow squash, cabbage, onion, garlic, tomatoes, and cucumbers. Leafy vegetables are grown mainly in private kitchen gardens.

Vegetation renewal of meadow and pasture herbs occurs in the second decade of April. Usually, they are harvested twice per season, in June (2nd decade) and July (3rd decade). In some cases, depending on weather conditions, there is opportunity for one more hay cutting in September (2nd decade).

Efficiencies of the hay and grass lands in forage production are rather high: wild hay lands provide 0.14 kg m^{-2}, and perennial seeded grass lands provide 0.30 kg m^{-2}. Yields for clover and alfalfa vary from 0.5 to 0.7 kg hay per m^2. Green-cut maize is the main component of silage; its amount is about 4.0 kg m^{-2} (Table I-XXXII).

The grazing season begins in May (1st decade) and lasts usually up to the middle of October. The average duration of indoor cattle maintenance is about 170 to 180 days, but it can vary widely from 145 to 200 days (Table I-XXXIII).

I–1.3.3.4. Use of feeds

To feed animals during their indoor maintenance as well as at the beginning and the end of the grazing season, green-cut forage, hay, silage, root crops, potatoes, and concentrated fodder are used. Feeding rations for cattle vary considerably depending on the feed available at farms. Table I-XXXIV gives the feeding rations for bull calves being fattened on a farm in the Novozybkov district where long term observations are made. The recommended rations for dairy cows and pigs in the test area are shown in Tables I-XXXV and I-XXXVI. The rations for hens are presented in Table I-XXXVII.

I–1.3.3.5. Production output

Low soil fertility and farming efficiency result in rather moderate crop yields (Table I-XXXVIII). Productivity of dairy herds is not high, with the milk yields being 2,000 to 3,000 litres per year. This is due to violations in the feeding rations and insufficient forage supplies at some farms and settlements. The mean milk yields per cow in 1986 are given in Table I-XXXIX. Slaughter weight of pigs is 80–100 kg, and that of cattle is 400 to 500 kg. In 1986–1996 a decrease in production of grains, potatoes, milk, and meat was registered in the test area. This is due to the fact that the lands with a ^{137}Cs contamination density of more than 1,480 Bq m^{-2} were not involved in agricultural practices. Another reason is attributed to the economic problems.

I–1.3.3.6. Contamination of agricultural lands

Table I-XL presents the general distribution of arable and grazing lands by their contamination density. More detailed information about contamination of agricultural lands is given in Table I-XLI.

I–1.3.3.7. Change of biological availability and vertical migration of ^{137}Cs in agricultural soils

Natural geochemical processes and various anthropogenic factors induce some variations in biological mobility of radionuclides and their redistribution along the soil profile of agricultural lands. Data indicate a high immobilization of ^{137}Cs in the absorbing soil complex and its decreased transfer to plants by a factor of 3 to 6 for the period 1987–1990. As a result of vertical migration, the radionuclides move to the underlying soil layers, but at present the major portion of radionuclides occurs in the top 0 to 5 cm layer. The type of soil and land-tenure are the major factors controlling vertical migration of ^{137}Cs along the soil profile.

The largest portion of ^{137}Cs (17.4%) occurs in the top 5 to 10 cm layer of the flood plain meadow (Table I-XLII). The radionuclide distribution is rather uniform along the soil profile during the re-ploughing period of agricultural soils.

I–1.3.4. Population information

I–1.3.4.1. Sex and age distribution

The distribution of the population in the test region by sex and age is given in Table I-XLIII.

I–1.3.4.2. Reference data for external dose estimation

For the purpose of external dose evaluation, adult rural inhabitants of the test area are classified according to daytime occupation into three groups: indoor workers (accountants, sellers, teachers, economists, librarians, medical staff, industrial workers, office workers, etc.), outdoor workers (machine operators, field workers, cattle- and swine-breeders, drivers, herdsmen, forest workers, carpenters, masons, laborers, etc.) and pensioners (Jacob et al., 1996; Golikov et al., 1999; Balonov et al., 1992; Reconstruction, 1996). The type of house where the people live (one-storey wooden or one-storey brick house) is another relevant parameter. The total number of population groups considered is six. The attenuation factor for 0.66 MeV gamma radiation is 2.1 for one-storey wooden and 8 for one-storey brick houses. The typical size of a house foundation is 7 × 8 meters. The windows comprise about 8% of the vertical outside surface area of a house.

The distribution of the adult rural population of the test area according to the indicated factors is presented in Table I-XLIV. Table I-XLV presents the seasonal average, standard deviation, 5th and 95th percentile values of occupancy factors for three groups of the rural population in the Bryansk region, obtained from 808 responses to a questionnaire in the summer of 1989 in the test region (Jacob et al., 1996). The occupancy factors, in relative units, are equal to the fraction of day time spent by representatives of the population group in the typical location of a settlement or its vicinity. Table I-XLVI presents annual average occupancy factors.

I–1.3.4.3. Data for internal dose estimation

Diet for adult rural inhabitants: Table I-XLVII presents typical food rations of adult rural inhabitants in the test area before the Chernobyl accident, according to the data from the poll. Table I-XLVIII presents results from interviews of inhabitants of two villages on consumption rates of natural food products (Jacob et al., 1996; Shutov et al., 1993; Bruk et al., 1998; 1999; Reconstruction, 1996).

Countermeasures implemented after the Chernobyl accident are described below; these countermeasures caused considerable alteration of the food rations of the local population. Tables I-XLIX to I-L present data from regular polls of inhabitants about their food rations after the Chernobyl accident. Thus, consumption of milk from privately owned cattle by inhabitants of the "Controlled Area" (see Section I–1.3.5) fell in the first decade of May by approximately 20%, and in the second decade, by almost half. By the beginning of September the consumption rate was only 20% of the initial level. By the middle of September, after the purchasing of dairy cattle, it fell down to 1% of the initial level. Meanwhile, consumption of "clean" milk from shops increased, but the pre-accident level of total milk consumption was not reached. Consumption of meat from privately owned cattle by inhabitants of the "Controlled Area" had already decreased by almost twice by May, and later it was only 20% of the initial level.

Hunting, fishing, collecting of mushrooms and berries: During the initial period after the accident, the internal doses of the rural population of the investigated region were determined primarily by the consumption of agricultural foods, especially consumption of milk. This group of foods contributed 70–85% of the total intake of ^{137}Cs. The contribution of natural foods in this period constituted only 5–15%. In the later period after the accident, the role of the natural factors increased. Relevant to the use of natural products in these territories are the activities of fishing and hunting, as well as collecting of mushrooms and berries. Only 1–3% of the population engages in hunting.

The data from the poll of the local residents reflect changes in consumption of fish from local pools and of mushrooms (Tables I-LI and I-LII). In the region, consumption of "nature gifts" strongly decreased after the accident. In villages of the "Controlled Area", consumption of mushrooms and fish fell by a factor of 2 to 5, of berries by a factor of 2 to 3. In the rest of the area ("non-controlled area" or "Observed Area"), consumption of all natural products decreased by a factor of 1.5 to 3.

I–1.3.5. Countermeasures

I–1.3.5.1. General information

Since 1986, a set of long term countermeasures have been applied in the test area to decrease irradiation of the population (Balonov et al., 1992; Alexakhin, 1993; Reconstruction, 1996). The countermeasures extended to health care and common life (individual protection), as well as to agriculture and forestry. Since May 1986, the inhabitants of the entire contaminated area were encouraged not to consume local animal food products, leaf vegetables and early berries, mushrooms, or fish from local rivers and lakes. Also, they were encouraged to spend vacations outside the contaminated area. Besides that, it was proposed to re-dig private kitchen gardens, to introduce lime, manure and mineral fertilisers, and to stop cultivating some crops (for example, legumes), that most intensively accumulate cesium radionuclides. It was also recommended that methods of cooking meals be changed: wash and clean vegetables thoroughly, cook poured off soups, soak mushrooms, etc.

Thorough washing of fruit and berries decreased ^{137}Cs activity by approximately 10%, washing of table greens, up to 60%, and soaking of mushrooms, by 50%, on average. Also, the population was proposed to subject to radiometric monitoring food products from private plots and "nature gifts" (mushrooms, berries and local fish). All food products coming to shops and markets were monitored by the bodies of the State Sanitary Inspection in accordance with the standards adopted by the Ministry of Health of the USSR, the temporary permissible levels (TPL's; see Table I-LIII).

In August 1986, the contaminated test area was divided into the "Controlled Area", 69 villages with ^{137}Cs soil activity density above 555 kBq/m^2 (15 Ci/km^2), and the "Observed Area", the remaining 46 villages of the district. In the same month, the dairy and meat cattle and poultry privately owned by inhabitants of the "Controlled Area" were compulsorily purchased by state bodies and transferred to public farms. Instead, delivery of milk, meat, and dairy and meat products produced in "clean" territories was organised. Outside the "Controlled Area", cattle and poultry were not compulsorily purchased from the population, but processing of milk and meat contaminated above the adopted TPL's was undertaken.

The applied set of countermeasures caused strong alteration of the food rations of the local population (see above), especially with respect to consumption of meat and dairy products and "nature gifts". Due to the change of economic situation in the country after 1992, the countermeasures were gradually weakened.

I–1.3.5.2. Agricultural countermeasures

The application of agricultural countermeasures depended on the time elapsed since the accident. In the first period after the accident, when the iodine isotopes were a major hazard, the following measures were recommended:

- Transfer of cattle from pasture to indoor keeping;
- Sorting of agricultural production, where iodine concentrations exceeded the set provisional permissible standards; and
- Processing of agricultural products.

After 3 May, maximum permissible ^{131}I levels in milk were 3,700 Bq L^{-1} for adults and 370 Bq L^{-1} for children. After 6 May, standards were established for water, fish, and leafy vegetables. It was recommended that consumption of berries, mushrooms, and game be stopped.

In the second period (June 1986 to spring 1987), countermeasures were concentrated on the reduction of cesium uptake. The provisional permissible standards of radionuclide concentration in products were introduced on 30 May 1986 (Table I-LIII). In this period the following countermeasures were recommended:

(1) Slaughtering of cattle was forbidden in regions with contamination levels exceeding 555 kBq m^{-2}. It was recommended that cattle be kept on uncontaminated forage at least 1.5 months before slaughtering;

(2) Change of agricultural crop treatment: reduction of operations resulting in dust generation, reduction of the frequency of weeding, and direct harvesting of top parts of the crops;

(3) Restriction on the use of contaminated manure;

(4) Laying-in of dried grass and silage instead of hay; and

(5) Obligatory dosimetric control.

After 1987, the soil has been the main pathway of radionuclide uptake by agricultural production. Agricultural use of arable lands subjected to contamination densities exceeding 1480 kBq m^{-2} was terminated in 1987 to 1988. For the reduction of radionuclide accumulation, large scale countermeasures were applied in the district. The complex of countermeasures for the agricultural industry, which were applied in the medium and long term periods after fallout, may be classified into five groups: organisational, agrotechnical, agrochemical, veterinary and food processing.

Organisational countermeasures principally concern changes in land use. This includes increasing the area of land allocated to crops characterised by low accumulation of radionuclides, and in the case of areas of very high deposition, the abandoning of land for agricultural production. Other changes in land use include substitution for the existing crop with hay, grain, potatoes or grazing animals.

Agrotechnical countermeasures include deep ploughing with turnover of the upper layer (on high fertility soils) and radical or superficial improvement of pastures. The techniques have been placed into two categories: radical and surface improvement. In addition many combinations of ameliorants (lime, organic fertilisers and mineral fertilisers) which can be potentially useful have been evaluated experimentally. It should also be noted that some countermeasures have limitations, for instance, deep ploughing is not applicable for soils with a thin humus layer. Radical improvement of meadows was the main method based on re-ploughing of forage lands and application of lime (on acid soils), mineral and organic fertilisers, as well as sowing of perennial grasses. This is a traditional method for cultivation of forage grass, and it is normally used for all forage land where available. The effectiveness of this option depends on the time lapsed after the deposition. In the first period after deposition, the effectiveness of this option is 2–4 times higher. Radical improvement cannot be implemented in river valleys. The options require a calculation of optimal doses of fertilisers and lime application, taking into account the plant demands for nutrients and acidity of soil. These countermeasures may be effective for several (3–4) years after their application. The data on effectiveness of these countermeasures are shown in Table I-LIV.

Agrochemical countermeasures include liming of acidic soils, application of increased doses of mineral fertilisers, addition of natural sorbents (different kinds of clay minerals), and use of organic fertilisers. The feature of the application of mineral fertilisers to contaminated soils is the modification of the ratio of the main plant nutrients. Liming is also one of the most important countermeasures that has been used to reduce cesium contamination levels in plants. The effectiveness of the main options related to this type of countermeasure is given in Table I-LV.

Countermeasures involving changes in animal husbandry include a shift from full-time grazing on open pasture to a mixture of pasture grazing and indoor supplementary feeding, use of clean feeds before slaughtering and use of different forms of ferrocine sorbents (e.g., Prussian blue) to reduce the ^{137}Cs content in animal products. The relevant data on effectiveness of application of Prussian blue in forms typical for the test area are presented in Table I-LVI.

Food processing. The primary objective of countermeasures in Russia after the Chernobyl accident was to produce "clean" agricultural products. However, the processing of milk, meat, cereals and vegetables was also implemented in contaminated districts. As mentioned earlier, general recommendations included processing of milk (especially that exceeding the DILs standard) into cheese, butter and other milk products. Information about the effectiveness of these options is shown in Table I-LVII.

A general summary of the effectiveness of the countermeasures applied is given in Table I-LVIII. In the summer of 1988, stricter standards on permissible levels of ^{137}Cs were introduced; these standards were specified in 1991 (Table I-LIV). However, general recommendations for agriculture during that period (1987 to 1996) were analogous to those presented above. Data on the scale of application of agrochemical measures in 1986 to 1989 for the agricultural lands are listed in Table I-LIX. Similar information concerning the application of agrotechnical countermeasures on hay lands and pastures is shown in Table I-LX.

In assessment of the effectiveness of the countermeasures, the levels of soil contamination with ^{137}Cs relative to isolines 555 kBq m^{-2} and 1480 kBq m^{-2} are of particular practical importance. The 555 kBq m^{-2} contamination level was taken as a threshold for farming and home gardening without obligatory decontamination. The isoline 555 kBq m^{-2} is a boundary of the territory where people were thought to be able to live without imported food products. The 1480 kBq m^{-2} level was taken as a threshold for people to live in the area. In the regions with soil contamination densities of 555 to 1480 kBq m^{-2}, effective countermeasures resulting in a significant reduction of radioactive contamination of home-raised food products were implemented on approximately one-half of the farms.

Practical implementation of countermeasures in the areas with different contamination levels of agricultural lands had its special features.

(1) Areas of up to 185 kBq m^{-2}: No countermeasures were applied.

(2) Areas from 185 to 555 kBq m^{-2}: Agricultural lands were cultivated without any restrictions in accordance with the technologies accepted for this soil-climatic region. Simplified improvement and amelioration of meadows was performed.

(3) Areas from 555 to 1480 kBq m^{-2}: Mineral fertilizers were applied to agricultural lands at a rate of one and one-half or two times the usual dose; lands under potatoes and other vegetables were treated with organic fertilizers. Lime materials were applied to lands with low pH at a rate of one or one and one-half times the usual dose with respect to hydrolytic acidity on cycles of liming. Radical amelioration of hay lands and pastures was conducted. In 1987 to 1988, the pasture lands were ploughed up. To reduce contamination with ^{137}Cs, beginning in 1988, cattle were fed on clean forage during the last 1.5 to 2 months of fattening.

(4) Areas with ^{137}Cs activity density higher than 1480 kBq m^{-2}: In 1987 about 40% of agricultural lands with this contamination density were taken out of agricultural production. In 1988 all agricultural lands with a contamination density over 1480 kBq m^{-2} were completely taken out of agricultural production.

A feature of agricultural countermeasures in the private sector is that restrictive countermeasures were applied directly after the accident, but application of other countermeasures such as agrochemical and agrotechnical ones were started only in 1990–1991. They consisted mainly in providing private cows with clean feedstuffs. With this purpose, in each settlement the pastures and haylands for private cattle were cultivated, resulting in some cases in a lower ^{137}Cs concentration in the milk of private cows as compared to milk produced in the collective sector. However, the effectiveness of these countermeasures decreased in 1993–1996, and the main method for decreasing the contamination of agricultural products became the application of Prussian blue (see examples given below).

I–1.3.5.3. Examples of the effectiveness of agricultural countermeasures application

Restrictive countermeasures. The restrictive countermeasures concerned restriction in consumption of local food products and forest gifts in the area with ^{137}Cs activity density higher than 555 kBq m^{-2}. These settlements can serve as an illustration of restrictive countermeasures properly observed, where up to now the consumption of milk produced in private farms in these settlements does not exceed 15%. The main sources of milk and milk products for inhabitants were shops and markets. Within the last 5–7 years, the number of private cows has increased rapidly in those settlements from which they had been removed. Hence the internal exposure increases in these settlements as well. Nowadays there are two groups of inhabitants in these settlements distinguished by sources of milk. So, a group of inhabitants not consuming private milk is characterised by a lower level of internal dose than the average calculated for the settlements. On the other hand, the level of internal irradiation of the inhabitants consuming private milk exceeds the average level, and this group might be considered as a critical one. In this case, to avoid an increase in internal dose, it might be reasonable to provide private cows with cultivated pastures and haylands, i.e., to apply radical improvement on private haylands.

A good example for evaluation of the main features and factors governing dose formation in settlements under the condition of intensive application of countermeasures is the settlement Shelomy. This settlement was studied carefully in several Russian and international projects. In particular, some important information for the present study was presented in the final report of ECP9 (Strand et al., 1996). It has been shown that, at present, two cohorts of inhabitants may be distinguished in this settlement, taking into account sources of milk consumed. One group, about 10% of the population of Shelomy, consumes private milk, and the other group consumes milk only from state shops. It should be noted that there is a big difference between ^{137}Cs concentrations in private milk and in milk from shops. The average activity of ^{137}Cs in private milk was about 100 Bq L^{-1}, while the ^{137}Cs concentration in milk from the shops was about ten times less. Accordingly, internal doses attributed to the consumption of milk varied considerably. For the first cohort of inhabitants, the internal dose calculated on the basis of data on contamination of private milk and other products derived in the frame of this project was 1.1 mSv a^{-1}, and for the second group, 0.36 mSv a^{-1}. The average internal dose calculated for inhabitants of the settlement in 1991–1995 amounted to 0.445 Sv a^{-1}, which is in good agreement with doses calculated from whole body measurements (0.42 mSv a^{-1}). This allows the estimation of the effect of removal of private cows as the difference between doses calculated for the cohort of inhabitants consuming private milk and doses calculated for each year on the basis of data on whole body measurements. On the whole, these results allow a conclusion that the annual averted dose in 1991–1995 was about 0.6 mSv a^{-1}.

The contributions of agricultural products to internal dose varied for different cohorts of inhabitants of this settlement (Table I-LXI). In the existing situation the main dose-forming products are mushrooms. The contribution of external dose to the irradiation of inhabitants is rather high (1.15 mSv a^{-1}). The total dose for inhabitants of the settlement is above 1 mSv a^{-1}, which requires countermeasure application. Besides, there is a tendency toward an increase in the number of private cows, which will result in an increase in internal dose to the population.

Improvement of fodder lands. In the example shown in Figure I-4, until 1991 all the private cows used unimproved pastures, thus resulting in a high level of milk contamination and, due to that, in high internal doses to the population. In 1992, when the pastures had been radically improved, they were allocated to private cows, and the milk contamination decreased sharply; it became lower than that of collective milk, thereby illustrating the high efficiency of this countermeasure. Figure I-4 also demonstrates that in 1992–1995, a certain increase in ^{137}Cs concentration in the milk of private cows was detected due to the reduced efficiency of radical improvement within this period of time. However, this example illustrates a rather high efficiency for this countermeasure, which was widely applied on the territory of Russia subjected to contamination after the Chernobyl accident.

Application of ^{137}Cs binders. In 1993–1996 ^{137}Cs binders were widely used in many settlements in the form of bifege or boli. Figure I-5 illustrates the dynamics of population internal doses (based on whole body measurements) in the settlement of Smyalch and the dynamics of the efficiency of the increase in the binder doses per cow. The figure shows that its application allowed the population exposure doses to be decreased significantly (by a factor of 2).

I–1.3.5.4. Forest countermeasures

For implementation of countermeasures, the forests of the Novozybkov district were divided into 3 zones: A, B and C, corresponding to different levels of ^{137}Cs deposition. Forests with a level of deposits above 1480 kBq m^{-2} (zone A) were completely excluded from economic use. These forests were permitted only measures to preserve their quality, prevent fires, and control dispersion of pests and diseases. Public access to these forests and collection of forest products (mushrooms, berries, etc.) was prohibited.

These restrictions were also applied to forests of zone B, with levels of ^{137}Cs deposition between 555 and 1480 kBq m^{-2}. The main forestry task in this case was to maintain the ecological role of the forest. Timber production was partially suspended in these forest stands until special technologies, machines and mechanisms could be developed to ensure occupational radiation safety and to obtain timber with the contamination below the adopted Intervention Limits. Any usage of forest products (mushrooms, berries, medical herbs, etc.) was also prohibited, and this prohibition continues till the present time.

Restrictions on the gathering of berries and mushrooms were also imposed in forests belonging to group C, with levels of ^{137}Cs deposition between 185 and 555 kBq m^{-2}. However, unlike the previous classes, sanitary felling and production of industrial timber were permitted. Artificial forest restorations were not allowed. Harvesting of trees to produce industrial timber is carried out on the basis of radiological survey results to guarantee that external dose rates and contamination of wood have minimal values.

Within zones C and B there are also small areas with densities of ^{137}Cs deposition below 185 kBq m^{-2}. Forestry without restriction and use of forest fodder for animals (including grazing of milk cows on forest clearings and collection of firewood in the forest) are allowed in these forests. However, gathering of berries and mushrooms is allowed only in forests with levels of ^{137}Cs deposition less than 74 kBq per m^{-2}.

The measures described for forests are mainly of a restrictive character and were intended to decrease exposure of the population, taking into account the main dose forming pathways. However, these countermeasures were adopted by the rural population only until 1990. Since 1990, gathering of mushrooms and berries by the local population has been (illegally) re-established on the whole territory except for areas of wood production, which are under the official control of the local forest authorities.

I–1.3.5.5. Countermeasures against external irradiation applied in contaminated settlements

In the summer of 1989, the nine most contaminated settlements of the test area were decontaminated. This procedure included removal of the upper layer of virgin soil from squares, streets, sports and rest grounds, grounds around production targets and dwellings; covering cleaned and contaminated plots with clean soil and sand; and covering of streets and yards with asphalt. Kindergartens and schools, as well as strips 10–15 meters wide around them, were carefully decontaminated. Some village parts and their surroundings (kitchen gardens, fruit gardens, arable land) were not decontaminated. The effectiveness of decontamination was estimated from the measurements of dose rates in different locations before and after decontamination. The observed decrease of the dose rate varied between a factor of 1.1–1.5 for houses to a factor of 1.5–5 for streets and yards. The measurements performed during the following years showed that the decontamination effect persisted in time.

Table I-LXII presents the average efficiency of decrease of the annual external dose in different population groups in three large villages after decontamination, determined by calculations and confirmed by individual TLD measurements of the dose in inhabitants.

FIG. I-1. Position of the test region on the map of Russia.

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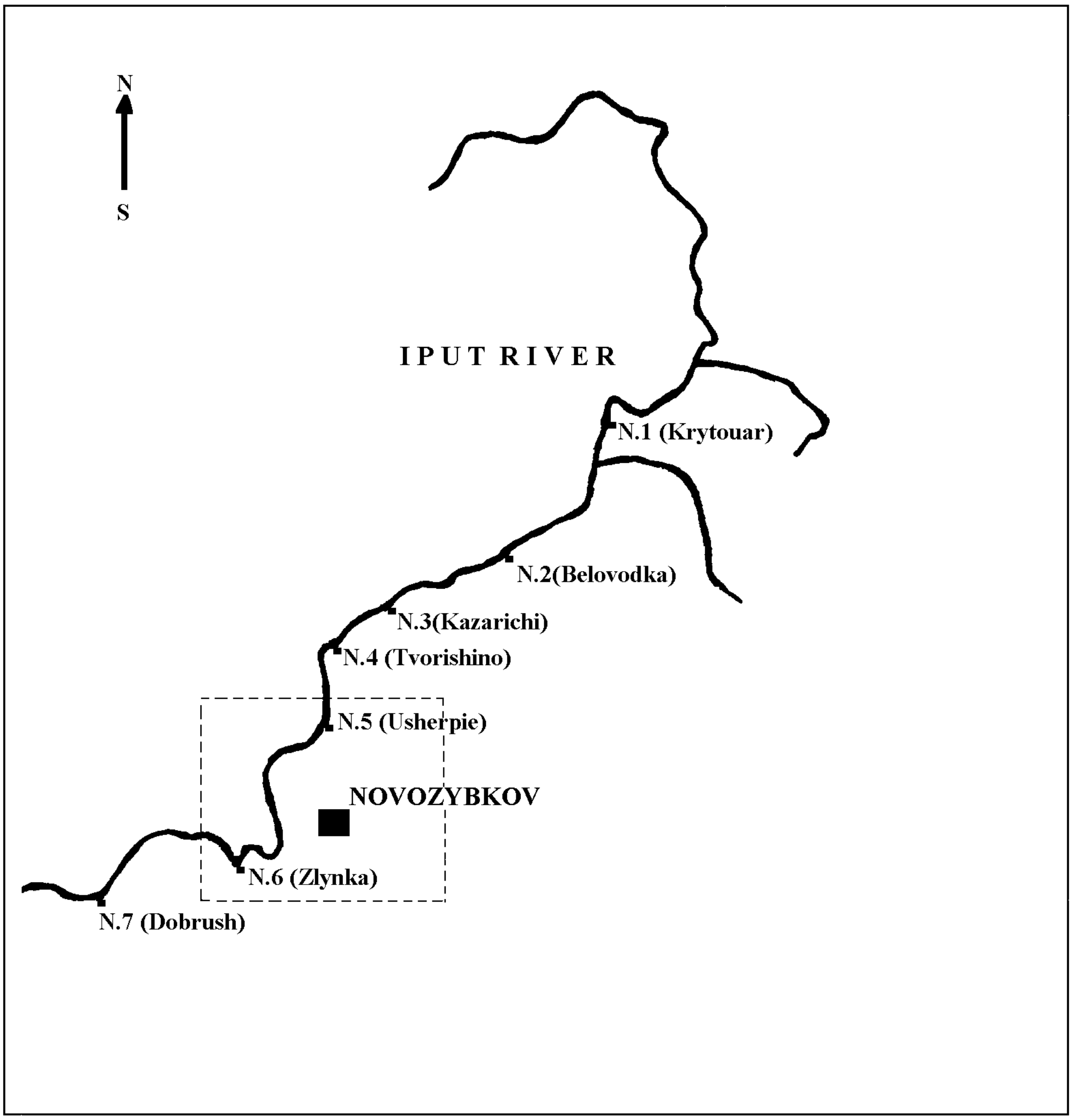

FIG. I-2. Scheme of the Iput River, showing the area considered in the test scenario.

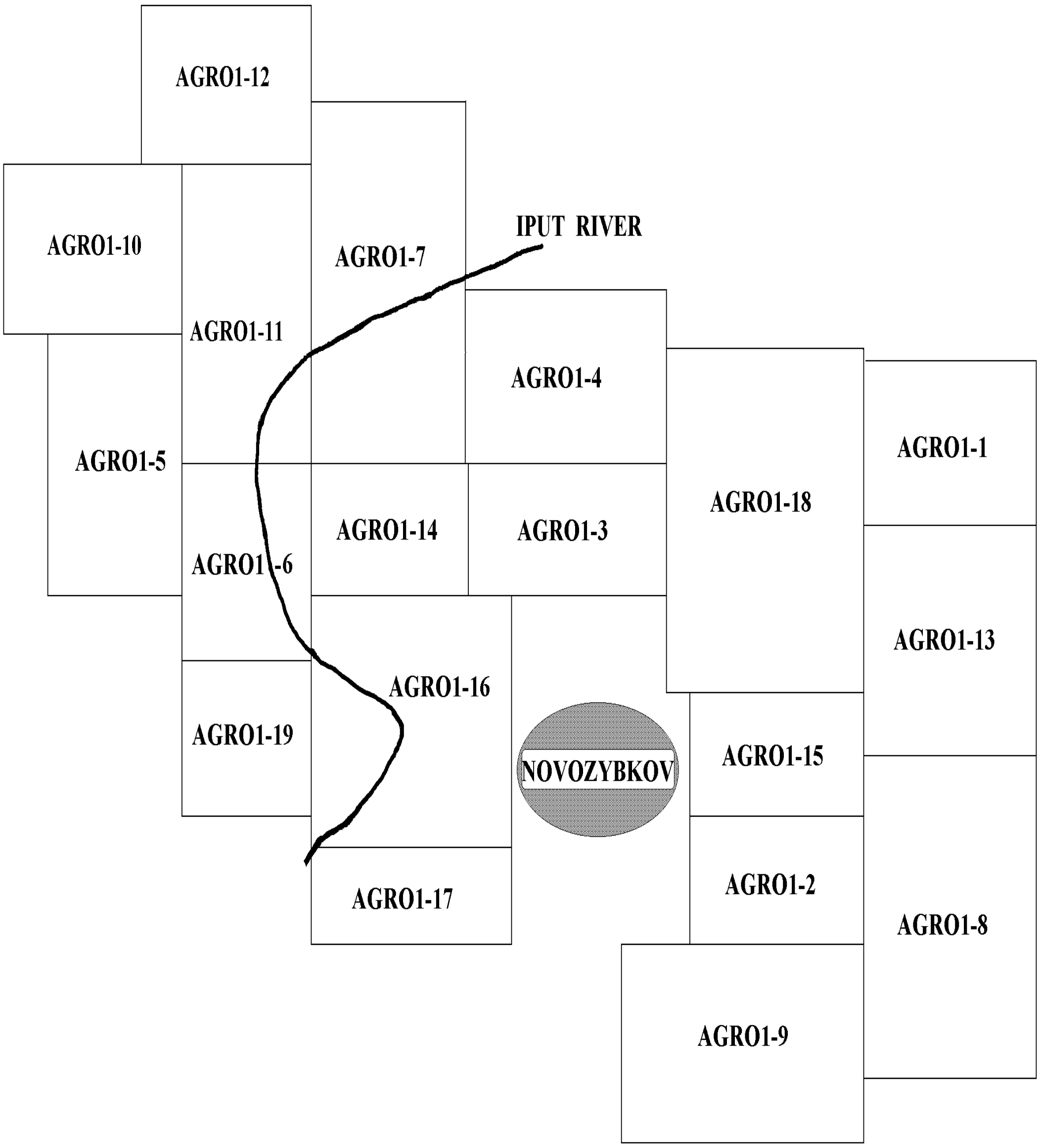

FIG. I-3. Scheme of agricultural subareas in the test region.

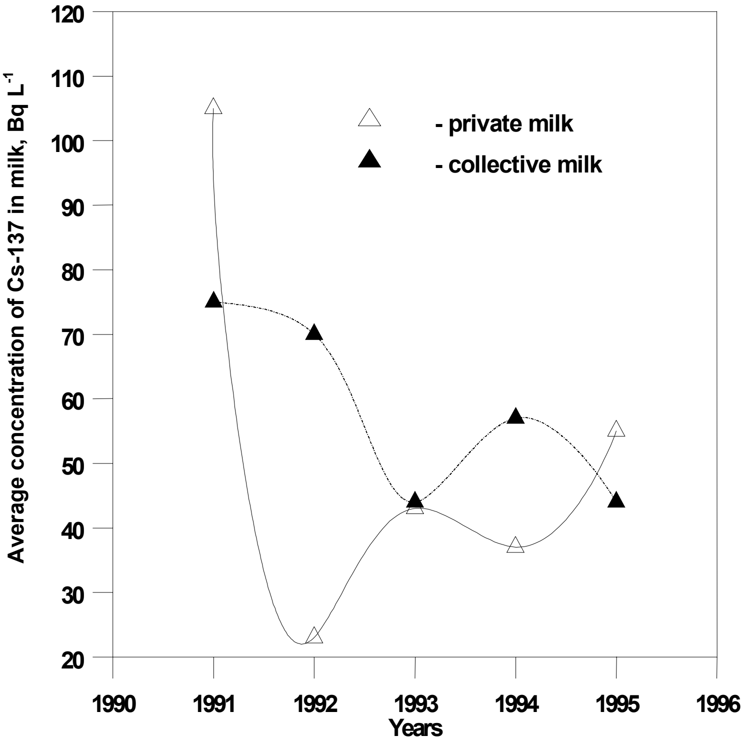

FIG. I-4. Dynamics of the ^{137}Cs specific activity in milk of private and collectively owned cows (settlement Pobozheyevka).

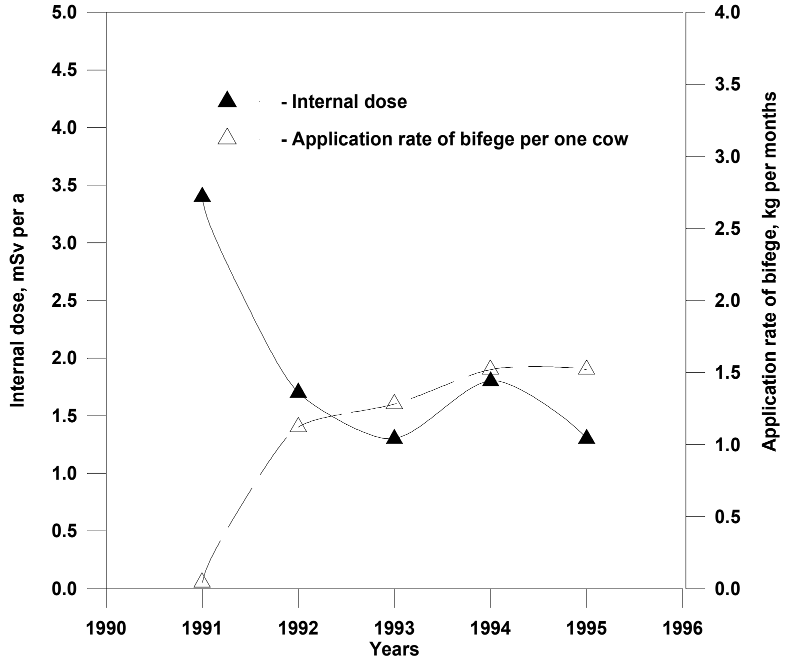

FIG. I-5. Internal doses and dynamics of the application rate of bifege per cow in Smyalch settlement. The total number of private milk cows in the settlement in the period under consideration was about one hundred.

TABLE I-I. ASSESSMENTS OF THE ^{137}Cs CONCENTRATIONS IN GROUND LEVEL AIR OF THE TEST AREA, 1986 (NOVOZYBKOV DISTRICT)

Time	Concentration, mBq m^{-3}
28.04–30.04.86	60000 ± 40000
1.05–10.05.86	2000 ± 1200
11.05–20.05.86	400 ± 200
21.05–31.05.86	200 ± 100
1.06–30.06.86	80 ± 40

TABLE I-II. RELATIVE CONTENT OF RADIONUCLIDES IN THE SOIL OF THE TEST AREA (30 MAY 1986)

Radionuclide	Relative content, %
^{89}Sr	2.7 ± 1.6
^{90}Sr	0.5 ± 0.3
^{95}Zr	1.2 ± 0.5
^{95}Nb	1.5 ± 0.5
^{103}Ru	24.0 ± 4.8
^{106}Ru	9.0 ± 5.2
^{131}I	12.2 ± 4.8
^{134}Cs	13.4 ± 4.0
^{137}Cs	25.3 ± 8.0
^{140}Ba	3.5 ± 0.9
^{140}La	3.7 ± 1.1
^{141}Ce	1.8 ± 0.6
^{144}Ce	1.2 ± 0.7

TABLE I-III. DENSITY OF ^{137}Cs CONTAMINATION WITH AND COMPOSITION OF THE POPULATION IN THE SETTLEMENTS OF NOVOZYBKOV DISTRICT (1 OCTOBER 1991)

Subarea	Number of samples	Density of contamination with ^{137}Cs, kBq m^{-2}			Composition of population		
		Min.	Ave.	Max.	Total	Male	Female
AGRO1-1	143	140	380	1380	778	324	454
AGRO1-2	36	40	460	660	857	382	475
AGRO1-3	95	110	610	1890	785	346	439
AGRO1-4	118	260	730	1470	776	322	454
AGRO1-5	124	320	980	2290	874	381	493
AGRO1-6	112	290	860	2160	1316	567	749
AGRO1-7	73	170	700	1310	899	384	515
AGRO1-8	49	70	280	470	995	441	554
AGRO1-9	95	130	530	940	990	420	570
AGRO1-10	34	190	1700	2670	681	275	406
AGRO1-11	85	460	900	1750	985	419	566
AGRO1-12	107	160	600	1140	1435	617	818
AGRO1-13	51	125	310	550	769	323	446
AGRO1-14	50	100	700	1200	746	325	421
AGRO1-15	75	55	470	1030	1666	747	919
AGRO1-16	118	150	1020	1560	622	249	373
AGRO1-17	165	155	920	2460	1102	485	617
AGRO1-18	24	110	420	620	432	181	251
AGRO1-19	53	300	910	1400	144	61	83

TABLE I-IV. VERTICAL DISTRIBUTION OF ^{137}Cs IN NOVOZYBKOV AREA SOILS (1 AUGUST, 1990)

Layer (cm)	^{137}Cs, kBq kg^{-1}	^{137}Cs, kBq m^{-2}	%
A. Uncultivated soils, fields			
0–2.5	30	726	82
2.5-5.0	2.0	75	8.5
5–10	0.64	62	7
10–15	0.25	22	2.5
0–15	-	885	-
B. Cultivated soils, kitchen-gardens			
0–5	3.0	187	33
5–10	2.8	214	38
10–15	1.9	138	24
15–20	0.4	26	4.6
20–30	0.02	2	<1
0–30	-	567	-
C. Forest soils			
0–2.5	57	1022	92
2.5–5.0	1.3	54	5
5–10	0.4	24	2
10–15	0.15	15	1
0–15	-	1115	-

TABLE I-V. DISTRIBUTION OF ^{137}Cs ACTIVITY ON SOIL PARTICLES OF DIFFERENT SIZE IN 1987

Region	Size of soil fractions, mm					
	<0.05	0.05–0.1	0.1–0.25	0.25–0.5	0.5–1.0	>1.0
Novozybkov district, Bryansk Region	52–55	-	22–30	6–7	3–4	8–10
Chernobyl area	15–20	8	20–30	22–24	19–22	7–12

TABLE I-VI. SECTION-AVERAGED CONCENTRATIONS OF ^{137}Cs IN THE RIVER WATER DURING A FLOODING PERIOD (9 APRIL–15 APRIL, 1991)

Hydrometric post	Distance from Iput river source, km	Concentration of ^{137}Cs, mBq L^{-1}	
		Solution	Suspension
1	170	3.0 ± 1.1	1.1 ± 0.2
2	230	3.3 ± 1.1	<0.1
3	254	21.1 ± 0.7	1.1 ± 0.1
4	264	14 ± 7	6.3 ± 1.8
5	304	170 ± 30	4.4 ± 0.4
6	330	166 ± 26	7.8 ± 0.7
7	363	366 ± 40	17 ± 10

TABLE I-VII. SECTION-AVERAGED CONCENTRATIONS OF ^{137}Cs IN THE RIVER WATER DURING A LOW-WATER PERIOD (27 JULY–9 AUGUST, 1991)

Hydrometric posts	Concentration of ^{137}Cs, mBq L^{-1}	
	Solution	Suspension
1	1.5	<0.1
2	2.6	1.1
3	3.0	<0.1
4	44	3
5	94	11
6	151	12
7	257	20

Note: The average uncertainty is 20% (95% confidence interval).

TABLE I-VIII. AVERAGE CONCENTRATIONS OF ^{137}Cs IN THE LAKE WATER (1991)

Sample	Solution	Suspension
^{137}Cs, Bq L^{-1}	14 ± 6	0.4 ± 0.3

TABLE I-IX. CONTAMINATION DENSITY, VERTICAL DISTRIBUTION, AND SPECIFIC ACTIVITY OF ^{137}Cs IN THE UPPER 20-CM SOIL LAYER OF THE FLOOD PLAIN OF THE IPUT RIVER NEAR HYDROMETRIC POSTS NOS.1–7 (15 APRIL 1991)

Settlement	Layer depth, cm	Contamination density ^{137}Cs, kBq m^{-2}	Specific activity of soil, Bq kg^{-1}
Krytoiar (near hydrometric post No. 1)	0–2	1.1	43
	3–4	2.0	58
	5–6	2.4	68
	7–7	2.7	65
	9–10	0.7	17
	11–15	0.5	5
	16–20	0.7	9
Belovodka (near H. post No. 2)	0–2	0.7	21
	3–4	0.4	11
	5–6	0.4	9
	7–8	0.6	14
	9–10	0.4	10
	11–15	0.6	7
	16–20	<0.1	<0.4
Kazarichi (near H. post No. 3)	0–2	8.5	370
	3–4	25	750
	5–6	33	910
	7–8	2.2	56
	9–10	0.5	12
	11–15	0.4	4
	16–20	<0.1	<0.4
Tvorishino (near H. post No. 4)	0–2	15	670
	3–4	8.1	220
	5–6	5.9	140
	7–8	13.0	315
	9–10	52	1385
	11–15	43	530
	16–20	2.2	25

TABLE I-IX. (cont.)

Settlement	Layer depth, cm	Contamination density ^{137}Cs, kBq m^{-2}	Specific activity of soil, Bq kg^{-1}
Usherpie (near H. post No. 5)	0–2	20	950
	3–4	23	940
	5–6	28	1025
	7–8	34	780
	9–10	26	620
	11–15	2.6	32
	16–20	1.8	20
Starue Bobovichi (near H. post No.6)	0–2	82	2270
	3–4	90	2550
	5–6	82	2440
	7–8	94	2750
	9–10	317	7960
	11–15	131	1200
	16–20	0.7	10
Vyskov (near H. post No. 7)	0–2	84	5340
	3–4	585	21090
	5–6	1260	34040
	7–8	200	5620
	9–10	33	890
	11–15	42	630
	16–20	18	250

Note: The average uncertainty is 20% (95% confidence interval).

TABLE I-X. ^{137}Cs CONTENT IN BOTTOM SEDIMENTS (IPUT RIVER, SUMMER 1991)

Hydrometric posts	Layer depth, cm	Contamination density with^{137}Cs, kBq m^{-2}	Specific activity of bottom sediments, Bq kg^{-1}
4	0–2	3.7	118
	3–4	4.2	96
	5–6	5.8	122
	7–8	4.0	81
	9–10	0.5	10
	11–15	<0.1	<0.6
5	0–2	4.4	130
	3–4	5.3	150
	5–6	5.4	115
	7–8	0.6	12
	9–10	0.5	12
	11–15	<0.1	<0.4
6	0–2	76	2720
	3–4	83	2430
	5–6	98	2180
	7–8	18	420
	9–10	0.7	16
	11–15	0.3	2.6

Note: The average uncertainty is 20% (95% confidence interval).

TABLE I-XI. CHARACTERISTICS OF THE IPUT WATERSHED CONTAMINATED WITH ^{137}Cs

Hydrometric post	Local watershed		Total watershed (cumulative)	
	Watershed area, km^2	Activity stored in watershed, TBq	Watershed area, km^2	Activity stored in watershed, TBq
1. (Krytojar)	4020	34	4020	34
2. (Belovodka)	1340	13	5360	47
3. (Kazarichi)	510	16	5860	64
4. (Tvorishino)	180	58	6040	122
5. (Usherpie)	2280	483	8320	604
6. (St. Bobovichi)	855	660	9170	1265
7. (Vishkov)	440	410	9610	1676

TABLE I-XII. AVERAGE ANNUAL ACTIVITY OF ^{137}Cs IN WATER (Bq L^{-1}) OF THE IPUT RIVER (HYDROMETRIC POST IN DOBRUSH, BELORUSSIA, NEAR THE INFLOW OF THE IPUT RIVER INTO THE SOZH RIVER)

Year	1987	1988	1989	1990	1991
Iput, near Dobrush	2.0	1.4	0.60	0.55	0.23

TABLE I-XIII. DAILY RAINFALL OBSERVATION (APRIL–MAY, 1986)

Code of rainfall measuring station	Year	Month	Day	Daily precipitation, mm
26898	1986	04	20	13.1
26898	1986	04	21	no rain
26898	1986	04	22	no rain
26898	1986	04	23	no rain
26898	1986	04	24	no rain
26898	1986	04	25	no rain
26898	1986	04	26	no rain
26898	1986	04	27	no rain
26898	1986	04	28	no rain
26898	1986	04	29	no rain
26898	1986	04	30	no rain
26898	1986	05	1	no rain
26898	1986	05	2	no rain
26898	1986	05	3	no rain
26898	1986	05	4	no rain
26898	1986	05	5	no rain
26898	1986	05	6	no rain
26898	1986	05	7	no rain
26898	1986	05	8	no rain
26898	1986	05	9	no rain
26898	1986	05	10	no rain
26898	1986	05	11	no rain
26898	1986	05	12	no rain
26898	1986	05	13	no rain
26898	1986	05	14	no rain
26898	1986	05	15	no rain
33042	1986	04	20	4.7
33042	1986	05	20	2.3

TABLE I-XIII. (cont.)

Code of rainfall measuring station	Year	Month	Day	Daily precipitation, mm
26882	1986	04	20	8.9
26882	1986	05	02	0.6
26882	1986	05	11	0.5
26882	1986	05	12	0.8
26882	1986	05	17	0.9
26882	1986	05	18	2.2
26882	1986	05	20	0.6
26882	1986	05	21	5.6
26976	1986	04	20	19.4
26976	1986	04	26	0.1
26976	1986	04	28	1.6
26976	1986	04	30	0.6
26976	1986	05	2	0.8
26976	1986	05	11	3.2
26976	1986	05	12	10.8
26976	1986	05	13	2.6
26976	1986	05	18	1.9
26976	1986	05	20	5.4
26976	1986	05	21	2.1
26974	1986	04	20	6.6
26974	1986	04	28	11.9
26974	1986	04	29	0.4
26974	1986	04	09	1.7
26974	1986	05	11	7.2
26974	1986	05	12	1.2
26974	1986	05	13	3.3
26974	1986	05	18	2.8
26974	1986	05	20	4.5

TABLE I-XIV. HYDROGRAPHIC CHARACTERISTICS OF THE IPUT RIVER

Hydrometric post, No.	River width, m	River depth, m	Flow rate, m s^{-1}	River plain width, km
1	20–40	1.5–3.0	0.1–0.4	0.2–0.5 (max=2)
2–4	10–96	0.7–3.0	0.2–0.3	5.0
5	60	4	0.2	1–6
6–7	30–68	1.2–3.0	0.2	-

TABLE I-XV. ANNUAL AVERAGE CHARACTERISTICS OF WATER AND SEDIMENT DISCHARGE FOR THE IPUT RIVER

Characteristic distribution	Average discharge	Cumulative frequency of the annual discharge, %					
		1	5	10	25	50	74
Annual							
Water discharge, $m^3 s^{-1}$	42.8	81.3	68.4	60.0	48.8	37.2	28.6
Sediment discharge, 10^3 tonnes a^{-1}	11	37	26	22	14	9.0	5.6
Over a flooding event							
Water discharge, $m^3 s^{-1}$	87.4	508	200	183	173	73.4	45.4
Sediment discharge, 10^3 tonnes a^{-1}	7.6	38	23	17	9.9	4.7	2.5

TABLE I-XVI. COMPONENTS OF WATER BALANCE OF THE IPUT RIVER

Components of water balance, mm	Value
Precipitation	730
River flow:	
total	173
surface	131
underground	42
Evaporation	557
Infiltration	599
Runoff coefficient	0.24
Infiltration coefficient	0.82

TABLE I-XVII. MONTH-TO-MONTH DISTRIBUTION OF DISCHARGES OF WATER AND SUSPENDED MATTER TO THE IPUT RIVER

Month	Average water discharge, $m^3 s^{-1}$	Suspended matter discharge, $kg s^{-1}$
January	20	0.13
February	15	0.097
March	38	0.45
April	230	2.3
May	73	0.41
June	20	0.17
July	14	0.12
August	14	0.099
September	19	0.079
October	22	0.086
November	26	0.13
December	23	0.13

TABLE I-XVIII. RANGE OF MONTHLY AIR TEMPERATURES IN THE TEST AREA (LONG TERM OBSERVATIONS)

Month	Temperature (^oC)		
	Min	Average	Max
January	-40	-7	+5
February	-37	-6	+7
March	-32	0	+21
April	-18	+7	+30
May	-7	+12	+34
June	-2	+13	+36
July	-2	+15	+37
August	-2	+15	+32
September	-12	+13	+30
October	-26	0	+21
November	-35	-3	+12
December	-40	-7	+5

TABLE I-XIX. RANGE OF SURFACE WATER TEMPERATURES IN LAKES OF THE TEST AREA (LONG-TERM OBSERVATIONS)

Month	Temperature (^{o}C)
April	5.0–15.0
May	13.3–15.2
June	17.2–18.7
July	18.6–22.5
August	19.4–22.0
September	13.6–16.8
October	7.2–9.2

TABLE I-XX. CHARACTERISTICS OF THE FORESTS IN THE TERRITORY OF THE IPUT TEST AREA

Forest Unit	Area, km^{-2}	Contamination, kBq m^{-2}		Type of forest	Number of inhabitants
		Average	St. Err.		
1	13.6	1100	220	Deciduous, 56%	1535
2	19.8	870	150	Deciduous, 66%	1950
3	17.2	1900	640	Coniferous, 52%	1508
4	3.5	1500	340	Coniferous, 60%	1420
5	15	910	100	Coniferous, 91%	1716
6	24.5	520	100	Coniferous, 90%	1074
7	3	780	170	Deciduous, 68%	863
8	8.5	620	120	Coniferous, 81%	296
9	6.7	460	40	Coniferous, 66%	682
10	8.8	360	80	Deciduous, 85%	1031
11	13	1500	330	Coniferous, 77%	134
12	28.9	1500	410	Coniferous, 81%	919
13	6.8	810	130	Coniferous, 92%	85
14	48.6	750	190	Coniferous, 67%	1183
15	11.4	910	100	Coniferous, 58%	985

TABLE I-XXI. POTENTIAL YIELD OF MUSHROOMS IN THE TERRITORY OF THE IPUT TEST AREA, kg a^{-1}

Forest unit	*Boletus edulis*	*Cantharellus cibarius*	*Suillus luteus*	*Russula cyanoxantha*	*Lactarius necator*	*Tricholoma flavovirens*	*Xerocomus badius*
1	5651	4011	12183	4011	2546	4751	5671
2	8227	5839	17737	5839	3707	6917	8257
3	7147	5072	15408	5072	3220	6009	7172
4	1454	1032	3135	1032	655	1223	1460
5	6233	4424	13437	4424	2808	5240	6255
6	10180	7225	21947	7225	4586	8559	10217
7	1247	885	2687	885	562	1048	1251
8	3532	2507	7614	2507	1591	2969	3545
9	2784	1976	6002	1976	1254	2341	2794
10	3656	2595	7883	2595	1647	3074	3670
11	5402	3834	11645	3834	2434	4542	5421
12	12008	8523	25889	8523	5410	10096	12051
13	2825	2005	6091	2005	1273	2376	2836
14	20193	14332	43536	14332	9098	16978	20266
15	4737	3362	10212	3362	2134	3983	4754

TABLE I-XXII. POTENTIAL YIELD OF BERRIES IN THE TERRITORY OF THE IPUT TEST AREA, kg a^{-1}

Forest unit	*Vaccinium myrtillus*	*Rubus idaeus*	*Fragaria vesca*
1	9067	3022	1511
2	13200	4400	2200
3	11467	3822	1911
4	2333	778	389
5	10000	3333	1667
6	16333	5444	2722
7	2000	667	333
8	5667	1889	944
9	4467	1489	744
10	5867	1956	978
11	8667	2889	1444
12	19267	6422	3211
13	4533	1511	756
14	32400	10800	5400
15	7600	2533	1267

TABLE I-XXIII. GENERAL CHARACTERISTICS OF THE TEST AREA (1989)

Number of populated sites	103
Number of farms (subareas)	19
Distribution of farms according to contamination with ^{137}Cs, kBq m^{-2}:	
< 555 kBq m^{-2}	6
555–1480 kBq m^{-2}	9
1480–2960 kBq m^{-2}	4

TABLE I-XXIV. STRUCTURE OF LAND USE IN THE TEST AREA (AGRO1)

Agricultural lands	Area, km^2	Area, %
Plough lands	386	64.3
Long term plantings and gardens	5	0.8
Hay lands	100	16.7
Pastures	109	18.2
Total agricultural area, km^2	600	100

TABLE I-XXV. LIST OF COLLECTIVE FARMS (SUBAREAS) SITUATED ON THE TEST AREA

Agricultural subarea	Main settlement (Name of farm)
AGRO1-1	Manyuki ("Vperiod")
AGRO1-2	Trostan ("Voskhod")
AGRO1-3	Vnukovitchyi ("Imeni Kirova")
AGRO1-4	Chaleevitchyi ("Kommunar")
AGRO1-5	Staryi Vischkov ("Komsomolets")
AGRO1-6	Stariye Bobovitchi ("Krasnya Put")
AGRO1-7	Katitchyi ("Imeni Lenina")
AGRO1-8	Staryi Kryivetc ("Novaya Zhizn")
AGRO1-9	Snovskoye ("Pamyati Lenina")
AGRO1-10	Svyatsk ("Imeni XXII Partsyezda")
AGRO1-11	Noviye Bobovitchi ("Reshitelny")
AGRO1-12	Verestchakyi ("Rossiya")
AGRO1-13	Kataschin ("Udarnik")
AGRO1-14	Schelomi ("Rodina")
AGRO1-15	Zamischevo ("Boyevik")
AGRO1-16	Novoye Mesto ("Volna Revolyutsii)
AGRO1-17	Dyemenka ("NBIFASS")
AGRO1-18	Krutoberyozka ("Krutoberyozka")
AGRO1-19	Perevoz ("Novozybkovsky")

TABLE I-XXVI. LAND USE ON FARMS (SUBAREAS) OF THE TEST AREA, km^2

Agricultural subareas	Total area of agricultural lands, km^2	Plough land, km^2	Hay lands and pastures, km^2
AGRO 1-1	25	20	5
AGRO 1-2	23	17	6
AGRO 1-3	30	22	8
AGRO 1-4	28	19	9
AGRO 1-5	30	16	14
AGRO 1-6	25	13	12
AGRO 1-7	41	21	20
AGRO 1-8	54	41	13
AGRO 1-9	46	31	15
AGRO 1-10	21	12	9
AGRO 1-11	45	25	20
AGRO 1-12	48	27	21
AGRO 1-13	27	22	5
AGRO 1-14	23	16	7
AGRO 1-15	21	16	5
AGRO 1-16	43	28	15
AGRO 1-17	6	4	2
AGRO 1-18	28	24	4
AGRO 1-19	34	21	13

TABLE I-XXVII. DISTRIBUTION OF AGRICULTURAL LANDS IN THE TEST AREA BY SOIL TYPES, %

Soil	Distribution, %
Soddy-podzolic	93.2
Soddy-podzolic gley	2.2
Peaty-swamped	0.4
Flooded	4.2

TABLE I-XXVIII. AGROCHEMICAL CHARACTERISTICS OF MAJOR SOIL TYPES IN THE TEST AREA

Soil	Mechanical composition	pH	Humus, %	P	K	Ca	Mg	Total exchange bases
				mg per 100 g soil				mg-eq. per100 g soil
Soddy-podzolic	Sandy	5.4	1.3	2.2	7.4	3.2	1.8	5.5
Soddy-podzolic	Sandy loam	5.3	3.3	3.3	9.4	3.8	1.8	5.6
Soddy-podzolic	Light sandy loam	4.8	1.7	4.9	1.6	4.6	1.8	7.6
Soddy-podzolic	Light sandy loam	6.5	5.0	17.2	15.6	7.6	0.8	-
Soddy	Inter-mediate loam	6.8	4.8	2.5	16.4	10.9	1.5	12.4
Swamp-gley	Inter-mediate loam	4.5	7.5	1.5	17.8	15.6	3.3	18.9
Light-grey forest	Inter-mediate loam	5.6	2.1	12.4	10.7	5.8	1.1	-
Grey forest	Light loam	4.9	2.1	30.6	36.1	10.1	1.3	14.7
Grey forest	Intermediate	6.9	4.4	33.3	30.1	21.7	1.3	23.8

TABLE I-XXIX. PROPORTIONS OF DIFFERENT SOIL TYPES BY AGRICULTURAL SUBAREAS (%)

Agricultural subarea	Soil types				
	soddy-podzolic		soddy-podzolic gley (sandy loam)	peaty swamped	flooded
	sandy	sandy loam			
AGRO1-1	39.7	46.1	7.6	5.5	1.1
AGRO1-2	38.7	54.3	1.0	-	6.0
AGRO1-3	49.9	29.7	5.0	2.8	12.5
AGRO1-4	11.6	66.0	-	12.5	9.9
AGRO1-5	6.0	74.2	-	19.1	0.7
AGRO1-6	59.9	21.0	-	2.1	17.0
AGRO1-7	6.1	52.3	-	24.0	16.7
AGRO1-8	2.3	71.8	10.9	3.1	11.9
AGRO1-9	58.9	26.8	4.7	1.5	8.1
AGRO1-10	8.0	72.7	-	12.4	6.9
AGRO1-11	13.6	73.9	-	8.4	4.1
AGRO1-12	32.6	44.7	-	22.7	-
AGRO1-13	-	94.8	1.2	-	4.0
AGRO1-14	9.3	73.2	-	17.5	-
AGRO1-15	-	88.9	-	11.1	-
AGRO1-16	49.3	30.0	-	2.9	17.8
AGRO1-17	26.9	56.3	-	6.4	10.4
AGRO1-18	53.7	40.3	1.0	2.4	2.6
AGRO1-19	54.3	41.0	-	1.7	3.0

TABLE I-XXX. AVERAGE ACIDITY OF DIFFERENT SOILS BY AGRICULTURAL SUBAREAS

Agricultural subareas	Soils	pH	
		ploughed layer	subsoil
AGRO1-1	Soddy-podzolic sandy	4.8	4.6
	soddy-podzolic sandy loam	5.2	4.8
	soddy-podzolic gley sandy loam	5.3	5.6
	peaty swamped	4.2	4.2
	flooded	5.3	5.8
AGRO1-2	soddy-podzolic sandy loam	5.2	5.5
	soddy-podzolic gley sandy loam	5.3	5.4
	flooded	5.2	5.2
AGRO1-3	soddy-podzolic sandy	5.3	5.3
	soddy-podzolic gley sandy loam	5.4	5.4
	peaty swamped	5.8	4.8
	flooded	6.2	7.0
AGRO1-4	soddy-podzolic sandy	5.5	4.9
	soddy-podzolic sandy loam	4.9	5.4
AGRO1-5	soddy-podzolic sandy loam	5.2	6.0
	peaty swamped	5.3	5.5
	flooded	5.2	5.2
AGRO1-6	soddy-podzolic sandy	4.6	4.6
	flooded	5.4	5.6
AGRO1-7	soddy-podzolic sandy loam	5.2	5.3
AGRO1-8	soddy-podzolic sandy loam	4.7	5.1
	peaty swamped	5.4	6.0
	flooded	5.4	5.0
AGRO1-9	soddy-podzolic sandy	4.5	4.3
	soddy-podzolic sandy loam	5.5	5.3
	soddy-podzolic gley sandy	4.4	4.4
	soddy-podzolic gley sandy loam	4.4	4.4
AGRO1-10	soddy-podzolic sandy loam	5.0	5.1
	peaty swamped	5.6	5.6
	flooded	6.2	6.2
AGRO1-11	soddy-podzolic sandy	5.0	4.8
	soddy-podzolic sandy loam	5.2	5.2
	peaty swamped	5.0	5.5
	flooded	4.8	4.8
AGRO1-12	soddy-podzolic sandy	4.9	4.9
	soddy-podzolic sandy loam	5.0	5.7
	peaty swamped	5.7	6.1
AGRO1-13	soddy-podzolic sandy loam	5.2	5.2
	soddy-podzolic light loam	5.4	4.8
	soddy-podzolic gley sandy loam	5.3	5.4
	flooded	4.6	4.6
AGRO1-14	soddy-podzolic sandy	4.6	4.6
	soddy-podzolic sandy loam	4.8	4.7
	peaty swamped	5.2	5.6
AGRO1-15	soddy-podzolic sandy loam	5.2	5.3
	flooded	4.8	4.9
AGRO1-16	soddy-podzolic sandy	5.5	5.1
	soddy-podzolic sandy loam	5.2	5.4
	peaty swamped	5.2	5.8
	flooded	4.6	4.6

TABLE I-XXX. (cont.)

Agricultural subareas	Soils	pH	
		ploughed layer	subsoil
AGRO1-17	soddy-podzolic sandy loam	4.8	4.8
	soddy-podzolic sandy loam	5.6	4.7
	soddy-podzolic gley sandy loam	5.3	4.6
	flooded	4.8	5.4
AGRO1-18	soddy-podzolic sandy	4.9	4.8
	soddy-podzolic sandy loam	4.6	4.8
	peaty swamped	4.6	4.6
	flooded	5.8	5.6
AGRO1-19	Soddy-podzolic sandy	5.1	4.9
	Soddy-podzolic sandy loam peaty	4.9	5.2
	swamped	5.2	5.4
	Flooded	5.0	5.3

TABLE I-XXXI. TIME OF SOWING AND HARVESTING OF CROPS

Crop type	Dates of sowing	Dates of harvesting
Winter rye	20.08–10.09	20.07–05.09
Winter wheat	20.08–10.09	20.07–05.09
Spring barley	15.04–05.05	20.08–30.08
Maize (for silage)	10.05–30.05	01.09–15.09
Potato	01.05–10.05	20.09–10.10
Root crops	20.04–10.05	20.09–30.09
Cabbage	15.05–30.05	20.08–30.08 (early) 20.09–30.09 (late)
Vegetables	20.05–30.05	20.07–10.08
Grasses	10.04–20.04	1 term 10.06–20.06 2 term 20.07–30.07 3 term 10.09–20.09

TABLE I-XXXII. YIELDS OF GRASS STAND AND SILAGE IN THE TEST AREA, 1986

Type	Yield (kg m^{-2})
Hay: perennial grasses (dry weight)	0.308
Natural grasses (dry weight)	0.136
Silage (fresh weight)	4.05

TABLE I-XXXIII. KEEPING OF ANIMALS

Pasture period	Start 1 May–10 May End 10 Oct.–20 Oct. Average duration is 170–180 days
Stable period	Duration of stable period may range from 146 to 200 days

TABLE I-XXXIV. ANNUAL RATION FOR BULL CALVES AT A FARM IN THE TEST AREA, kg a^{-1}

Components of ration	Amount, kg a^{-1}
Green	2724
Hay	532
Silage*	3163
Root crops	146
Potato	125
Pasture	-
Concentrates **	815

* The main component of silage is green-cut maize, content of dry matter is 20%.

**Concentrates include grain of barley, ray, wheat, mineral and vitamin supplements, phosphorus acid ammonium salts.

TABLE I-XXXV. DAILY RATION FOR DAIRY COWS IN DIFFERENT SEASONS, kg per d (weight, 500 kg; productivity, 5–6 L d^{-1})

Component of ration	Amount, kg day^{-1}
Stable period	
Hay	4
Straw	2
Silage	15
Beet roots	3
Concentrates	2
Pasture period	
Grass stand	50
Concentrates	2

TABLE I-XXXVI. RATION OF PIGS, kg d^{-1} (weight 80–120 kg)

Components of ration	Amount, kg d^{-1}
Winter period	
Concentrates	2
Beet roots	6
Ground hay	0.2
Summer period	
Concentrates	2.8
Grass (legumes)	5.5

Concentrates include meals (barley, oats, wheat, pea); bran (wheat, meat, meat + bone or fish meal) and mineral supplements.

TABLE I-XXXVII. FEED PROPORTIONS IN RATIONS FOR HENS, % (Consumption 110–140 g d^{-1} per capita)

Feeds	% feed in ration
Grain, unbroken (barley, oat, rye)	35–40
Grain, crushed or ground	30–35
Animal feeds (dry)	7–8
Green or succulent	20
Mineral supplements (gravium not included)	3

TABLE I-XXXVIII. YIELDS IN 1986 FOR THE AGRICULTURAL AREA AGRO1, NOVOZYBKOV DISTRICT

Crop	Yield, kg m^{-2}
Cereals	0.19
Vegetables	2.3
Potatoes	2.0
Root vegetables	2.8

TABLE I-XXXIX. AVERAGE MILK PRODUCTION PER COW IN 1986

Agricultural area	District	Milk production, L a^{-1}
AGRO 1	Novozybkov	2,600

TABLE I-XL. DISTRIBUTION OF AGRICULTURAL LANDS IN THE TEST AREA BY ^{137}Cs CONTAMINATION

Contamination level kBq m^{-2}	Contaminated area, km^2		
	plough land	hay pasture	total
37–185	3	5	8
185–370	72	16	88
370–555	96	49	145
555–1,100	161	90	251
1,100–1,480	37	19	56
1,480–2,960	25	26	51

TABLE I-XLI. DISTRIBUTION OF AGRICULTURAL SUBAREAS BY CONTAMINATION DENSITY

Agricultural subarea	Land use	Area, Ha	Contamination level, kBq m^{-2}						
			<37	37–185	185–370	370–555	555–1110	1110–1480	>1,480
AGRO1-1	Arable land	1,953	-	-	380	1,498	75	-	-
	Pasture	526	-	-	-	526	-	-	-
	Total	2,479	-	-	380	2,024	75	-	-
AGRO1-2	Arable land	1,732	-	-	487	1,176	69	-	-
	Pasture	554	-	-	-	554	-	-	-
	Total	2,286	-	-	487	1,730	69	-	-
AGRO1-3	Arable land	2,177	-	-	-	457	1,720	-	-
	Pasture	814	-	-	190	87	393	144	-
	Total	2,991	-	-	190	544	2,113	144	-
AGRO1-4	Arable land	1,896	-	-	10	-	-	1,644	128
	Pasture	922	-	-	-	125	429	221	-
	Total	2,818	-	-	10	125	429	1,865	128
AGRO1-5	Arable land	1,580	-	-	-	-	42	148	1,390
	Pasture	1,452	-	-	-	-	206	141	1,105
	Total	3,032	-	-	-	-	248	289	2,495
AGRO1-6	Arable land	1,306	-	-	71	102	94	574	465
	Pasture	1.231	-	-	-	-	82	554	595
	Total	2,537	-	-	71	102	176	1,128	1,060
AGRO1-7	Arable land	2,104	-	-	-	21	1,865	218	-
	Pasture	2,024	-	-	136	289	1,599	-	-
	Total	4,128	-	-	136	310	3,464	218	-
AGRO1-8	Arable land	4,064	36	86	2,810	970	162	-	-
	Pasture	1,328	-	93	206	777	252	-	-
	Total	5,392	36	179	3,016	1,747	414	-	-
AGRO1-9	Arable land	3,151	-	63	980	1,100	1,008	-	-
	Pasture	1,493	-	194	337	738	224	-	-
	Total	4,644	-	257	1,317	1,838	1,232	-	-
AGRO1-10	Arable land	1,163	-	-	-	-	77	531	555
	Pasture	916	-	66	-	-	-	379	471
	Total	2,079	-	66	-	-	77	910	1,026
AGRO1-11	Arable land	2,514	-	-	-	-	1,674	840	-
	Pasture	1,963	-	-	-	177	1,388	80	318
	total	4,477	-	-	-	177	3,062	920	318
AGRO1-12	Arable land	2,717	-	-	-	-	2,159	558	-
	Pasture	2,132	-	-	120	125	1,793	94	-
	Total	4,849	-	-	120	125	3,952	652	-
AGRO1-13	Arable land	2,202	-	132	1,708	362	-	-	-
	Pasture	465	-	37	234	194	-	-	-
	Total	2,667	-	169	1,942	556	-	-	-
AGRO1-14	Arable land	1,573	-	-	90	114	1,369	-	-
	Pasture	758	-	91	-	-	573	94	-
	Total	2,331	-	91	90	114	1,942	94	-
AGRO1-15	Arable land	1,615	-	-	144	1,326	145	-	-
	Pasture	473	-	-	40	97	336	-	-
	Total	2,088	-	-	184	1,423	481	-	-
AGRO1-16	Arable land	2,765	-	-	-	-	2,478	287	-
	Pasture	1,514	-	-	181	561	678	94	-
	Total	4,279	-	-	181	561	3,156	381	-
AGRO1-17	Arable land	441	-	-	-	-	35	406	-
	Pasture	165	-	-	-	-	36	129	-
	Total	606	-	-	-	-	71	535	-
AGRO1-18	Arable land	2,372	-	-	500	1,564	308	-	-
	Pasture	467	-	-	-	51	386	30	-
	Total	2,839	-	-	500	1,615	694	30	-
AGRO1-19	Arable land	2,092	-	-	25	896	1,171	-	-
	Pasture	1,280	-	-	50	288	786	156	-
	Total	3,372	-	-	75	1,184	1,957	156	-

TABLE I-XLII. ^{137}Cs VERTICAL DISTRIBUTION ON VARIOUS AGRICULTURAL LANDS, % (1990)

Depth, cm	Agricultural lands			
	Plough land	Pasture	Dry meadow	Flooded meadow
0–5	25.0	88.2	97.9	76.8
5–10	25.8	6.0	1.2	17.4
10–15	30.1	2.9	0.3	2.3
15–20	18.6	1.4	0.1	2.6
20–25	0.3	0.7	0.2	0.4
25–30	0.1	0.5	0.2	0.2
30–40	0.0	0.2	0.1	0.2
40–50	0.0	0.1	0.0	0.1

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

Age group, years	Women (%)	Men (%)
0–4	6.6	8.0
5–9	6.3	7.5
10–14	6.1	7.2
15–19	5.7	6.9
10–24	5.5	6.6
25–29	6.8	8.3
30–34	7.1	8.5
35–39	6.4	7.6
40–44	6.4	4.6
45–49	5.1	5.3
50–54	6.4	5.3
55–59	7.2	6.2
60–64	8.1	6.4
65–69	5.3	5.4
70–74	3.8	2.4
75–79	3.8	1.6
80–84	2.18	1.3
85–89	0.9	0.62
90–94	0.24	0.22
>95	0.08	0.06

TABLE I-XLIV. DISTRIBUTION OF ADULT RURAL INHABITANTS OF THE TEST AREA ACCORDING TO DWELLING TYPE AND OCCUPATION GROUP (FOR EXTERNAL DOSE EVALUATION)

Dwelling type	Occupation group, %		
	Indoor	Outdoor	Pensioners
One-storey wooden house	18	33	19
One-storey brick house	8	14	8

TABLE I-XLV. SEASONAL VALUES OF OCCUPANCY FACTORS FOR RURAL ENVIRONMENT, RELATIVE UNITS

Type of location	Mean	5th quintile	95th quintile	Std. dev.
Indoor workers, November–March				
Living area (indoors)	0.59	0.49	0.70	0.066
Living area (outdoors)	0.11	0.00	0.28	0.080
Work area (indoors)	0.24	0.13	0.30	0.056
Work area (outdoors)	0.05	0.00	0.10	0.039
Ploughed field	0.00	-	-	-
Virgin land	0.00	-	-	-
Rest area	0.01	0.000	0.03	0.009
Indoor workers, April–October				
Living area (indoors)	0.42	0.27	0.58	0.100
Living area (outdoors)	0.28	0.10	0.50	0.120
Work area (indoors)	0.23	0.07	0.31	0.077
Work area (outdoors)	0.02	0.000	0.17	0.061
Ploughed field	0.02	0.000	0.16	0.069
Virgin land	0.01	0.000	0.02	0.018
Rest area	0.02	0.000	0.10	0.035
Outdoor workers, November–March				
Living area (indoors)	0.55	0.33	0.73	0.106
Living area (outdoors)	0.11	0.000	0.33	0.093
Work area (indoors)	0.12	0.000	0.36	0.142
Work area (outdoors)	0.10	0.000	0.33	0.123
Ploughed field	0.10	0.000	0.38	0.147
Virgin land	0.02	0.000	0.21	0.071
Rest area	0.00	-	-	-
Outdoor workers, April–October				
Living area (indoors)	0.42	0.31	0.61	0.097
Living area (outdoors)	0.19	0.04	0.33	0.099
Work area (indoors)	0.05	0.000	0.31	0.100
Work area (outdoors)	0.07	0.000	0.33	0.115
Ploughed field	0.21	0.000	0.50	0.187
Virgin land	0.04	0.000	0.28	0.086
Rest area	0.02	0.000	0.08	0.062
Pensioners, November–March				
Living area (indoors)	0.84	0.67	0.96	0.096
Living area (outdoors)	0.15	0.04	0.33	0.093
Work area (indoors)	0.00	-	-	-
Work area (outdoors)	0.00	-	-	-
Ploughed field	0.00	-	-	-
Virgin land	0.00	-	-	-
Rest area	0.01	0.000	0.013	0.013
Pensioners, April–October				
Living area (indoors)	0.56	0.34	0.85	0.144
Living area (indoors)	0.40	0.16	0.60	0.129
Work area (indoors)	0.00	-	-	-
Work area (outdoors)	0.00	-	-	-
Ploughed field	0.00	-	-	-
Virgin land	0.00	-	-	-
Rest area	0.04	0.000	0.14	0.055

TABLE I-XLVI. ANNUAL AVERAGE OCCUPANCY FACTORS FOR RURAL POPULATION

Type of location	Occupancy factors, relative units		
	Indoor workers	Outdoor workers	Pensioners
Living area (indoors)	0.49	0.47	0.68
Living area (indoors)	0.21	0.16	0.30
Work area (indoors)	0.23	0.08	0.00
Work area (outdoors)	0.03	0.08	0.00
Ploughed field	0.02	0.17	0.00
Virgin land	0.01	0.03	0.00
Rest area	0.01	0.01	0.02

TABLE I-XLVII. FOOD CONSUMPTION RATE BY THE ADULT RURAL INHABITANTS OF THE TEST AREA *BEFORE THE CHERNOBYL ACCIDENT*, kg d^{-1} (Mean ± SD)

Food origin	Sex	Milk	Meat*	Potato*	Vegetables*	Bread
Local	Male	0.76 ± 0.78	0.177 ± 0.099	0.64 ± 0.30	0.30 ± 0.11	-
	Female	0.56 ± 0.48	0.170 ± 0.122	0.56 ± 0.22	0.27 ± 0.09	-
Imported	Male	0.016	0.020	0.005	0.003	0.39 ± 0.16
	Female	0.016	0.016	0.006	0.005	0.29 ± 0.12

* Mass of raw product. Real consumption is less by 20–30%.

TABLE I-XLVIII. CONSUMPTION RATE OF NATURAL FOOD PRODUCTS BY THE POPULATION SURVEYED IN THE VILLAGES OF THE TEST AREA, g d^{-1}

Area, Time period	Gender	Number of respondents	Wild mushrooms*	Forest berries
"Controlled", Nov. 1994	Male	59	18	3.4
	Female	74	9	4.0
"Controlled", Oct. 1994	Male	67	15	3.7
	Female	34	11	6.2
"Observed" Oct. 1995	Male	58	33	12
	Female	103	25	12

* Mass of raw product. Real consumption is less by 20–30%.

Note: Average fish consumption in 1994–1996 is 18 g d^{-1}.
The average uncertainty for consumption of natural food products is 40–60%.

TABLE I-XLIX. MEAN DAILY CONSUMPTION OF MAJOR *LOCALLY PRODUCED* FOOD PRODUCTS BY INHABITANTS OF THE “CONTROLLED AREA” BEFORE AND AFTER THE CHERNOBYL ACCIDENT, kg d^{-1} OR L d^{-1} (Mean ± SE)

Year	Gender	Local food product				
		Milk	Meat*	Potato*	Vegetables*	Bread
1985	M	0.80 ± 0.07	0.174 ± 0.010	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.59 ± 0.03	0.186 ± 0.010	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
10 May 1986	M	0.66 ± 0.07	0.082 ± 0.010	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.56 ± 0.07	0.088 ± 0.010	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
20 May 1986	M	0.46 ± 0.04	0.072 ± 0.010	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.38 ± 0.04	0.082 ± 0.010	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
June 1986	M	0.45 ± 0.05	0.072 ± 0.007	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.37 ± 0.03	0.082 ± 0.008	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
July 1986	M	0.40 ± 0.04	0.072 ± 0.007	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.35 ± 0.03	0.081 ± 0.008	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
August 1986	M	0.36 ± 0.04	0.072 ± 0.007	0.60 ± 0.02	0.30 ± 0.01	0.40 ± 0.02
	F	0.34 ± 0.03	0.081 ± 0.008	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
September 1986	M	0.15 ± 0.02	0.034 ± 0.02	0.60 ± 0.02	0.30 ± 0.01	0.34 ± 0.02
	F	0.16 ± 0.02	0.042 ± 0.004	0.53 ± 0.02	0.27 ± 0.01	0.28 ± 0.01
1987	M	0	0.030 ± 0.003	0.55 ± 0.04	0.30 ± 0.01	0.40 ± 0.02
	F	0	0.041 ± 0.004	0.48 ± 0.04	0.27 ± 0.01	0.28 ± 0.01
1988	M	0	0.028 ± 0.003	0.55 ± 0.04	0.30 ± 0.01	0.40 ± 0.02
	F	0	0.041 ± 0.004	0.48 ± 0.04	0.27 ± 0.01	0.28 ± 0.01
1990	M	0	0.010 ± 0.004	0.50 ± 0.04	0.25 ± 0.04	0.36 ± 0.03
	F	0	0.016 ± 0.003	0.39 ± 0.02	0.21 ± 0.01	0.28 ± 0.01
1993	M	0.13 ± 0.06	0.148 ± 0.020	0.84 ± 0.02	0.29 ± 0.02	0.40 ± 0.02
	F	0.11 ± 0.04	0.095 ± 0.013	0.63 ± 0.03	0.28 ± 0.02	0.31 ± 0.01
1994	M	0.24 ± 0.05	0.164 ± 0.012	0.81 ± 0.05	0.21 ± 0.01	0.41 ± 0.02
	F	0.29 ± 0.04	0.109 ± 0.086	0.70 ± 0.39	0.18 ± 0.01	0.34 ± 0.02

* Mass of raw product. Real consumption is less by 20–30%.

TABLE I-L. MEAN DAILY CONSUMPTION OF MAJOR *LOCALLY PRODUCED* FOOD PRODUCTS BY INHABITANTS OF THE “OBSERVED AREA” (“NON-CONTROLLED AREA”) BEFORE AND AFTER THE CHERNOBYL ACCIDENT, kg d^{-1} OR L d^{-1} (Mean ± SE)

Year	Gender	Local food product				
		Milk	Meat*	Potato*	Vegetable*	Bread
1985	M	0.70 ± 0.07	0.186 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.55 ± 0.03	0.161 ± 0.08	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
10 May 1986	M	0.54 ± 0.03	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.48 ± 0.04	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
20 May 1986	M	0.39 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.30 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
June 1986	M	0.38 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.29 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
July 1986	M	0.37 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.27 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
August 1986	M	0.38 ± 0.04	0.140 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.27 ± 0.03	0.105 ± 0.01	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
September 1986	M	0.36 ± 0.04	0.124 ± 0.01	0.69 ± 0.04	0.31 ± 0.01	0.38 ± 0.02
	F	0.26 ± 0.03	0.084 ± 0.008	0.58 ± 0.02	0.27 ± 0.01	0.29 ± 0.01
1987	M	0.35 ± 0.04	0.124 ± 0.01	0.52 ± 0.05	0.31 ± 0.01	0.38 ± 0.02
	F	0.25 ± 0.03	0.084 ± 0.008	0.53 ± 0.05	0.27 ± 0.01	0.29 ± 0.01
1988	M	0.36 ± 0.04	0.124 ± 0.01	0.52 ± 0.05	0.31 ± 0.01	0.38 ± 0.02
	F	0.24 ± 0.03	0.084 ± 0.008	0.53 ± 0.05	0.27 ± 0.01	0.29 ± 0.01
1990	M	0.20 ± 0.05	0.044 ± 0.006	0.45 ± 0.03	0.21 ± 0.02	0.29 ± 0.02
	F	0.15 ± 0.02	0.058 ± 0.006	0.46 ± 0.02	0.23 ± 0.01	0.28 ± 0.01
1993	M	0.35 ± 0.06	0.150 ± 0.018	0.84 ± 0.05	0.26 ± 0.02	0.37 ± 0.03
	F	0.39 ± 0.04	0.116 ± 0.008	0.66 ± 0.03	0.29 ± 0.02	0.30 ± 0.02
1994	M	0.57 ± 0.09	0.160 ± 0.026	0.77 ± 0.08	0.29 ± 0.02	0.53 ± 0.05
	F	0.52 ± 0.05	0.107 ± 0.007	0.59 ± 0.03	0.20 ± 0.01	0.48 ± 0.02

* Mass of raw product. Real consumption is less by 20–30%.

TABLE I-LI. PERCENT OF ADULT RURAL INHABITANTS OF THE TEST REGION CONSUMING LOCAL FISH BEFORE AND AFTER THE CHERNOBYL ACCIDENT

Time	Sex	Number	No (%)	Yes (%)
Before accident (total area)	Male	196	54	46
	Female	390	60	40
1986–87 (Controlled Area)	Male	83	86	14
	Female	165	92	8
1986–87 (Observed Area)	Male	102	56	44
	Female	198	55	45
1990 (total area)	Male	110	86	14
	Female	300	89	11
1993 (total area)	Male	71	61	39
	Female	141	75	25
1994 (Controlled Area)	Male	76	59	41
	Female	112	78	22
1995 (settlement Voronok)	Male	40	58	42
	Female	86	62	38

TABLE I-LII. PERCENT OF ADULT RURAL INHABITANTS OF THE TEST REGION CONSUMING MUSHROOMS BEFORE AND AFTER THE CHERNOBYL ACCIDENT

Territories	Sex	Number	No (%)	Yes (%)
Before accident (total area)	Male	195	30	70
	Female	391	29	71
1986–87 (Controlled Area)	Male	83	52	48
	Female	165	57	43
1986–87 (Observed Area)	Male	102	54	46
	Female	198	50	50
Settlement Korchi, 1994	Male	22	27	73
	Female	21	57	43
Settlement Shelomii, 1994	Male	38	32	68
	Female	53	38	62
Settlement Gordeevka, 1994	Male	67	30	70
	Female	34	20	80
Settlement Voronok, 1995	Male	58	16	84
	Female	103	19	81

TABLE I-LIII. PROVISIONAL LIMITS FOR RADIONUCLIDE CONCENTRATIONS IN FOODSTUFFS AND DRINKING WATER IN THE CHERNOBYL-AFFECTED AREAS, Bq kg^{-1}

	30.05.86	10.06.88	22.01.91	1993
Foodstuffs	total beta-activity	$^{137}Cs + ^{134}Cs$	^{137}Cs	^{137}Cs
Drinking water	370	18.5	18.5	-
Milk	370* (since 1.08.86)	370	370	370
Cheese	7,400	370	370	370
Butter	7,400	1,110	370	
Condensed milk	18,500	1,110	1,110	
Meat and fish products	3,700	1,850	740	600
Eggs	1,850 per one egg	1,850	740	-
	370			
Bread, cereals	1,850	370	370	370
Sugar	3,700	370	370	-
Vegetables,		740	590	-
fruit, juices	18,500			-
Mushrooms	3,700	1,850	1,480	600
Wild berries	-	1,850	1,480	600
Baby food		370	185	185

Note: * before August, 1986: 3,700 Bq L^{-1}.

TABLE I-LIV. EFFECTIVENESS OF AGROTECHNICAL COUNTERMEASURES

Agrotechnical countermeasures	Soil category	Grass as a crop type	Reduction in root uptake transfer
Rotary cultivation or disking	Soddy-podzolic sandy, sandy loam	Natural meadow	1.2–1.5
	Peaty		1.3–1.8
Ploughing	Soddy-podzolic sandy, sandy loam	Natural meadow	1.8–2.5
	Peaty		2.0–3.2
Ploughing with turnover of the upper layer	Soddy-podzolic sandy, sandy loam	Natural meadow	8.0–12.0
	Peaty		10.0–16.0
Radical improvement	Soddy-podzolic sandy, sandy loam	Natural meadow	2.7–5.3
		Perennial grasses	2.3–4.6
	Peaty	Natural meadow	2.9–6.2
		Perennial grasses	3.9–11.2
Superficial improvement	Soddy-podzolic sandy, sandy loam	Natural meadow	1.6–2.9
		Perennial grasses	1.3–1.8
	Peaty	Natural meadow	1.8–3.1
		Perennial grasses	1.5–2.7

TABLE I-LV. EFFECTIVENESS OF AGROCHEMICAL COUNTERMEASURES

Agrochemical countermeasures	Soil category	Crop type	Reduction in root uptake transfer
Liming	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	1.8–2.3
Application of increased doses of P-K fertilizers	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	1.2–2.2
Application of organic fertilizers	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	1.3–1.6
Application of clay minerals	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	Dubious effect, in light soils results mainly in 1.5–3.0 fold decrease of radionuclide accumulation by plants
Combined application of lime, organic and mineral fertilizers	Soddy-podzolic sandy, sandy loam	Barley, winter rye, oats, maize silage, potato, beet roots, vegetable	2.5–3.5

TABLE I-LVI. EFFECTIVENESS OF COUNTERMEASURES IN ANIMAL BREEDING (APPLICATION OF SORBENTS)

Type of treatment	Product	Dosage	Reduction factor
Ferrocine	Milk	3–6 g per day	3–5
	Meat(cows)	3–6 g per day	2–3
	Meat (sheep)	0.5–1 g per day	3–4
Boli ferrocine	Milk	2–3 boli per 3 month	2–3
Bifege ferrocine	Milk	40 g per day	2–4

TABLE I-LVII. EFFECTIVENESS OF FOOD PROCESSING OPTIONS

Row product	Type of processing	Reduction (Bq kg^{-1} per Bq kg^{-1})
Milk	Milk to butter	2.5–15
	Milk to cheese	0.4–2
	Milk to cream	0.5–1.7
	Milk to skimmed milk	1.0–1.1
Meat	Soaking	1.4–2.0
	Salting	2.0–3.3

TABLES I-LVIII. EFFECTIVENESS OF VARIOUS COUNTERMEASURES IN AGRICULTURE

Groups of protective measures	Reduction factor	
	Range	Best estimates
Amelioration of meadows and pastures	2.5–8.0	3
Application of mineral fertilisers	1.2–2.5	1.5
Liming of acid soil	1.5–2.0	1.7
Technological processing of milk into butter	2.5–15	10
Application of Prussian blue	2–5	3
Crop selection according to ^{137}Cs accumulation	up to 4.5	3

TABLE I-LIX. AGROCHEMICAL MEASURES IN THE TEST AREA (NOVOZYBKOV DISTRICT, AGRICULTURAL AREAS), 1986–1989

Agrochemical Measures	1986	1987	1988	1989
Lime:				
area treated, km^2	271	206	108	105
application, kg m^{-2}	0.73	0.67	0.75	0.84
Phosphorite:				
area treated, km^2	92	100	51	52
application, kg m^{-2}	0.13	0.14	0.16	0.15
Mineral fertilizers (active matter), 10^6 kg:				
N	8.1	8.3	7.0	8.1
P	5.1	5.7	4.9	6.7
K	8.3	12.3	10.0	12.2
Total NPK:				
area treated, km^2	460	600	450	600
application, kg m^{-2}	0.033	0.031	0.034	0.034
Organic fertilizers				
area treated, km^2	169	128	145	145
application, kg m^{-2}	7.0	8.5	7.9	7.9

TABLE I-LX. RADICAL AMELIORATION OF NATURAL FORAGE LAND IN THE TEST AREA (NOVOZYBKOV DISTRICT, AGRICULTURAL AREA AGRO1), 1986–1990

Year	Cumulative percentage of re-cultivated haylands and pastures
1986	6.4
1987	14.0
1988	35.7
1989	64.6
1990	95.4

TABLE I-LXI. CONTRIBUTION OF AGRICULTURAL AND NATURAL PRODUCTS TO INTERNAL DOSE OF SHELOMY, %. (AVERAGE DATA FOR 1991–1995)

Cohort of habitants	Products				Internal dose, mSv (1995)
	Milk	Meat	Potato	Mushrooms	
Consuming private milk	55.3	16.0	4.8	21.0	0.97
Consuming milk from shop	7.8	18.0	9.2	60	0.34
All inhabitants	20	14.0	7.8	53	0.44

TABLE I-LXII. MEAN EFFECTIVENESS OF ANNUAL EXTERNAL DOSE REDUCTION FOR INHABITANTS OF THE VILLAGES DECONTAMINATED IN 1989

Population group	Outdoor workers	Indoor workers, Pensioners, and Schoolchildren	Pre-school children	Mixed * group
Dose reduction factor	1.2	1.3	1.4	1.3

* 40% outdoor workers, 20% indoor workers, 15% pensioners, 15% schoolchildren, 10% pre-school children.

I–2. DATA FOR MODEL TESTING AND COMPARISON

I–2.1. SAMPLING OF AGRICULTURAL AND ENVIRONMENTAL COMPONENTS

I–2.1.1. Soil sampling

I–2.1.1.1. Soil sampling on non-arable agricultural land

Soil samples were collected up to the moment of grass vegetation onset and during grass harvest. Prior to soil sampling, at the control site, the exposure dose rate of gamma radiation was measured at heights of 1 m and 3–4 cm above the ground. At the site, 5 points were selected with a frequently observed exposure dose rate of gamma-radiation, one next to the center and the rest at its periphery. Sampling at control sites was carried out with a standard ring 5 cm in height and 14 cm in diameter or a sampler 10 cm in height and 11–14 cm in diameter.

I–2.1.1.2. Sampling on arable agricultural land

Soil samples on arable land were collected prior to the beginning of spring field work and just before harvesting. Prior to soil sampling, at the control site, the exposure dose rate of gamma radiation was measured at heights of 1 m and 3–4 cm above the ground. Each sample collected at the control site was made of 10 or more individual samples, uniformly taken throughout the whole area of the site. When a coring tube was used for sampling, the number of pricks depended on the diameter of its operating part. All samples were then bulked, and a combined soil sample of no less than 2 kg in weight was compiled by the quartering method. The sampling depth of individual samplers was required to correspond to the depth of the arable layer (depth of basic soil cultivation). Recommended standards for sample number are summarized in Table I-LXIII.

TABLE I-LXIII. RECOMMENDED STANDARDS FOR COLLECTING MIXED SAMPLES

^{137}Cs density of contamination, kBq m^{-2}	Maximum area to obtain a combined sample
<37	5 samples per administrative district
37–185	1 sample per elementary site*
185–555	1 sample per 400 ha
555–1480	1 sample per 100 ha
>1480	1 sample per 50 ha

* An elementary site is a field occupied by one crop.

I–2.1.2. Collection of plants and plant product samples

I–2.1.2.1. Plant sampling at control sites

For sampling at control sites, it is essential that plant sampling be done in conjunction with soil sampling, i.e., both plant and soil samples are collected at the same site and time. Plant samples were collected at harvest time. For a combined plant sample of no less than 1 kg in weight, no fewer than 10 point (individual) samplings are recommended. The above ground part of plants was cut at a height of 3–4 cm, without soil loading. The samples were placed on plastic film or paper. A combined sample is made of either the entire plant or separate parts, e.g., stems, leaves, fruit, grain, roots. The weight of a combined sample depends on the crop species.

I–2.1.2.2. Grain sampling

Grain sampling from a lorry was performed with a mechanical sampler or by hand with a probe. The number of sampling points depends on the body length of the lorry and amounts to 4–8 samples. Samples were collected at a distance of 0.5–1 m from the front and rear of the lorry and 0.5 m from the sides of the lorry. Point samples with a mechanical sampler were taken throughout the whole depth of the grain bulk. Point samples with a hand probe were taken from the upper and lower layers. In lorry trains, samples were collected from each trailer. The overall weight of the averaged sample was no less than 1–2 kg. Samples from loading or unloading of grain into vans, ships, warehouses and elevators were collected from the grain stream at the point of the drop with a mechanical sampler or special cup by crossing the stream at regular intervals during the whole period of lot movement. The weight of one point sample was no less than 100 g. Point sampling of grain from bags depended on the number of bags in a lot, from each second bag to each tenth. From sewn bags, point samples were taken by bag probe at three accessible points. A combined sample is a set of point samples. The total weight of point samples was no less than 2 kg.

I–2.1.2.3. Sampling of roots, tubers and potatoes

Samples of tubers and roots were collected from piles, bulks, heaps, lorries, trailers, vans, barges, storage facilities, etc. Point samples were taken along the diagonal of the site surface of a pile, bulk, or heap, or the central line of the body of a lorry, trailer, van, etc., at regular intervals at a depth of 20–30 cm. Tubers and roots were collected at three consecutive points (arbitrarily) by hand. Each point sample was 1–1.5 kg in weight. Combining the point samples yielded a combined sample. Of the latter, an averaged sample no less than 2 kg in weight was taken for analyses, with a preliminary sorting of roots and tubers by size.

I–2.1.3. Sampling of fodder for farm animals

Fodder sampling was carried out at sites of its growing, production, storing or animal feeding. The weights (volumes) of average samples for radiological studies necessary to ensure that the error was no more than ± 50% are listed in Table I-LXIV and I-LXV.

I–2.1.3.1. Grass and green mass of farm crops

Grass samples from pastures or haylands were collected immediately before pasturing of animals or harvesting for fodder. To this end, at the site selected for sampling, 8 to 10 registration plots were identified, about 1 or 2 m^2 in size. Point samples were collected along the diagonal of a square 100 m on each side at a rate of 10–12 samples, each 0.4–0.5 kg in weight. The grass stand was harvested (cut) at a 3–5 cm height. The point samples were bulked and mixed.

From the green mass delivered for livestock feeding or for making silage and haylage, or from dried fodder, no fewer than 10–15 samples were taken from different points. The weight of a point sample was 0.4–0.5 kg. The point samples were mixed, and arranged into an even layer, and then average samples were collected by means of quartering.

TABLE I-LXIV. WEIGHTS OR VOLUMES OF SAMPLES NECESSARY FOR VARIOUS MEASURING TECHNIQUES

Technique to determine specific activity (A_{sp})	Ranges of A_{sp} of controlled products, Bq kg^{-1}	
	0.037–18.5	Above 18.5
^{137}Cs gamma-radiometry express-method		0.5–1.0 L or kg
^{137}Cs gamma-spectrometry		
a – native material	1.0 L or kg	0.3–0.5 L or kg
b – ash residue	1.0–3.0 L or kg	
Radiochemical method and others	0.2–3.0 L or kg	0.2–0.5 L or kg

TABLE I-LXV. SAMPLING RATES FOR FODDER (ROUGH, SUCCULENT, CONCENTRATES, ROOT-TUBER) BY LOT SIZE

Lot weight, t	Number of samples
Below 5.0	1
5.1–10.0	2
10.1–15.0	3
15.1–20.0	5
20.1–50.0	7
50.1–80.0	9
80.1–100.0	10
101–10000	1 extra sample per each 100 t above 100 t
Above 10000	1 extra sample per each 200 t

I–2.1.3.2. Rough fodder (hay, straw)

Point samples from hay or straw lots stored in stacks and ricks were collected along the perimeter at equal intervals at a height of 1–1.5 m above the ground on all accessible sides at a depth of no less than 0.5 m. Point samples were bulked to produce a combined sample of 2 kg in weight. For this purpose, point samples were arranged in an even layer (3–4 cm) on a tarpaulin and carefully mixed to exclude plant breaking and plant dust formation. An average sample was then taken for analysis from the combined sample. To this end, wisps of hay 60–120 g in weight were collected from no fewer than 10 sites across the whole width and length of the layer. An average 1 kg sample was packed into a sturdy paper or plastic bag.

For sampling of fodder from pressed bales (rolls), the following samples were taken: from a lot up to 15 tons, 3% of the bales; above 15 tons, 1%. Point samples of 0.2–0.3 kg were taken from each bale (roll) from different strata and then arranged on a tarpaulin, where they were mixed and an average sample was isolated.

I–2.1.3.3. Silage, haylage

Samples were collected no sooner than 4 weeks after making. Point samples from trenches and towers were collected by a sampler at a depth of 2 m and carefully mixed. An average sample was taken from a combined one by a square method.

I–2.1.3.4. Roots, tubers

Sampling was performed from fields, piles, warehouses, storages, lorries, etc. From a packed lot (bags, boxes, etc.), a sample consisted of 2.5% of the packages, but no fewer than 3; from piles, bulk point samples were taken from different layers, 10–15 each, and along the perimeter. These were then mixed to yield an average sample from the combined sample.

I–2.1.3.5. Concentrates (mixed feed, grain fodder, oilcake, etc.)

Samples were collected by a scoop or cone probe in staggered order from different layers. When samples were taken from bags, 3 to 5.5 package units were sampled. Point samples were collected from each sampling unit at 3 points. These were then combined and carefully mixed, and average samples were obtained by quartering.

I–2.1.4. Sampling of animal products

I–2.1.4.1. Milk and liquid milk and sour milk products

Sampling of milk and of liquid milk and sour milk products was performed at sites of their production, processing, storage, or sale. Prior to sampling, milk was carefully mixed for 1 to 20 min, depending on the reservoir volume. Point samples from different points of the reservoir were taken with a mug, scooper (0.5 L capacity), or metal (or plastic) tube with an inner diameter of 10 mm. The same number of samples (no less than 3), was taken from each reservoir. Pouring the point samples taken from one reservoir together yielded a combined sample. After mixing, an average sample of a required volume was collected and sent to the laboratory for examination.

I–2.1.4.2. Sour cream, cottage cheese and curds

In sampling of sour cream, cottage cheese or curds packed in large or transportation containers, 10% of the containers were opened and sampled as controls. When fewer than 10 units were available, one was opened. Depending on the consistency of the sour cream, sampling was carried out by a scooper, probe or tube, dipped to the container bottom. Point samples were combined into one clean reservoir, carefully mixed (if needed, by heating to 35ºC). Then an average sample was taken.

I–2.1.4.3. Meat, meat products

Samples of meat and meat products were collected from farms, markets, meat packing plants and cold stores. In meat packing plants and cold stores, sampling from each homogeneous lot included 10% of the carcasses (half-carcasses) of cattle, 5% of the carcasses of sheep and pigs, or 25 frozen or cooled blocks of meat and products, but no fewer than 3. Point samples were taken from each sample carcass or its part as a whole piece of meat of 200 g in weight.

A combined sample was derived from the point samples. The weight of the combined sample depended on the specific activity of the samples and the examination procedure. To form an average 0.2–0.3 kg sample, meat was cut into small pieces (10–15 g) with a knife or minced and then mixed.

I–2.1.5. Sampling of aquatic components

Standard methods were applied for sampling of water and other aquatic objects (Makhonko, 1990). Most of the water samples were collected in the near-surface water layers at a depth of 0.2–0.6 m. Water was passed through fine-pore filters to separate suspended particles larger than 10^{-6} m in size. Upon completion of the filtration, the filters were slightly dried, placed in sealed porcelain crucibles and incinerated in a muffle furnace at a temperature of 400–500^{o}C. The filtered water samples were passed through ion-exchange resin columns with a grain size of 0.5–1 mm. Then the resins removed from the columns were packed in measuring containers for spectrometric analysis.

Samples of bottom sediments were collected using special samplers of two types designed and manufactured at SPA “Typhoon”, and a pneumatic sampler. The collected samples were analyzed in layers of a thickness of 1–2 cm each. The first type of sampler was a duralumin tube, 12 cm in diameter and 70 cm long. The sampler was pressed into the bottom sediment layer at the sampling site. Then the cores were treated in one of two ways, depending on the porosity of bottom sediments. At sufficiently small porosity, the bag with a core was removed from the tube and the core was separated with a knife into layers of the required thickness, which were further treated as individual samples. At large porosity (liquid bottom sediments), the core was separated into layers directly in the duralumin tube, beginning from the top and using a special spoon. Then the core layers were weighed and packed in plastic bags. After that, the samples were dried in the air or in a drying chamber at a temperature of no more than 100°C, weighed again, and packed in standard containers for spectrometric analysis.

The second type of sampler was a duralumin tube, 8.3 cm in diameter and up to 50 cm in length, attached to a rod. After sampling, the core was squeezed out with a piston and separated into layers. Then the samples were treated as with the first type of sampler. From the wet and dry weights of samples and the volume of wet samples, it was possible to determine the density of bottom sediment particles and their porosity. The error in the determination of

^{137}Cs concentrations by layers of bottom sediments includes errors of gamma-quantum count statistics and gamma spectrometer calibration, as well as errors in the determination of layer thickness (occurring in core separation into layers) and wet weight.

Fish samples were collected from the Iput River and from lakes. Preliminary preparation included determination of the species of a fish, measurement of its weight and length, and sampling of its muscles. The preparation of a sample for measurement of ^{137}Cs consisted in the preliminary concentrating of the sample by incineration or by acid decomposition of the organic component of the sample.

I–2.2. RADIOCESIUM MEASUREMENTS

I–2.2.1. Agricultural sample measurement

The measurements of agricultural production samples were carried out by the local authorities belonging to the system of Radiation Control of the Russian Ministry of Agricultural Production and the Russian Institute of Agricultural Radiology and Agroecology (RIARAE). The specific activity of radiocesium in samples was determined by standard methods established by the Ministry of Agricultural Production of the Russian Federation. Several different techniques were used for measurements: semiconductor and scintillation gamma spectrometry, and scintillation gamma radiometry; the measurement error was ± 15%. However, all sampling and measuring techniques were adopted by the organizations, which are responsible for measurement quality control and have the appropriate certificates. The specification of the detection blocks used for measurements is given in Table I-LXVI.

In RIARAE, the specific activity of ^{137}Cs in samples was measured by Canberra γ-spectrometers with a superpure Ge-Li detector, measurement error being ± 10%. The quality of measurements provided by RIARAE was tested in the frame of the intercalibration procedure of the International Chernobyl Project. The intercalibration of results between the Russian authorities responsible for measurements of agricultural production and RIARAE was performed in 1991–1994. The results of measurements provided by the Ministry of Agricultural Production of the Russian Federation were analysed and adopted for official application by an Interministry commission which is responsible for the evaluation of the radiological situation in the territories of Russia subjected to contamination.

I–2.2.1.1. Estimation of ^{137}Cs concentrations in different species of mushrooms and berries

Data obtained at 15 stationary forest sites were used for the estimation of ^{137}Cs concentrations in different species of mushrooms and berries. The average ^{137}Cs contamination density of these sites differs from the average contamination density of forests located in the test area. Therefore, a two-step approach was applied for estimating the contamination of forest products for the whole test area. In the first stage, aggregated transfer factors values (T_{ag}) from soil to different species of berries or mushrooms were calculated as a ratio of the ^{137}Cs concentration (fresh mass) of berries or mushrooms (Bq kg^{-1}) to its deposition density on the soil-vegetation cover (kBq m^{-2}). In the second stage, the ^{137}Cs concentration in each species of berries and mushrooms was recalculated for the whole territory of the test area taking into account the deviation of individual T_{ag} values and the contamination of forests.

TABLE I-LXVI. SPECIFICATIONS OF DETECTION BLOCKS FOR MEASUREMENT TECHNIQUES

Registration technique	Energy range of radiation to be registered, MeV	Activity range of samples measured, Bq	Measurement geometry, sample dimension
Semiconductor and scintillation gamma spectrometry	0.05–3.0	$0.5–10^5$	Marinelly vessel 0.5 L; 1 L
Scintillation gamma radiometry	0.05–3.0	$0.5–10^5$	Marinelly vessel 0.5 L; 1 L; Petri dish 100 mm

I–2.2.2. Environmental sample measurement

The activity of radiocaesium in environmental samples was determined by standard gamma-spectrometric methods with lead protection, using highly sensitive semiconductor detectors and multichannel pulse analyzers (Makhonko, 1990; Kryshev, 1996). Gamma-spectrometric analysis was performed using a Canberra 35+ type spectrometer equipped with a 7229P-type detector with an effective volume of 180 cm^3, and multichannel pulse analysers of the NOKIA LP-4900 type with semiconductor detectors with volumes of 60 cm^3 and 80 cm^3. Measuring errors did not exceed 20% for water, and 10% for bottom sediments and fish. Measurements of ^{137}Cs taken in the laboratories were subjected to intercalibration within the framework of the International Chernobyl Project.

I–2.3. EXPOSURE MEASUREMENTS

I–2.3.1. External exposure

I–2.3.1.1. Effective external dose from deposited radionuclides

After the Chernobyl accident, individual external doses to members of the population were measured with TL-dosimeters distributed to the inhabitants of the most contaminated areas of Russia, including the test area. The measurements were performed with dosimeters based on TL-detectors of type DTG-4 (LiF:Mg,Ti; monocrystals 5 mm in diameter and 0.9 mm thick), produced by the Institute of Geochemistry, Irkutsk, Russia. Each dosimeter consists of two chips. The thickness of the plastic holder walls of the dosimeter corresponds to a surface density thickness of 1 g cm^{-2}. A Harshaw 2000-D reader was used to determine doses absorbed by the detectors. The detectors were calibrated in conditions of free-air geometry by gamma radiation with a reference source of ^{137}Cs at the St. Petersburg Centre of Metrology, Russia. The basic relative error of a reading did not exceed ± 15% per detector at the 95% confidence level. The detection limit, defined as the smallest value of dose that can be detected at a specified (95%) confidence level, was determined to be 30 μGy. The conversion factor c_i from readings of an individual dosimeter to the value of the effective dose was determined on the basis of irradiation experiments with physical anthropomorphic phantoms. Values of c_i were 0.9 Sv Gy^{-1} for adults.

TL-dosimeters were distributed with the help of the local administration to inhabitants of the contaminated area during the spring/summer time. They were used for a period of approximately one month (25–35 days). Corresponding doses per month were calculated by a simple time scaling. The inhabitants were instructed to wear the dosimeters all the time in a pocket or by a string around the neck. When a dosimeter was assigned, basic information on the person was registered, including name, age, sex, occupation, material of construction of the inhabitant's house (wood or brick), and number of stories. The TL signals accumulated during transport and storage before and after use were estimated with the help of control dosimeters, and subtracted from the total reading. Both the terrestrial and cosmic background radiation contributions were subtracted from the results of measurements. In accordance with the goals of the present work, we also subtracted from the dosimeter readings the contribution of ^{134}Cs gamma radiation in the dose. This contribution was assessed on the basis of the ratio of activities ^{134}Cs/^{137}Cs at the time of measurement (at the time of deposition, 28.04.1986, the ratio ^{134}A/^{137}A was 0.54).

Measurements of individual doses in the test area (the Novozybkov district of the Bryansk region) started in December 1986 and continued during all of 1987 by several series of 3 to 4 months each. Later, measurements were performed episodically during one month in different seasons of the year. The measurements were performed in the following rural settlements of the Novozybkov district (in parentheses, the soil contamination density with ^{137}Cs as of 28.04.1986 is given, MBq m^{-2}): Vereshaki (0.7); Svyatsk (1.49); Stary Vyshkov (1.47); VIUA (1.05); Novoye Mesto (1.04); Vnukovichi (0.71); Starye Bobovichi (1.04). During 1987, 215 measurements of individual doses were performed, during 1989 (May) 90 measurements, during 1991 (October) 105 measurements, and during 1992 (November) 259 measurements.

The measurement results for the indicated groups of the adult population during each time period were normalised for the soil contamination density (MBq m^{-2}) and were weighted in accordance with the composition of these groups in the representative sample for the investigated region. The obtained distribution of individual doses was approximated by the lognormal distribution and checked by means of Kolmogorov-Smirnov and ChI-Square tests. Table I-LXVII presents the parameters of the distributions obtained for measured individual external doses. Table I-LXVIII gives the corresponding results, taking into account the variability of the soil contamination density in the investigated region (see Dose calculations, Section I–2.4.1).

TABLE I-LXVII. PARAMETERS OF INDIVIDUAL EXTERNAL DOSE DISTRIBUTION FOR A REFERENCE SAMPLE OF POPULATION IN THE INVESTIGATED REGION ACCORDING TO THE TL-MEASUREMENTS (NORMALIZED TO ^{137} Cs SOIL DEPOSITION OF 1 MBq m^{-2})

Time	Duration	Geom. mean	Geom. st. dev.	Arithmetic mean ± SE.	St. dev.	Percentiles, mSv			
	months	mSv		mSv	mSv	2.5%	5%	95%	97.5%
December 1986–December 1987	12	2.23	1.36	2.34 ± 0.17	0.730	1.21	1.34	3.70	4.12
May 1989	1	0.200	1.34	0.208 ± 0.012	0.063	0.111	0.123	0.324	0.359
October 1991	1	0.132	1.44	0.141 ± 0.013	0.053	0.064	0.072	0.241	0.274
November 1992	1	0.094	1.43	0.100 ± 0.006	0.037	0.046	0.052	0.170	0.192

TABLE I-LXVIII. PARAMETERS OF INDIVIDUAL EXTERNAL DOSE DISTRIBUTION FOR A REFERENCE SAMPLE OF POPULATION IN THE INVESTIGATED REGION ACCORDING TO THE TL-MEASUREMENTS

Time	Duration	Geom. mean	Geom. st. dev.	Arithmetic mean ± SE	St. dev.	Percentiles, mSv			
	months	mSv		mSv	mSv	2.5%	5%	95%	97.5%
December 1986–December 1987	12	1.59	1.71	1.84 ± 0.19	1.02	0.54	0.66	3.85	4.65
May 1989	1	0.142	1.69	0.163 ± 0.015	0.084	0.050	0.060	0.338	0.406
October 1991	1	0.094	1.77	0.111 ± 0.013	0.069	0.030	0.037	0.241	0.294
November 1992	1	0.067	1.76	0.079 ± 0.007	0.048	0.022	0.026	0.170	0.208

I–2.3.2. Internal exposure

I–2.3.2.1. Whole body measurement technique

In 1986–88, on-site measurements of the internal content of cesium radionuclides in the body of inhabitants were performed mainly by means of scintillation radiometers SRP-68-01 produced in the USSR. Also, single-channel radiometers RFT-20046 (Robotron 20046) produced in the GDR with NaI(Tl) crystals 25 x 25 or 40 x 40 mm in size were applied. After 1988, the RFT radiometers were equipped with BDEG-type detectors produced in Russia and NaI(Tl) crystals 63 x 63 mm in size, to increase their sensitivity. Calibration factors and techniques for measurements with these devices were developed at the Leningrad Institute of Radiation Hygiene.

To perform whole body measurements at contaminated areas, premises were chosen with a low background level, usually multi-storey brick buildings. Measuring devices and the persons to be investigated were located in the place most remote from windows. Before the beginning of measurements, the background level (P_b, μR/hour or pulse/sec) was determined in the place where measurements of persons were performed.

Two variants of the measurement technique were used:

(a) The investigated person sat on a chair and put his or her feet on a support about 20 cm high. The radiometer detector was put next to the lower part of the stomach. The investigated person bent, enveloping the detector with his or her body and holding it with his or her hands. The measurement time was 30 s if the arrow indicator of the SRP-68-01 device was used, or 100 s, if the device worked with pulse recording.

(b) When investigating persons who had difficulties in bending (children below 3 years, pregnant women, obese and ill persons), the detection unit was put next to the loins of a standing person.

The content of cesium radionuclides in the bodies of inhabitants was calculated in accordance with the official technique developed during the first months after the Chernobyl accident:

$$A = K * T * (P - K_s * P_b)$$

where A is the content of caesium radionuclides in the body of the investigated person, µCi;
K is the calibration factor, µCi/(cm*µR/hour) for SRP-68-01 and µCi/(cm*pulse/sec) for Robotron 20046 device;
T is the waist length, cm;
P is the device reading of the measurement of the person, µR/hour or pulse/sec;
P_b is the average value of the device background, µR/hour or pulse/sec;
K_s is the shielding factor of the external background by the body of the person (unitless). In the position "standing," K_s is 0.9, and in the position "sitting bending," K_s depends on the body mass:

$K_s = 0.9$ at $M \leq 10$ kg;
$K_s = 0.85$ at 10 kg $< M \leq$ 30 kg;
$K_s = 0.8$ at 30 kg $< M \leq$ 60 kg;
$K_s = 0.7$ at Ì > 60 kg.

The calibration factors for different devices were obtained by means of measurements of metrologically certified whole body phantoms and of volunteers (Table I-LXIX).

Since 1992, a whole body counter of the SEG-04T model (Russia) mounted in a mobile radiometric laboratory based on a Mercedes minibus was used for radiometric investigations in the population. The technique of measurements with SEG-04T devices, in the geometry of the armchair, was certified at the Mendeleev Research Institute of Metrology at the stage of producing the devices. The technique was repeatedly calibrated by means of the certified anthropomorphic whole body phantom UF-02T produced in Russia. The design of this polyethylene phantom carrying rod radionuclide sources permits simulation of a human body with a mass from 10 to 110 kg. The devices and techniques used for large scale whole body measurements of the population permit detection of the cesium radionuclide activity with a measurement error not greater than 30% at the minimum detectable activity of ^{137}Cs, 0.03–0.05 µCi (1100–1850 Bq).

I–2.3.2.2. Whole body measurement data

Results of whole body measurements of ^{137}Cs in men and women are provided in Tables I-LXX to I-LXXIV, for both the controlled and non-controlled (observed) areas. Figures I-6 to I-9 show the dynamics of ^{137} Cs specific activity in the whole body (men and women) of the test area.

TABLE I-LXIX. CALIBRATION FACTORS FOR WHOLE BODY COUNTING

Position of the investigated person	SRP-68-01, µCi/(cm*µR/h)	Robotron with NaI(Tl) 25x25 mm, µCi/(cm*cps)	Robotron with NaI(Tl) 40x40 mm, µCi/(cm*cps)	Robotron with NaI(Tl) 63x63 mm, µCi/(cm*cps)
"Sitting bending"	0.0005	0.0024	0.00058	0.00019
"Standing" or "sitting straight"	0.00125	0.0038	0.0010	0.0003

TABLE I-LXX. SPECIFIC ACTIVITY OF ^{137}Cs IN THE WHOLE BODY OF ADULT MEN LIVING IN THE CONTROLLED AREA, NORMALIZED TO ^{137}Cs SOIL DEPOSITION OF 1 MBq m^{-2} (Bq kg^{-1} m^{2} MBq^{-1})

Date of measurement	Number of persons	Arithm. mean	Stand. deviation	Stand. Error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	1215	2060	2850	82	153	220	1210	6650	9540
15.03.87	45	525	434	65	95	123	404	1330	1710
15.09.87	43	385	317	48	70	90	297	974	1250
15.10.90	34	295	390	67	24	34	179	936	1330
15.09.91	87	198	174	19	33	43	148	518	675
15.03.92	17	175	128	31	38	48	141	416	524
01.06.92	78	102	90	10	17	22	76	267	349
15.09.92	26	307	707	139	8	13	122	1150	1850
15.09.93	37	580	1780	293	8	14	179	2250	3840
15.09.94	35	314	302	51	45	59	226	859	1140
15.09.95	13	292	365	101	26	37	182	903	1270
15.09.96	22	180	159	34	29	38	134	471	615
15.09.97	21	315	196	43	85	104	267	687	840
18.09.98	32	579	530	94	90	118	427	1550	2030

TABLE I-LXXI. SPECIFIC ACTIVITY OF ^{137}Cs IN THE WHOLE BODY OF ADULT MEN LIVING IN THE OBSERVED AREA, NORMALIZED TO ^{137}Cs SOIL DEPOSITION OF 1 MBq m^{-2} (Bq kg^{-1} m^{2} MBq^{-1})

Date of measurement	Number of persons	Arithm. mean	Stand. deviation	Stand. error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	762	1850	1640	59	301	393	1380	4860	6350
15.03.87	119	972	499	46	329	390	865	1920	2270
15.09.87	13	1407	845	234	398	483	1210	3010	3660
15.09.97	15	442	465	120	54	74	305	1270	1710
18.09.98	20	1150	1500	335	96	136	702	3630	5140

TABLE I-LXXII. SPECIFIC ACTIVITY OF ^{137}Cs IN THE WHOLE BODY OF ADULT WOMEN LIVING IN THE CONTROLLED AREA, NORMALIZED TO ^{137}Cs SOIL DEPOSITION OF 1 MBq m^{-2} (Bq kg^{-1} m^{2} MBq^{-1})

Date of measurement	Number of persons	Arithm. mean	Stand. deviation	Stand. error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	1631	1890	2610	65	141	203	1110	6100	8750
15.03.87	71	445	320	38	99	125	362	1050	1320
15.09.87	46	299	263	39	49	64	225	783	1020
15.10.90	53	201	384	53	8	12	93	720	1110
15.03.91	17	119	125	30	15	20	82	341	460
15.09.91	143	111	107	9	16	21	80	304	404
15.03.92	62	96	82	10	16	21	73	247	321
01.06.92	140	72	57	5	14	18	57	179	228
15.09.93	21	346	667	146	13	20	159	1240	1920
15.09.94	17	199	219	53	22	31	133	582	796
15.09.95	13	158	179	50	17	23	105	469	644
15.09.97	19	135	127	29	20	26	98	366	483
18.09.98	18	350	619	146	16	24	172	1230	1870

TABLE I-LXXIII. SPECIFIC ACTIVITY OF ^{137}Cs IN THE WHOLE BODY OF ADULT WOMEN LIVING IN THE OBSERVED AREA, NORMALIZED TO ^{137}Cs SOIL DEPOSITION OF 1 MBq m^{-2} (Bq kg^{-1} m^{2} MBq^{-1})

Date of measurement	Number of persons	Arithm. mean	Stand. deviation	Stand. error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.09.86	870	1700	1560	53	259	341	1250	4550	5990
15.03.87	159	691	439	35	182	224	584	1520	1870
15.09.87	57	1310	793	105	367	446	1120	2820	3430
15.10.90	46	333	346	51	42	56	231	948	1280
15.09.97	41	209	236	37	23	31	138	618	848
18.09.98	61	851	1150	147	66	94	506	2720	3890

TABLE I-LXXIV. SPECIFIC ACTIVITY OF ^{137}Cs IN THE WHOLE BODY OF ADULT MEN AND WOMEN (IN TOTAL) LIVING IN THE CONTROLLED AREA, NORMALIZED TO ^{137}Cs SOIL DEPOSITION OF 1 MBq m^{-2} (Bq kg^{-1} m^{2} MBq^{-1})

Date of measurement	Number of persons	Arithm. mean	Stand. deviation	Stand. Error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.06.89	94	149	169	17	16	22	98	441	607
01.06.92	15	91	94	24	11	15	63	259	349
01.06.93	140	208	240	20	21	30	136	621	857
01.06.94	29	160	116	22	35	44	129	378	475

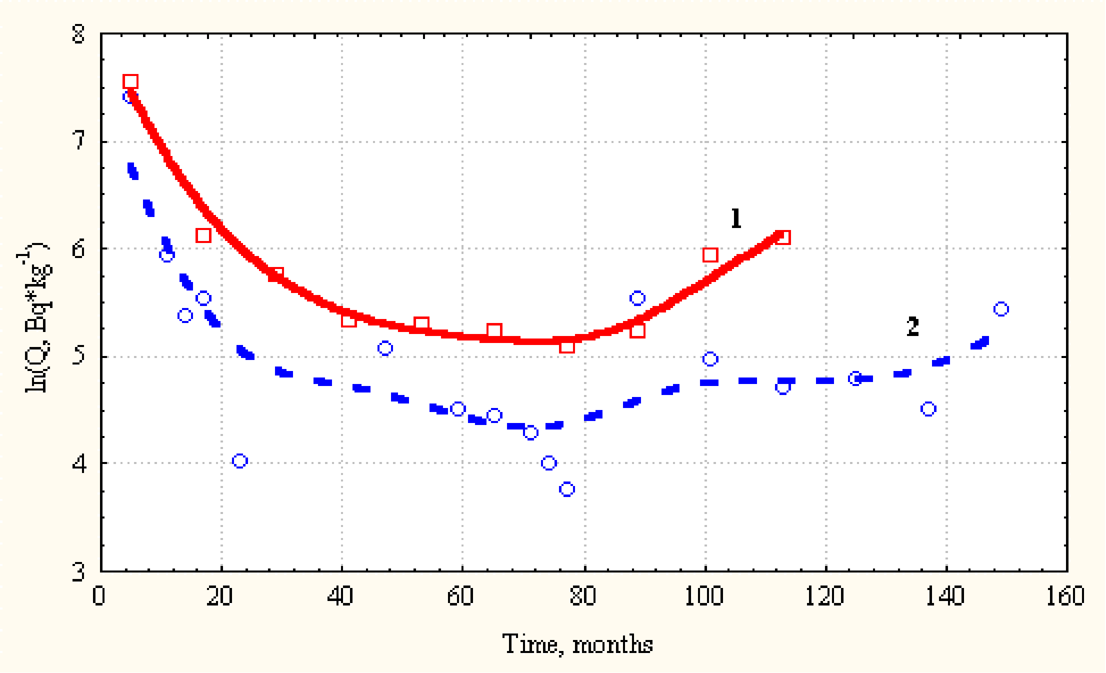

FIG. I-6. Specific activity of ^{137}Cs in the whole body of adult women living in the Controlled Area (1 – calculated, 2 – WBC measurements).

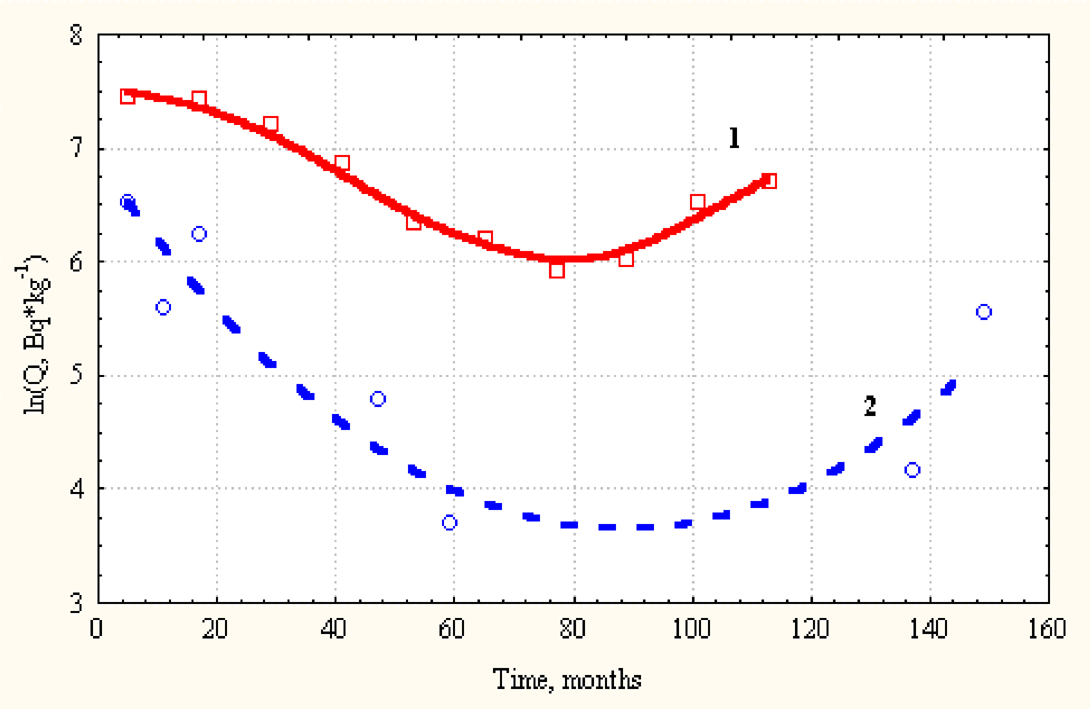

FIG. I-7. Specific activity of ^{137}Cs in the whole body of adult women living in the Observed Area (1 – calculated, 2 – WBC measurements).

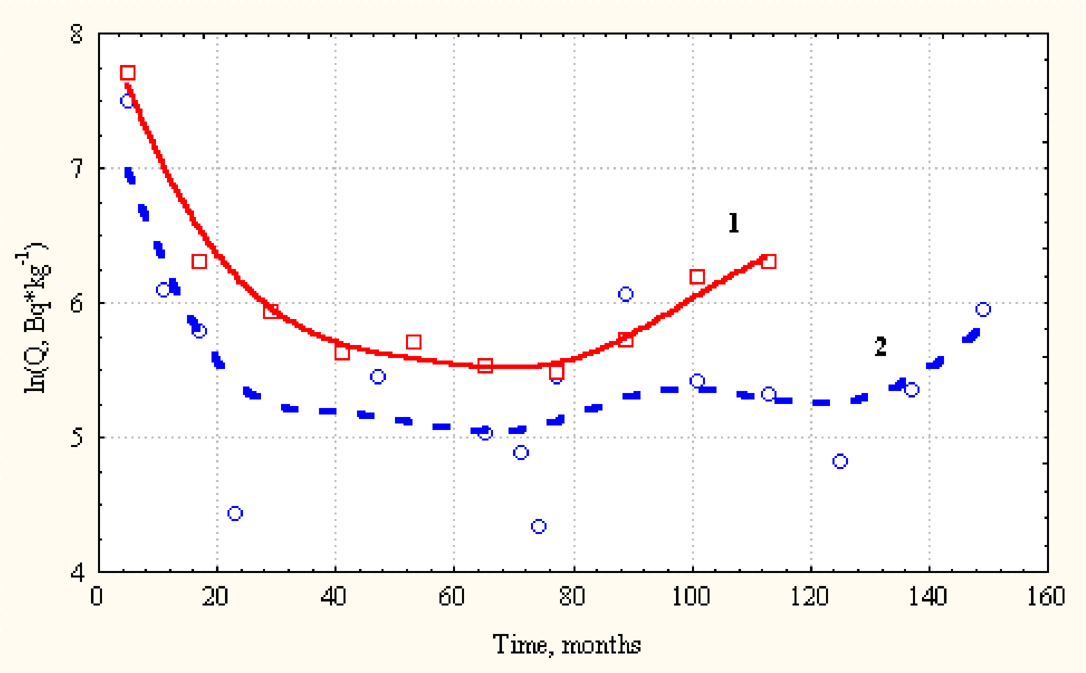

FIG. I-8. Mean specific activity of ^{137}Cs in the whole body of adult men living in the Controlled Area (1 – calculated, 2 – WBC measurements).

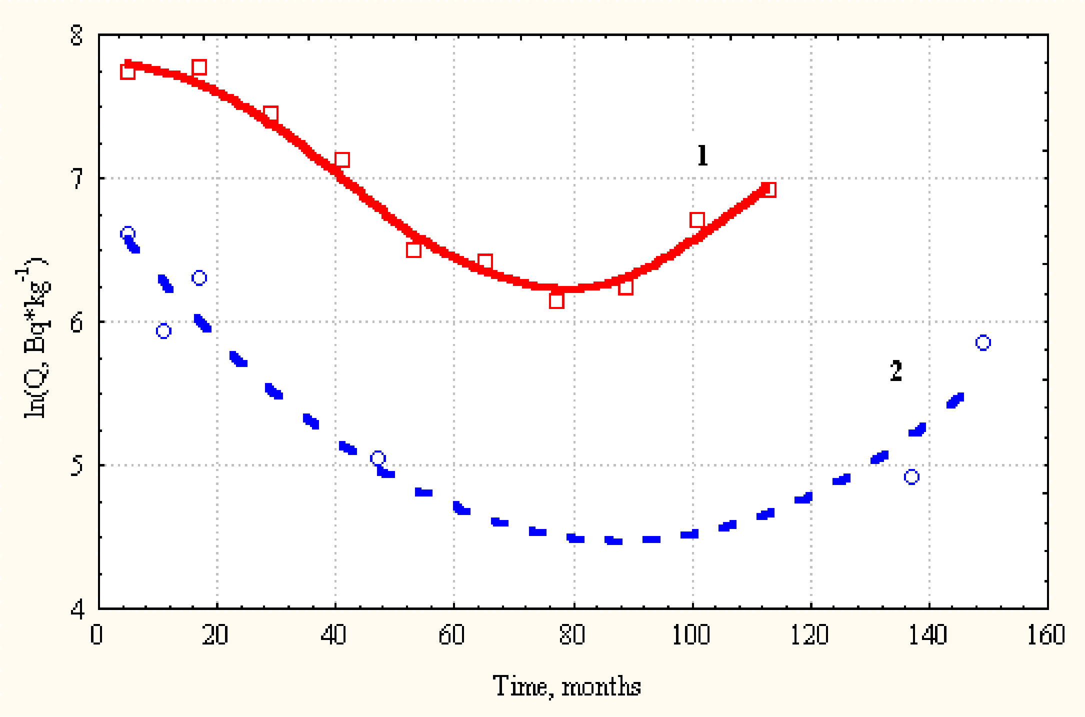

FIG. I-9. Specific activity of ^{137}Cs in the whole body of adult men living in the Observed Area (1 – calculated, 2 – WBC measurements).

I–2.4. DOSE CALCULATIONS

I–2.4.1. External exposure

I–2.4.1.1. Ground contamination

For the purpose of external dose assessment, the weighted average density A^{137}_{mean} of soil contamination with ^{137}Cs was calculated for the whole test area, as well as for “controlled” and “observed” parts of the test area:

$$A^{137}_{mean} = \frac{\sum_i N_i \cdot A^{137}_i}{\sum_i N_i} \quad , \quad \text{MBq m}^{-2} \qquad (1)$$

where N_i is the number of inhabitants in the I-th settlement; and A_i^{137} is the mean soil contamination density with ^{137}Cs in the I-th settlement, MBq m^{-2}. For the whole test area, A^{137}_{mean} is equal to 0.79 MBq m^{-2} ± 0. 06 MBq m^{-2} (mean ± st. error); for the “Controlled” area, A^{137}_{mean} is equal to 0.87 MBq m^{-2} ± 0. 06 MBq m^{-2}; for the “Observed” area, A^{137}_{mean} is equal to 0.40 MBq m^{-2} ± 0.04 MBq m^{-2}. To assess the distribution of the individual external doses in a population of 115 settlements of the test area, the distribution of A^{137}_{mean} was considered as a logarithmic one with the geometric mean equal to 0.71 MBq m^{-2} and a geometric standard deviation of 1.55. The appropriate arithmetic mean is 0.79 MBq m^{-2}, with a standard deviation of 0.36 MBq m^{-2}.

I–2.4.1.2. External dose model

Cloud exposure

The dose from an external exposure of the *I*-th population group E_i^{cloud} from a radioactive cloud was calculated according to the expression:

$$E_i^{cloud} = e_i^{cloud} \cdot (p_i^{out} + f^{cloud} \cdot (1 - p_i^{out})) \cdot \int_{t_0}^{t_e} C^{137}(t) \cdot dt \qquad (2)$$

where e_i^{cloud} = 9.3 x 10^{-11} (mSv m^3 h^{-1} mBq) is the dose factor; p_i^{out} = 0.55 (unitless) is a weighted average according to a composite of the population fraction of daily outdoor residence time during passage of the plume; f^{cloud} = 0.1 (unitless) is a weighted average according to the type of dwellings in the investigated region (value of location factor); and C^{137} = 6 x 10^4 ± 4 x 10^4 (2 st. err.) is the activity concentration (mBq m^{-3}) of ^{137}Cs in outdoor air (it is assumed to be constant during passage of the radioactive cloud).

Ground exposure

The model was developed earlier within the project JSP5 — Pathway Analysis and Dose Distributions (Jacob et al., 1996). The validation of the deterministic model predictions has been described in detail by Golikov et al. (1999). It consists of four sub-models for the following issues:

- absorbed dose rate in air at a reference site in the settlement;
- absorbed dose rate in air at various types of rural or urban locations relative to the reference site;
- occupancy times of different population groups at various types of locations; and
- conversion factor from absorbed dose rate in air to effective dose rate.

The first sub-model calculates the absorbed dose rate $d(t)$ in air at a height of 1 m above a virgin plot of soil, normally lawns or meadows (reference site). A plane source below a soil slab with a mass per unit area of 0.5 g cm^{-2} has been chosen as a reference distribution to approximate the energy and angular distribution of the radiation field in air over an undisturbed field during the first year after the deposition for wet deposition as occurred in the studied areas of Russia. The photon field in the model must approximate the real situation because the conversion factors k_i of the absorbed dose rate in air to the effective dose rate in sub-model 2 depend on these parameters.

Absorbed dose rates in air at rural or urban locations of type j are expressed by location factors f_j, defined as the ratio of the absorbed dose rate at such locations in a settlement to the absorbed dose rate above the reference site (Meckbach and Jacob, 1998).

The behaviour of man in the radiation field is described by means of occupancy factors p_{ij}, which are the fraction of time spent by representatives of the *I*-th population group at locations of type *j* in the settlement. The type of house where the people live (one-storey wooden or one-storey brick) is an additional parameter.

According to the model, the effective dose rate of representatives of the *I*-th population group $E_i(t)$ due to external exposure from deposited ^{137}Cs can be written in the following way:

$$\dot{E}_i(t) = \dot{d}(t) \cdot k_i \cdot \sum_j f_j \cdot p_{ij} \tag{3}$$

$$\dot{d}(t) = r(t) \cdot A^{137} \cdot \dot{d}_s \cdot \exp(-\lambda^{137} \cdot t) \tag{4}$$

where A^{137} is the activity per unit area of ^{137}Cs on a reference site at the time radioactive deposition ends; accordingly, $\dot{d}_s$ is the gamma dose rate in air per activity per unit area with a reference distribution of ^{137}Cs in the ground, and λ^{137} is the decay constant of ^{137}Cs. The function *r(t)* is the gamma dose rate in air at the reference site divided by the gamma dose rate in air for the reference distribution. Results of more than 300 measurements performed in the period 1986 to 1995 at sites with distances in the range of 100 to 1000 km from the Chernobyl reactor plant were fitted in the form:

$$\mathrm{r(t)} = \mathrm{p}_1 \cdot \exp\left(-\frac{\ln 2}{\mathrm{T}_1} \cdot \mathrm{t}\right) + \mathrm{p}_2 \cdot \exp\left(-\frac{\ln 2}{\mathrm{T}_2} \cdot \mathrm{t}\right) \tag{5}$$

The resulting parameter values were $p_1 = 0.60$, $p_2 = 0.63$, $T_1 = 1.5$ years, and $T_2 = 50$ years (Golikov et al., 1999). The effective dose of external exposure accumulated during any time interval is determined by integration of the effective dose rate $E_i(t)$ over the time of interest.

Numeric values for the model parameters given below have been derived mainly from measurements in the investigated region, located at a distance of 150 to 300 km from the Chernobyl NPP in the northeast part of the Chernobyl trace and subjected to the main radioactive contamination during the period from 28 April to 1 May 1986. Mean values of conversion factors k_i which convert the gamma dose rate in air to the effective dose rate in a member of the population of (age) group *i* were obtained for the three groups of the population using results of phantom experiments (Jacob et al., 1996) and Monte-Carlo calculations (Jacob et al., 1990). For adults, the conversion factor is 0.75 Sv Gy^{-1}. Seasonal average values of occupancy factors for three groups of the rural population, their main statistical parameters, and values for annual occupancy factors were given earlier (Section I–1.3). The values of location factors were assumed to be time-dependent according to the expression

$$_{j,Cs}(t) = a_1 \cdot \exp(-\ln 2 \cdot t/T) + a_2 \tag{6}$$

where *t* is the time elapsed since the moment of the accident (years), and a_1, T, and a_2 are the parameters. The values of parameters a_1, T, and a_2 for different locations are given in Table I-LXXV.

TABLE I-LXXV. VALUES OF PARAMETERS IN EXPRESSION (6)

Type of location (j)	a_1, unitless	a_2, unitless	T, years
Living area (indoors)			
1 st. wooden house	0.07	0.13	1.7
1 st. brick house	0.05	0.07	1.7
multi-storey house	0.01	0.02	1.7
Living area (outdoors)	0.25	0.55	1.7
Work area (indoors)	0.05	0.07	1.7
Work area (outdoors)	0.37	0.33	1.7
Ploughed field	0	0.5	-
Virgin land	0	1	-
Rest area	0	1	-

The statistical characteristics of the model parameters for rural environments were calculated on the basis of measurement data in different locations in a settlement and its vicinity (Golikov et al., 1999).

For the attenuation function *r(t)*, it is proposed to use a lognormal distribution for each year with geometric means as calculated according to formula (5) and a time-independent value of the geometric standard deviation, which is 1.2.

For the location factors, it is proposed to use a lognormal distribution with geometric means as calculated according to formula (6) and time-independent values of the geometric standard deviations. On the basis of the available data, the following geometric standard deviations were derived: outdoor, 1.4; 1-storey wooden/brick, 1.5; ploughed, 1.2; virgin, 1.0 [the distribution is taken into account in the attenuation function *r(t)*]. Location factors are obtained by dividing the gamma-dose rate at a given location by the gamma-dose rate above a reference site with the average ^{137}Cs activity per unit area in the settlement. Due to this construction, the variability of the location factors contains the variability of ^{137}Cs activity per unit area in the settlement. Accordingly, the model will express the full variability of gamma-dose rates in air at the various locations by calculating with average values for the ^{137}Cs activity per unit area in the settlement and distributions for the location factors.

The values of the conversion factors k_i which convert the gamma dose rate in air to the effective dose rate in a member of population (age) group *i* are assumed here to be normally distributed with a mean value of 0.75 Sv Gy^{-1} for adults and a relative standard deviation of 0.05.

Results of model predictions

Table I-LXXVI gives the calculated distributions of individual external doses for the adult population of the study area.

TABLE I-LXXVI. PARAMETERS OF THE INDIVIDUAL EXTERNAL DOSE DISTRIBUTIONS FOR THE ADULT POPULATION OF THE STUDY AREA, ACCORDING TO THE MODEL PREDICTION

Time period	Geom. Mean, mSv	Geom. st. dev.	Arithm. Mean, mSv	St. dev., mSv	Percentiles, mSv			
GROUND EXPOSURE					2.5%	5%	95%	97.5 %
28 April 1986–30 April 1987	3.06	1.64	3.46	1.82	1.14	1.35	6.92	8.23
28 April 1986–31 December 1990	10.0	1.73	11.6	6.86	3.33	4.03	24.6	29.8
28 April 1986–31 December 1995	15.2	1.70	17.5	9.88	5.26	6.34	36.5	44.0
28 April 1986–31 December 2036	33.6	1.67	38.3	21.0	12.0	14.4	78.2	93.7

I–2.4.2. Internal exposure

I–2.4.2.1. Internal dose model (ingestion)

Internal doses in the population are determined by the intake of ^{137}Cs into the body of inhabitants, mainly with food (especially with milk, meat, potatoes and forest mushrooms). The average effective internal dose to inhabitants in a settlement from ^{137}Cs radiation attributed to its intake with food during the time period Δt (days) is determined on the basis of the data about the ^{137}Cs content in local agricultural and natural food products and about typical food rations of the population during the same time period. The internal effective dose (E_{int}, mSv) was calculated with the formula:

$$E_{int} = dk_{137} \cdot I \cdot \Delta t \tag{7}$$

where $dk_{137} = 1.3 \times 10^{-5}$ mSv Bq^{-1} is the dose factor for intake of ^{137}Cs in food in the body of adults, according to ICRP Publication 67; and I, Bq day^{-1}, is the average *daily* intake of ^{137}Cs in the body of adult inhabitants of the settlement during the time period Δt.

The average daily intake (I, Bq day^{-1}) of ^{137}Cs in the body of adult inhabitants of a settlement was determined with the formula:

$$I = V_m \cdot C_m + V_p \cdot C_p + V_{pot} \cdot C_{pot} + 0.5 \cdot V_{mush} \cdot C_{mush} \tag{8}$$

where: V_m, V_p, V_{pot}, V_{mush}, kg (or L) day^{-1}, is the average daily consumption of milk, meat (pork, because the rural population in the test region consumes mainly pork), potatoes and mushrooms, respectively; C_m, C_p, C_{pot}, C_{mush}, Bq/kg (or L), is the average ^{137}Cs concentration or specific activity in milk, pork, potatoes and mushrooms of local origin, respectively; and 0.5, (unitless), is the average factor of ^{137}Cs losses after culinary processing of fresh mushrooms.

The dose predicted from 1995 until 2036 was calculated on the basis of the starting data of 1995, assuming that the decontamination half-period of the main food products from ^{137}Cs is 10 years.

Effectiveness of dietary changes in reduction of the internal dose

Available data on human diets in the test area before and after the Chernobyl accident permit the estimation of the effectiveness of internal (ingestion) dose reduction based on changes in the diet. In this case the effectiveness factor F is defined as ratio of a mean ingestion dose E_{ing0} estimated from the intake with an undisturbed food ration to the mean ingestion dose E_{ing} estimated from the intake with the food ration changed in order to reduce internal exposure:

$$F = E_{ing0} / E_{ing}\text{, rel. units.} \qquad (9)$$

The effectiveness factor F was calculated according to formula (9) for adults of both genders living in two areas under consideration (Controlled and Observed areas), and for different time periods after the radioactive contamination of the test area due to the Chernobyl accident. Tables I-LXXVII to I-LXXX present mean values of the effectiveness factor F where E_{ing0} are hypothetical mean ingestion doses, calculated with an undisturbed food ration, and E_{ing} are ingestion doses calculated with the food ration changed for protection purposes.

It should be noted that values of the factor F do not reflect the effectiveness of agricultural countermeasures applied, because the Iput Scenario does not contain separate data sets on ^{137}Cs concentrations in food produced with and without application of agricultural countermeasures. As expected, the effectiveness of population protection from internal exposure was higher in the “Controlled area,” where F is 2.3–2.4 during the first year after area contamination and 3.8–4.6 in subsequent periods, against 1.5–2.0 in the “Observed area” during the whole decade 1986–1995.

TABLE I-LXXVII. EFFECTIVENESS FACTOR F RESULTING FROM DIETARY CHANGES FOR WOMEN IN THE “CONTROLLED AREA”

Time period	Mean dose, mSv		Effectiveness factor
	E_{ing0}[a]	E_{ing}[b]	F, rel. units
27 April 1986–30 April 1987	10.19	4.44	2.3
27 April 1986–31 December 1990	29.01	6.29	4.6
27 April 1986–31 December 1995	37.17	8.89	4.2

[a] without dietary changes.

[b] with dietary changes.

TABLE I-LXXVIII. EFFECTIVENESS FACTOR F RESULTING FROM DIETARY CHANGES FOR WOMEN IN THE “OBSERVED AREA”

Time period	Mean dose, mSv		
	E_{ing0}	E_{ing}	F, rel. units
27 April 1986–30 April 1987	9.48	5.67	1.7
27 April 1986–31 December 1990	27.03	13.84	2.0
27 April 1986–31 December 1995	34.80	19.64	1.8

TABLE I-LXXIX. EFFECTIVENESS FACTOR F RESULTING FROM DIETARY CHANGES FOR MEN IN THE "CONTROLLED AREA"

Time period	Mean dose, mSv		F, rel. units
	E_{ing0}	E_{ing}	
27 April 1986–30 April 1987	12.65	5.31	2.4
27 April 1986–31 December 1990	34.12	7.88	4.3
27 April 1986–31 December 1995	44.05	11.57	3.8

TABLE I-LXXX. EFFECTIVENESS FACTOR F RESULTING FROM DIETARY CHANGES FOR MEN IN THE "OBSERVED AREA"

Time period	Mean dose, mSv		F, rel. units
	E_{ing0}	E_{ing}	
27 April 1986–30 April 1987	11.60	7.56	1.5
27 April 1986–31 December 1990	31.76	18.73	1.7
27 April 1986–31 December 1995	41.26	25.99	1.6

I–2.4.2.2. Internal dose model (inhalation)

Inhalation dose from the radioactive cloud

We assessed the internal dose due to ^{137}Cs inhalation during the passage of the radioactive cloud with the formula:

$$E_i = C \cdot V \cdot \Delta T \cdot K \cdot d^{inh} \quad (10)$$

where C is the average concentration of ^{137}Cs in the above ground layer of air at the cloud passage (60 ± 40 Bq m^{-3}); V is the daily volume of inhaled air of an adult person (22.2 m^3 d^{-1}); ΔT is the time of the cloud passage (3 days); and K is the factor that takes into account the relative time of staying outdoors and indoors for a rural inhabitant, for which it is assumed that C is reduced twice indoors as compared with the same value outdoors, $K = 0.45 + (0.55 \times 0.5) = 0.725$ (unitless). The numeric value of the dose factor d^{inh} for adult inhabitants was assumed to be equal to 4.6×10^{-6} mSv Bq^{-1}.

Inhalation dose from resuspension

To assess the inhalation intake of ^{137}Cs in the body of inhabitants, regular information about the concentration in the above ground layer of atmospheric air within the settlement and its vicinity is necessary. In the absence of such data, the ^{137}Cs concentration in the air is assessed by multiplication of the resuspension factor (wind rise), W, by the average surface activity of the ^{137}Cs on soil, A^{137}, in the settlement and its vicinity. The average annual intake of ^{137}Cs in the body with inhaled air (inhalation intake), I^{inh}, is assessed with the formula:

$$I^{inh} = V_i \times W \times A^{137} \text{ kBq year}^{-1} \quad (11)$$

where V_i (m^3 a^{-1}) is the annual inhaled volume; W (m^{-1}) is the resuspension factor; and A^{137} (kBq m^{-2}) is the average surface activity of ^{137}Cs on soil in the settlement and its vicinity.

According to data from multiple observations in the zone of radiation accidents, the resuspension factor decreases with time and strongly depends on social and natural conditions. In 1989–1990, the resuspension factors were assessed at the following values: in settlements, 10^{-9} m^{-1}; at work outdoors, 10^{-8} m^{-1}; and at dust-forming operations, up to 10^{-7}–10^{-6} m^{-1}. Taking into consideration the occupation of a considerable portion of the rural inhabitants in outdoor work, and taking into account the seasonal character of this work, we assumed an average annual value for the resuspension factor W for the entire population of rural settlements to be equal to 3.3×10^{-9} m^{-1} ($0.84 \times 10^{-9} + 0.15 \times 10^{-8} + 0.01 \times 10^{-7}$), where 0.84, 0.15, and 0.01 are the fractions of time during a year for rural inhabitants to stay in the settlements proper, to work outdoors during the summer period, and to work at dust-forming operations during the summer period, respectively.

The results closest to these values (for rural settlements) are obtained when the Linsley calculation model is used (Linsley, 1978). We applied this model to assess ^{137}Cs inhalation intake in the body of inhabitants due to resuspension. This model gives the following regularity for variation of the resuspension factor directly in the settlements:

$$W(t) = 10^{-6}\exp(-3.65t) + 10^{-9},\ m^{-1} \qquad (12)$$

where *t* is the time elapsed after the accident in years.

Taking into account the occupations of the rural population at different jobs, including dust-forming ones, we assumed:

$$W(t) = 3.3 \times 10^{-6}\exp(-3.65t) + 3.3 \times 10^{-9},\ m^{-1} \qquad (13)$$

The annual inhaled volume for adults, V_i, was assumed to be equal to 8.1×10^3 m^3 a^{-1}.

The average annual effective dose from ^{137}Cs, E_{jnh}, was calculated with the formula:

$$E_{jnh} = d^{inh} \times I^{inh}, \qquad mSv\ a^{-1} \qquad (14)$$

The numeric value of the dose factor d^{inh} for adult inhabitants was assumed to be equal to 4.6×10^{-6} mSv Bq^{-1}.

I–2.4.2.3. Calculation of the average ^{137}Cs content in the body of inhabitants based on data on radionuclide intake

In the general form, the formula for calculation of the expected average content of ^{137}Cs in the body of inhabitants is the following:

$$\overline{Q}^{1}_{137} = \int_0^{t_1} I_{137}(\tau) \cdot R\,(t_1 - \tau)d\tau\ ,\ \text{Bq} \qquad (15)$$

where R(t) = 0.9·exp(-ln2·t/90), unitless, is the retention function for ^{137}Cs in the body of adult persons of both sexes; the ^{137}Cs excretion half-period from the body of an adult person is assumed to be equal to 90 days (according to our data); and $I_{137}(\tau)$, Bq d^{-1}, is the average *daily* intake of cesium-137 in the body of adult inhabitants of the settlement. This formula was used for determination of the radionuclide content in the body of inhabitants as of September 1986 (t_1 = 120 days).

In the rest of the cases, we assumed that ^{137}Cs intake was chronic, and the calculation was performed according to the formula:

$$(Q/M)_{av} = 1.67 * I_{137}(\tau), \quad Bq\cdot kg^{-1} \tag{16}$$

In the absence of specific data, we assumed that M = 70 kg.

I–2.4.3. Total dose

I–2.4.3.1. Total dose model

The total effective dose for an average adult living in the test region, I, is the sum of the doses from inhalation, ingestion and external radiation. The internal dose (ingestion) was based on the dietary intake. The inhalation dose was calculated separately to show its low contribution to the internal dose. The internal dose was given as a committed effective dose. The 95% confidence interval of the total dose was calculated on the basis of the values of the standard errors of its components:

$$95\% Conf.Int. = (\bar{E}_{ext} + \bar{E}_{\text{int}}) \pm 1.96 \cdot \sqrt{(st.err.)^2_{ext} + (st.err.)^2_{\text{int}}} \tag{17}$$

I–3. SUMMARY OF TEST DATA AND DOSE ESTIMATES

TABLE I-LXXXI. ^{137}Cs CONCENTRATIONS IN LEAFY VEGETABLES

Time period	Mean (Bq kg^{-1} f.w.)	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986	607	466	748	68
1987	270	194	346	30
1988	170	113	227	28
1989	179	140	217	25
1990	117	87	148	58
1991	70	56	84	49
1992	58	48	68	44
1993	45	35	54	45
1994	31	24	38	36
1995	66	45	88	48
1996	55	46	64	53

TABLE I-LXXXII. ^{137}Cs CONCENTRATIONS IN HAY

Time period	Mean (Bq kg^{-1})	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986	34627	27002	42252	134
1987	16238	14002	18473	134
1988	16715	9838	23592	67
1989	8761	7279	10243	71
1990	10140	6367	13120	74
1991	3130	2714	3547	104
1992	2290	1892	2689	154
1993	1110	979	1241	208
1994	2991	2364	3618	208
1995	3375	2822	3927	208
1996	2260	1996	2524	168

TABLE I-LXXXIII. ^{137}Cs CONCENTRATIONS IN POTATOES

Time period	Mean (Bq kg^{-1} f.w.)	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986	256	187	326	108
1987	156	127	185	64
1988	119	99	140	74
1989	98	69	126	56
1990	93	73	114	98
1991	75	66	84	114
1992	73	48	97	89
1993	34	28	39	97
1994	29	26	32	108
1995	51	39	63	67
1996	40	32	47	53

TABLE I-LXXXIV. ^{137}Cs CONCENTRATIONS IN GRAIN OF CEREALS, DRY WEIGHT

Time period	Mean (Bq kg^{-1} d.w.)	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986	670	568	772	161
1987	468	331	605	24
1988	434	208	660	24
1989	195	131	260	56
1990	82	50	115	123
1991	39	32	45	133
1992	33	30	37	198
1993	25	20	31	157
1994	38	33	42	258
1995	63	57	68	324
1996	56	47	64	313

TABLE I-LXXXV. ^{137}Cs CONCENTRATIONS IN MILK

Time period	Mean (Bq L^{-1})	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986, May	9609	7377	11841	57
1986, June	4438	3577	5298	68
1986, July	2968	2093	3844	73
1986, August	2544	1835	3252	184
1986, September	1961	1530	2391	166
1986, IV	1063	830	1296	94
1987, I	1183	903	1464	87
1987, II	1854	1563	2145	183
1987, III	1935	1539	2332	134
1987, IV	615	412	818	79
1988, I	623	541	706	148
1988, II	1762	1339	2185	62
1988, III	2016	1458	2575	81
1988, IV	730	557	903	143
1989, I	636	550	721	218
1989, II	1089	888	1290	176
1989, III	1610	1265	1955	188
1989, IV	403	360	446	206
1990, I	330	284	377	213
1990, II	428	362	494	240
1990, III	351	309	393	197
1990, IV	115	103	128	148
1991, I	125	109	141	193
1991, II	406	334	478	159
1991, III	449	348	550	174
1991, IV	122	107	137	193
1992, I	156	136	176	209
1992, II	215	174	256	254
1992, III	285	235	335	301
1992, IV	118	101	135	254
1993, I	136	117	155	182
1993, II	176	153	198	285
1993, III	159	141	177	297
1993, IV	122	98	146	184
1994, I	116	95	137	172
1994, II	311	265	357	312
1994, III	388	326	451	340
1994, IV	181	156	206	235
1995, I	156	129	182	196
1995, II	237	207	268	294
1995, III	489	367	610	306
1995, IV	140	123	157	216
1996, I	161	136	186	115
1996, II	228	192	264	220
1996, III	450	275	625	102
1996, IV	146	107	185	120

TABLE I-LXXXVI. ^{137}Cs CONCENTRATIONS IN BEEF

Time period	Mean (Bq kg^{-1} f.w.)	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986, May	6073	2449	9697	13
1986, June	7615	5673	9556	28
1986, July	8224	5065	11382	22
1986, August	4626	3076	6176	18
1986, September	5960	2524	9395	27
1986, IV	2908	2035	3781	41
1987, I	3334	2078	4591	12
1987, II	3653	2439	4867	34
1987, III	3654	2270	5038	28
1987, IV	1906	1254	2558	31
1988, I	1183	903	1464	87
1988, II	3079	2217	3941	57
1988, III	5256	3408	7105	79
1988, IV	1994	1605	2383	64
1989, I	1831	1338	2323	85
1989, II	3066	2165	3966	87
1989, III	3303	2399	4208	111
1989, IV	896	753	1038	86
1990, I	908	758	1058	73
1990, II	1328	984	1672	49
1990, III	2128	1732	2524	143
1990, IV	565	432	699	54
1991, I	464	356	572	36
1991, II	1001	649	1354	51
1991, III	957	723	1191	49
1991, IV	348	281	414	61
1992, I	393	307	479	58
1992, II	876	515	1238	72
1992, III	869	634	1104	81
1992, IV	509	310	708	29
1993, I	540	336	743	31
1993, II	606	322	890	28
1993, III	858	527	1188	31
1993, IV	437	328	546	26
1994, I	450	318	582	49
1994, II	600	427	774	43
1994, III	555	423	687	43
1994, IV	521	275	767	21
1995, I	526	325	727	39
1995, II	532	356	708	42
1995, III	518	399	637	46
1995, IV	477	244	710	19
1996, I	497	379	615	56
1996, II	351	309	393	197
1996, III	462	376	547	88
1996, IV	471	448	493	92

TABLE I-LXXXVII. ^{137}Cs CONCENTRATIONS IN PORK

Time period	Mean (Bq kg^{-1} f.w.)	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986, May	1325	815	1836	17
1986, June	4088	2556	5620	32
1986, July	3385	2151	4618	19
1986, August	3140	2407	3873	27
1986, September	1995	1518	2472	41
1986, IV	1508	927	2089	63
1987, I	1223	696	1750	54
1987, II	2340	1954	2726	87
1987, III	2879	1916	3841	56
1987, IV	1041	656	1425	71
1988, I	1002	786	1217	62
1988, II	1820	1417	2224	83
1988, III	3145	1707	4583	97
1988, IV	981	810	1152	78
1989, I	966	807	1124	94
1989, II	1787	1027	2547	87
1989, III	1308	1096	1519	102
1989, IV	521	402	640	94
1990, I	675	441	909	81
1990, II	922	743	1101	89
1990, III	1452	1077	1827	99
1990, IV	503	274	731	97
1991, I	311	243	379	54
1991, II	765	505	1025	101
1991, III	1284	862	1705	112
1991, IV	253	199	307	49
1992, I	410	277	543	36
1992, II	323	211	434	53
1992, III	352	322	383	58
1992, IV	124	94	155	51
1993, I	125	95	154	47
1993, II	133	81	186	14
1993, III	252	111	394	36
1993, IV	110	74	145	42
1994, I	173	114	233	27
1994, II	164	101	227	44
1994, III	224	160	288	52
1994, IV	151	124	177	67
1995, I	133	99	167	44
1995, II	166	110	223	46
1995, III	201	152	250	49
1995, IV	229	137	321	27
1996, I	216	134	297	54
1996, II	179	146	211	99
1996, III	192	154	230	145
1996, IV	150	100	199	87

TABLE I-LXXXVIII. ^{137}Cs CONCENTRATION IN FOREST, EDIBLE MUSHROOMS (MIXED SAMPLES)

Time period	Mean	95% confidence interval	
	(kBq kg^{-1} f.w.)	Lower bound	Upper bound
1986	11.2	7.6	14.8
1987	17.9	5.4	30.4
1988	12.0	5.7	18.3
1989	10.1	-	29.7
1990	13.4	5.8	21.0
1991	5.9	-	14.3
1992	7.0	4.2	9.7
1994	15.6	5.2	26.0
1995	15.3	2.3	28.3
1996	14.5	1.6	27.4

TABLE I-LXXXIX. SPECIFIC ACTIVITY OF ^{137}CS IN FOREST MUSHROOMS (MIXED SAMPLES, BQ KG^{-1} F.W.)

Year	Number of samples	Mean	Stand. deviation	Stand. error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
1986	198	11200	25700	1820	302	484	4510	42000	67300
1987	83	17900	57000	6260	241	415	5370	69600	120000
1988	99	12000	31200	3140	248	407	4320	45800	75500
1989	42	10100	63300	9800	34	68	1610	38200	74800
1990	163	13400	48400	3790	139	245	3580	52300	92800
1991	27	5950	21800	4200	59	106	1570	23200	41100
1992	77	6960	11900	1360	337	508	3500	24200	36500
1994	164	15600	66300	5180	116	211	3580	60800	111000
1995	261	15300	105000	6510	42	85	2190	56600	113000
1996	230	14500	98000	6460	42	84	2130	54000	107000

TABLE I-XC. ^{137}Cs CONCENTRATIONS IN WILD BERRIES

Time period	Mean	95% confidence interval	
	(kBq kg^{-1} f.w.)	Lower bound	Upper bound
1986	8.0	3.0	14.0
1987	4.0	1.2	7.0
1988	3.5	1.0	5.0
1989	2.6	0.9	4.3
1990	2.4	0.9	4.0
1991	2.3	0.8	4.0
1993	6.8	-	14.0
1995	2.1	-	7.1
1996	5.5	-	21.4

TABLE I-XCI. SPECIFIC ACTIVITY OF ^{137}Cs IN FOREST BERRIES (MIXED SAMPLES, BQ KG^{-1} F.W.)

Year	Number of samples	Mean	Stand. deviation	Stand. error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
1993	60	6800	28000	3620	54	97	1600	26500	48100
1995	61	2150	19400	2490	4	7	237	7600	15800
1996	46	5490	53900	7940	8	16	556	19000	40100

TABLE I-XCII. ^{137}Cs CONCENTRATIONS IN RIVER FISH

Time period	Mean (kBq kg^{-1} f.w.)	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986	2.0	0.8	3.4	6
1987	2.4	1.0	4.0	8
1988	1.4	0.6	2.2	6
1989	0.6	0.24	1.0	6
1990	0.58	0.2	1.0	14
1991	0.25	0.1	0.4	20
1992	0.25	0.06	0.42	20
1993	0.20	0.06	0.34	8
1994	0.17	0.05	0.30	4
1995	0.15	0.05	0.25	3
1996	0.15	0.10	0.20	23

TABLE I-XCIII. ^{137}Cs CONCENTRATIONS IN LAKE FISH

Time period	Mean (kBq kg^{-1} f.w.)	95% confidence interval		Number of Samples
		Lower bound	Upper bound	
1986	36	7	65	11
1987	42	9	75	10
1988	28	5	50	8
1989	16	3	30	6
1990	10	6	14	18
1991	12	7	18	30
1992	11	7	15	15
1993	10	7	13	24
1994	6.7	4.7	8.7	15
1995	4.0	1.0	7.0	4
1996	3.0	0.5	5.5	6

TABLE I-XCIV. AUTHORS' ESTIMATES OF AVERAGE HUMAN ^{137}Cs INTAKE (CONTROLLED AREA, WOMEN)

Time	Mean Bq d^{-1}	95% confidence interval	
		Lower bound	Upper bound
June 1986	2181	1681	2681
IV 1986	217	144	291
II 1987	251	176	327
IV 1987	198	126	270
II 1988	186	140	232
IV 1988	137	95	178
II 1989	139	46	232
IV 1989	106	14	198
II 1990	111	67	156
IV 1990	105	60	149
II 1991	94	52	136
IV 1991	74	33	115
II 1992	93	70	116
IV 1992	80	59	101
II 1993	103	47	159
IV 1993	95	40	149
II 1994	199	129	268
IV 1994	159	95	224
II 1995	191	115	268
IV 1995	170	90	250

TABLE I-XCV. AUTHORS’ ESTIMATES OF AVERAGE HUMAN ^{137}Cs INTAKE (NON-CONTROLLED AREA, WOMEN)

Time	Mean	95% confidence interval	
	Bq d^{-1}	Lower bound	Upper bound
June 1986	2010	1559	2461
IV 1986	710	516	904
II 1987	940	720	1161
IV 1987	552	373	732
II 1988	789	625	952
IV 1988	420	321	520
II 1989	510	254	766
IV 1989	291	42	540
II 1990	328	220	436
IV 1990	257	151	363
II 1991	257	147	368
IV 1991	160	52	267
II 1992	205	160	250
IV 1992	166	122	209
II 1993	244	103	385
IV 1993	220	80	361
II 1994	371	227	516
IV 1994	300	159	441
II 1995	362	189	536
IV 1995	319	146	491

TABLE I-XCVI. AUTHORS’ ESTIMATES OF AVERAGE HUMAN ^{137}Cs INTAKE (CONTROLLED AREA, MEN)

Time	Mean	95% confidence interval	
	Bq d^{-1}	Lower bound	Upper bound
June 1986	2546	1875	3216
IV 1986	292	159	425
II 1987	312	179	446
IV 1987	276	143	409
II 1988	224	149	299
IV 1988	190	117	264
II 1989	175	0	356
IV 1989	154	0	335
II 1990	176	92	261
IV 1990	172	88	257
II 1991	132	52	212
IV 1991	112	33	192
II 1992	138	98	177
IV 1992	123	86	161
II 1993	170	62	278
IV 1993	160	53	266
II 1994	265	151	379
IV 1994	232	121	343
II 1995	263	131	396
IV 1995	250	118	382

TABLE I-XCVII. AUTHORS’ ESTIMATES OF AVERAGE HUMAN ^{137}Cs INTAKE (NON-CONTROLLED AREA, MEN)

Time	Mean	95% confidence interval	
	Bq d^{-1}	Lower bound	Upper bound
June 1986	2603	2011	3194
IV 1986	944	677	1212
II 1987	1324	1020	1629
IV 1987	736	488	984
II 1988	1035	774	1296
IV 1988	536	380	691
II 1989	649	283	1015
IV 1989	370	29	712
II 1990	396	241	551
IV 1990	315	166	464
II 1991	314	160	469
IV 1991	199	52	347
II 1992	262	196	328
IV 1992	220	158	283
II 1993	296	101	491
IV 1993	273	80	467
II 1994	454	251	656
IV 1994	393	195	591
II 1995	461	220	702
IV 1995	416	177	655

TABLE I-XCVII. ^{137}Cs CONCENTRATION IN WHOLE BODY (CONTROLLED AREA, WOMEN), AS CALCULATED FROM INTAKE

Time	Mean	95% confidence interval	
	Bq kg^{-1}	Lower bound	Upper bound
30 September 1986	1906	1268	2544
30 September 1987	454	320	588
30 September 1988	320	236	404
30 September 1989	210	56	364
30 September 1990	199	124	274
30 September 1991	190	118	262
30 September 1992	164	124	204
30 September 1993	187	93	280
30 September 1994	378	249	506
30 September 1995	445	301	590

TABLE I-XCIX. ^{137}Cs CONCENTRATION IN WHOLE BODY (NON-CONTROLLED AREA, WOMEN), AS CALCULATED FROM INTAKE

Time	Mean	95% confidence interval	
	Bq kg^{-1}	Lower bound	Upper bound
30 September 1986	1782	1229	2336
30 September 1987	1699	1309	2089
30 September 1988	1355	1091	1619
30 September 1989	956	522	1389
30 September 1990	576	395	758
30 September 1991	494	308	681
30 September 1992	373	296	449
30 September 1993	417	182	652
30 September 1994	685	441	928
30 September 1995	825	526	1125

TABLE I-C. ^{137}Cs CONCENTRATION IN WHOLE BODY (CONTROLLED AREA, MEN), AS CALCULATED FROM INTAKE

Time	Mean Bq kg^{-1}	95% confidence interval	
		Lower bound	Upper bound
30 September 1986	2239	1448	3029
30 September 1987	544	319	768
30 September 1988	377	252	502
30 September 1989	277	0	578
30 September 1990	301	160	443
30 September 1991	253	119	387
30 September 1992	239	171	307
30 September 1993	308	129	487
30 September 1994	488	294	681
30 September 1995	547	314	779

TABLE I-CI. ^{137}CS CONCENTRATION IN WHOLE BODY (NON-CONTROLLED AREA, MEN), AS CALCULATED FROM INTAKE

Time	Mean Bq kg^{-1}	95% confidence interval	
		Lower bound	Upper bound
30 September 1986	2307	1600	3015
30 September 1987	2389	1848	2930
30 September 1988	1731	1235	2227
30 September 1989	1252	615	1889
30 September 1990	670	414	926
30 September 1991	610	350	871
30 September 1992	469	354	583
30 September 1993	511	187	834
30 September 1994	826	483	1169
30 September 1995	1013	590	1436

TABLE I-CII. DISTRIBUTION OF ^{137}Cs IN THE WHOLE BODY OF ADULT MEN LIVING IN THE CONTROLLED AREA*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	1215	1790	2480	71.3	133	191	1050	5790	8300
15.03.87	45	457	378	56.6	82.7	107	351	1160	1490
15.09.87	43	335	276	41.8	60.9	78.3	258	847	1090
15.10.90	34	257	339	58.3	20.9	29.6	156	814	1160
15.09.91	87	172	151	16.5	28.7	37.4	129	451	587
15.03.92	17	152	111	27.0	33.1	41.8	123	362	456
01.06.92	78	88.7	78.3	8.7	14.8	19.1	66.1	232	304
15.09.92	26	267	615	121	6.96	11.3	106	1000	1610
15.09.93	37	505	1550	255	6.96	12.2	156	1960	3340
15.09.94	35	273	263	44.4	39.2	51.3	197	747	992
15.09.95	13	254	318	87.9	22.6	32.2	158	786	1100
15.09.96	22	157	138	29.6	25.2	33.1	117	410	535
15.09.97	21	274	171	37.4	74.0	90.5	232	598	731
18.09.98	32	504	461	81.8	78.3	103	371	1350	1770

* Obtained from the normalised distribution (Table I-LXX) using an average deposition of 0.87 Bq m^{-2} for the Controlled Area (Section 5.6).

TABLE I-CIII. DISTRIBUTION OF ^{137}Cs IN THE WHOLE BODY OF ADULT MEN LIVING IN THE NON-CONTROLLED (OBSERVED) AREA.*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	762	740	656	23.6	120	157	552	1940	2540
15.03.87	119	389	200	18.4	132	156	346	768	908
15.09.87	13	563	338	93.6	159	193	484	1200	1460
15.09.97	15	177	186	48	21.6	29.6	122	508	684
18.09.98	20	460	600	134	38.4	54.4	281	1450	2060

* Obtained from the normalised distribution (Table I-LXXI) using an average deposition of 0.40 Bq m^{-2} for the Non-controlled Area (Section 5.6).

TABLE I-CIV. DISTRIBUTION OF ^{137}Cs IN THE WHOLE BODY OF ADULT WOMEN LIVING IN THE CONTROLLED AREA*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	1631	1640	2270	56.6	123	177	966	5310	7610
15.03.87	71	387	278	33.1	86.1	109	315	914	1150
15.09.87	46	260	229	33.9	42.6	55.7	196	681	887
15.10.90	53	175	334	46.1	6.96	10.4	80.9	626	966
15.03.91	17	104	109	26.1	13.1	17.4	71.3	297	400
15.09.91	143	96.6	93.1	7.83	13.9	18.3	69.6	264	351
15.03.92	62	83.5	71.3	8.7	13.9	18.3	63.5	215	279
01.06.92	140	62.6	49.6	4.35	12.2	15.7	49.6	156	198
15.09.93	21	301	580	127	11.3	17.4	138	1080	1670
15.09.94	17	173	191	46.1	19.1	27.0	116	506	693
15.09.95	13	137	156	43.5	14.8	20.0	91.4	408	560
15.09.97	19	117	110	25.2	17.4	22.6	85.3	318	420
18.09.98	18	305	539	127	13.9	20.9	150	1070	1630

* Obtained from the normalised distribution (Table I-LXXII) using an average deposition of 0.87 Bq m^{-2} for the Controlled Area (Section 5.6).

TABLE I-CV. DISTRIBUTION OF ^{137}Cs IN THE WHOLE BODY OF ADULT WOMEN LIVING IN THE NON-CONTROLLED (OBSERVED) AREA*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5%	5.0%	50%	95%	97.5%
01.09.86	870	680	624	21.2	104	136	500	1820	2400
15.03.87	159	276	176	14	72.8	89.6	234	608	748
15.09.87	57	524	317	42	147	178	448	1130	1370
15.10.90	46	133	138	20.4	16.8	22.4	92.4	379	512
15.09.97	41	83.6	94.4	14.8	9.2	12.4	55.2	247	339
18.09.98	61	340	460	58.8	26.4	37.6	202	1090	1560

* Obtained from the normalised distribution (Table I-LXXIII) using an average deposition of 0.40 Bq m^{-2} for the Non-controlled Area (Section 5.6).

TABLE I-CVI. DISTRIBUTION OF ^{137}Cs IN THE WHOLE BODY OF ADULT MEN AND WOMEN (IN TOTAL) LIVING IN THE CONTROLLED AREA*

Date of measurement	Number of people	Mean (Bq kg^{-1})	Standard deviation	Standard error	Percentiles				
					2.5 %	5.0 %	50 %	95 %	97.5 %
01.06.89	94	130	147	14.8	13.9	19.1	85.3	384	528
01.06.92	15	79.2	81.8	20.9	9.57	13.1	54.8	225	304
01.06.93	140	181	209	17.4	18.3	26.1	118	540	746
01.06.94	29	139	101	19.1	30.5	38.3	112	329	413

Obtained from the normalised distribution (Table I-LXXIV) using an average deposition of 0.87 Bq m^{-2} for the Controlled Area (Section 5.6).

TABLE I-CVII. AUTHORS' ESTIMATES OF THE MEAN EFFECTIVE EXTERNAL DOSE FROM THE CHERNOBYL ^{137}Cs IN THE TEST AREA

Time period	Mean (mSv)	95% confidence interval	
		Lower bound	Upper bound
Cloud Exposure	2×10^{-4}	0.7×10^{-4}	3.4×10^{-4}
Ground Expsoure			
28 April 1986–30 April 1987	3.53	2.84	4.22
28 April 1986–31 December 1990	11.1 (10.9)[a]	8.9 (8.8)	13.3 (13.0)
28 April 1986–31 December 1996	18.4 (17.6)	14.8 (14.1)	22.0 (21.1)
28 April 1986–lifetime	39.6 (37.3)	31.8 (30.0)	47.4 (44.6)

[a] The values in parentheses indicate the estimated dose accounting for the effect of decontamination.

TABLE I-CVIII. DISTRIBUTION OF THE INDIVIDUAL EXTERNAL DOSES FOR A REFERENCE SAMPLE OF THE POPULATION IN THE INVESTIGATED REGION ACCORDING TO THE TL-MEASUREMENTS (NORMALIZED TO A DEPOSITION OF 1 MBq m^{-2})

Duration months	Geom. mean mSv	Geom. std. dev.	Arith. mean ± std. error mSv	Std. dev. mSv	Percentiles mSv			
					2.5%	5%	95%	97.5%
December 1986–December 1987								
12	2.23	1.36	2.34 ± 0.17	0.73	1.21	1.34	3.70	4.12
May 1989								
1	0.200	1.34	0.208 ± 0.012	0.063	0.111	0.123	0.324	0.359
October 1991								
1	0.132	1.44	0.141 ± 0.013	0.053	0.064	0.072	0.241	0.274
November 1992								
1	0.094	1.43	0.100 ± 0.006	0.037	0.046	0.052	0.170	0.192

TABLE I-CIX. DISTRIBUTION OF INDIVIDUAL EXTERNAL DOSES FOR A REFERENCE SAMPLE OF THE POPULATION IN THE INVESTIGATED REGION ACCORDING TO THE TL-MEASUREMENTS

Duration	Geom. mean	Geom. std. dev.	Arith. mean ± std. error	Std. dev.	Percentiles mSv			
months	mSv		mSv	mSv	2.5%	5%	95%	97.5%
December 1986–December 1987								
12	1.59	1.71	1.84 ± 0.19	1.02	0.54	0.66	3.85	4.65
May 1989								
1	0.142	1.69	0.163 ± 0.015	0.084	0.050	0.060	0.338	0.406
October 1991								
1	0.094	1.77	0.111 ± 0.013	0.069	0.030	0.037	0.241	0.294
November 1992								
1	0.067	1.76	0.079 ± 0.007	0.048	0.022	0.026	0.170	0.208

TABLE I-CX. AUTHORS' ESTIMATES OF THE AVERAGE INHALATION DOSE FROM CHERNOBYL ^{137}Cs

Time period	Mean	95% confidence interval	
	mSv	Lower bound	Upper bound
Inhalation from cloud	0.013	0	0.03
Inhalation from resuspension			
28 April 1986–30 April 1987	0.026	0.022	0.029
28 April 1986–31 December 1990	0.027	0.023	0.031
28 April 1986–31 December 1995	0.027	0.023	0.031
28 April 1986–lifetime	0.029	0.025	0.033

TABLE I-CXI. AUTHORS' ESTIMATES OF THE AVERAGE INGESTION DOSE FROM CHERNOBYL (CONTROLLED AREA, WOMEN), WITH THE THREE MAJOR CONTRIBUTORS TO THE DOSE

Time period		Mean	95% confidence interval	
		mSv	Lower bound	Upper bound
28 April 1986–30 April 1987				
milk		3.23	2.22	4.24
meat		0.59	0.35	0.83
mushrooms		0.32	0.08	0.55
	Total	4.44	3.37	5.51
28 April 1986–31 December 1990				
milk		3.23	2.22	4.24
mushrooms		1.32	0.07	2.56
meat		1.32	0.83	1.81
	Total	6.29	4.57	8.02
28 April 1986–31 December 1995				
milk		4.04	2.74	5.35
mushrooms		2.47	0.13	4.81
meat		1.75	0.85	2.64
	Total	8.89	6.01	11.77
28 April 1986–lifetime				
milk		8.76	6.89	10.63
mushrooms		6.85	0	18.44
meat		2.81	0.15	5.47
	Total	20.32	14.58	26.06

TABLE I-CXII. AUTHORS’ ESTIMATES OF THE AVERAGE INGESTION DOSE FROM CHERNOBYL (NON-CONTROLLED AREA, WOMEN), WITH THE THREE MAJOR CONTRIBUTORS TO THE DOSE

Time period		Mean	95% confidence interval	
		mSv	Lower bound	Upper bound
28 April 1986–30 April 1987				
milk		3.55	2.42	4.69
meat		0.91	0.55	1.26
mushrooms		0.88	0.31	1.46
	Total	5.67	4.34	7.00
28 April 1986–31 December 1990				
milk		6.93	4.82	9.03
mushrooms		3.66	0.5	6.82
meat		2.68	1.81	3.55
	Total	13.84	9.92	17.77
28 April 1986–31 December 1995				
milk		8.86	6.3	11.41
mushrooms		6.87	0.9	12.83
meat		3.24	2.18	4.29
	Total	19.64	13.03	26.24
28 April 1986–lifetime				
mushrooms		19.04	0	95.97
milk		17.31	12.19	22.44
meat		3.45	2.8	4.1
	Total	41.72	28.83	54.61

TABLE I-CXIII. AUTHORS’ ESTIMATES OF THE AVERAGE INGESTION DOSE FROM CHERNOBYL (CONTROLLED AREA, MEN), WITH THE THREE MAJOR CONTRIBUTORS TO THE DOSE

Time period		Mean	95% confidence interval	
		mSv	Lower bound	Upper bound
28 April 1986–30 April 1987				
milk		3.89	2.63	5.15
mushrooms		0.64	0.18	1.09
meat		0.49	0.28	0.69
	Total	5.31	3.95	6.67
28 April 1986–31 December 1990				
milk		3.89	2.63	5.15
mushrooms		2.63	0.21	5.06
meat		0.98	0.59	1.36
	Total	7.88	5.09	10.68
28 April 1986–31 December 1995				
mushrooms		4.94	0.38	9.51
milk		4.61	2.96	6.25
meat		1.53	0.95	2.12
	Total	11.57	6.64	16.5
28 April 1986–lifetime				
mushrooms		13.71	0	58.09
milk		8.51	5.72	11.3
meat		1.87	1.47	2.27
	Total	26.48	16.68	36.28

TABLE I-CXIV. AUTHORS' ESTIMATES OF THE AVERAGE INGESTION DOSE FROM CHERNOBYL (NON-CONTROLLED AREA, MEN), WITH THE THREE MAJOR CONTRIBUTORS TO THE DOSE

Time period	Mean	95% confidence interval	
	mSv	Lower bound	Upper bound
28 April 1986–30 April 1987			
milk	4.75	3.26	6.23
mushrooms	1.2	0.4	2.01
meat	1.26	0.79	1.73
Total	7.56	5.8	9.33
28 April 1986–31 December 1990			
milk	9.67	6.42	12.91
mushrooms	4.98	0.58	9.37
meat	3.3	1.96	4.64
Total	18.73	13.09	24.37
28 April 1986–31 December 1995			
milk	11.69	7.69	15.68
mushrooms	9.34	1.06	17.62
meat	4.03	2.41	5.66
Total	25.99	16.63	35.35
28 April 1986–lifetime			
mushrooms	25.89	0	173.22
milk	20.96	8.04	33.87
meat	4.46	2.78	6.14
Total	54.09	36.07	72.12

TABLE I-CXV. AUTHORS' ESTIMATES OF THE AVERAGE TOTAL EFFECTIVE DOSE FROM CHERNOBYL ^{137}Cs (CONTROLLED AREA, WOMEN), WITH THE THREE MAJOR CONTRIBUTORS

Time period	Mean	95% confidence interval	
	(mSv)	Lower bound	Upper bound
28 April 1986–30 April 1987			
Total	8.3	7.0	9.7
Internal (ingestion): 53%	4.4	3.4	5.5
External (from ground): 47%	3.9 (0.39)	3.2	4.7
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986–31 December 1990			
Total	18.6	15.6	21.6
External (from ground): 66%	12.3 (1.22)	9.9	14.7
Internal (ingestion): 34%	6.3	4.6	8.0
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–31 December 1995			
Total	29.3	24.7	34.2
External (from ground): 70%	20.4 (2.04)	16.4	24.4
Internal (ingestion): 30%	8.9	6.0	11.8
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–ifetime			
Total	64.3	53.9	74.7
External (from ground): 68%	44.0 (4.39)	35.4	52.6
Internal (ingestion): 32%	20.3	14.6	26.1
Internal (inhalation from resuspension)	0.029	0.025	0.033

TABLE I-CXVI. AUTHORS' ESTIMATES OF THE AVERAGE TOTAL EFFECTIVE DOSE FROM CHERNOBYL ^{137}Cs (NON-CONTROLLED AREA, WOMEN), WITH THE THREE MAJOR CONTRIBUTORS

Time period	Mean (mSv)	95% confidence interval	
		Lower bound	Upper bound
28 April 1986–30 April 1987			
Total	7.5	6.1	8.9
Internal (ingestion): 76%	5.7	4.3	7.0
External (from ground): 24%	1.8 (0.18)	1.5	2.2
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986–31 December 1990			
Total	19.5	15.5	23.6
Internal (ingestion): 71%	13.8	9.9	17.8
External (from ground): 29%	5.7 (0.56)	4.6	6.8
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–31 December 1995			
Total	29.0	22.1	35.9
Internal (ingestion): 68%	19.6	13.0	26.2
External (from ground): 32%	9.4 (0.92)	7.6	11.2
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–lifetime			
Total	61.9	48.4	75.4
Internal (ingestion): 67%	41.7	28.8	54.6
External (from ground): 33%	20.2 (2)	16.2	24.2
Internal (inhalation from resuspension)	0.029	0.025	0.033

TABLE I-CXVII. AUTHORS' ESTIMATES OF THE AVERAGE TOTAL EFFECTIVE DOSE FROM CHERNOBYL ^{137}Cs (CONTROLLED AREA, MEN), WITH THE THREE MAJOR CONTRIBUTORS

Time period	Mean (mSv)	95% confidence interval	
		Lower bound	Upper bound
28 April 1986–30 April 1987			
Total	9.2	7.6	10.8
Internal (ingestion): 58%	5.3	4.0	6.7
External (from ground): 42%	3.9	3.2	4.7
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986–31 December 1990			
Total	20.2	16.5	23.9
External (from ground): 61%	12.3	9.9	14.7
Internal (ingestion): 39%	7.9	5.1	10.7
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–31 December 1995			
Total	32.0	25.9	38.3
External (from ground): 64%	20.4	16.4	24.4
Internal (ingestion): 36%	11.6	6.6	16.5
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–lifetime			
Total	70.5	57.5	83.5
External (from ground): 62%	44.0	35.4	52.6
Internal (ingestion): 38%	26.5	16.7	36.3
Internal (inhalation from resuspension)	0.029	0.025	0.033

TABLE I-CXVIII. AUTHORS' ESTIMATES OF THE AVERAGE TOTAL EFFECTIVE DOSE FROM CHERNOBYL ^{137}Cs (NON-CONTROLLED AREA, MEN), WITH THE THREE MAJOR CONTRIBUTORS

Time period	Mean (mSv)	95% confidence interval	
		Lower bound	Upper bound
28 April 1986–30 April 1987			
Total	9.4	7.6	11.2
Internal (ingestion): 81%	7.6	5.8	9.3
External (from ground): 19%	1.8	1.5	2.2
Internal (inhalation from resuspension)	0.026	0.022	0.029
28 April 1986–31 December 1990			
Total	24.4	18.7	30.2
Internal (ingestion): 77%	18.7	13.1	24.4
External (from ground): 23%	5.7	4.6	6.8
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–31 December 1995			
Total	35.4	25.9	44.9
Internal (ingestion): 73%	26.0	16.6	35.4
External (from ground): 27%	9.4	7.6	11.2
Internal (inhalation from resuspension)	0.027	0.023	0.031
28 April 1986–lifetime			
Total	74.3	55.8	92.8
Internal (ingestion): 73%	54.1	36.1	72.1
External (from ground): 27%	20.2	16.2	24.2
Internal (inhalation from resuspension)	0.029	0.025	0.033

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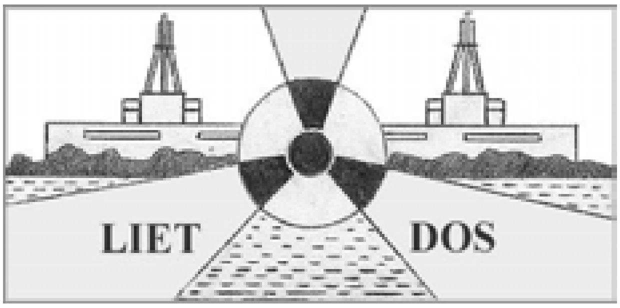
ANNEX II

DESCRIPTION OF MODELS AND INDIVIDUAL EVALUATIONS OF MODEL PERFORMANCE FOR THE IPUT RIVER SCENARIO



II–1. LIETDOS – LITHUANIAN DOSE ASSESSMENT MODEL

RADIONUCLIDE MIGRATION IN THE ENVIRONMENT SIMULATION AND HUMAN DOSE ASSESSMENT MODEL

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II–1.1. GENERAL MODEL DESCRIPTION

II–1.1.1. Name of model, model developer and model users

Model name: LIETDOS (*LIT*huanian *DOS*e Assessment Model).
Radionuclide migration in the environment simulation and human dose assessment model.
Model developer: Institute of Physics, Radiation Protection Department.
Model user: Institute of Physics, Environment Ministry of Lithuanian Republic

II–1.1.2. Important model characteristics

LIETDOS has been created, tested (by means of BIOMASS Hanford and the Iput River test exercises) and used for atmospheric dispersion, food chain modeling and dose assessment as well as release conversion factors and dose constraint evaluation in the vicinity of Nuclear Power Plant. In co-operation with Environment Ministry of Lithuanian Republic and other authorities, LIETDOS was used for the revision as well as updating of the Ignalina NPP routine release limitation system. In co-operation with Lithuanian Energy Institute LIETDOS was used for the assessment of radiological consequences in the case of some hypothetical Ignalina NPP accidents.

LIETDOS model and computer software package are flexible and can be used to predict radiological consequences for both routine and accidental atmospheric releases. For an accidental release, dynamic transfer factors are used, and in the case of routine release, the equilibrium transfer factors can be used. The atmospheric dispersion and the effect of deposition can be taken into account. LIETDOS consists of several submodels.

LIETDOS-FILTSEG atmospheric dispersion submodel and software package can be used to predict air activity concentration and deposition values. LIETDOS-FILTSEG is based upon the approach of segmental diffusion-convection radionuclide transfer in the air and considers non-steady state conditions. The radionuclide release and meteorological data are the input information for the model.[1]

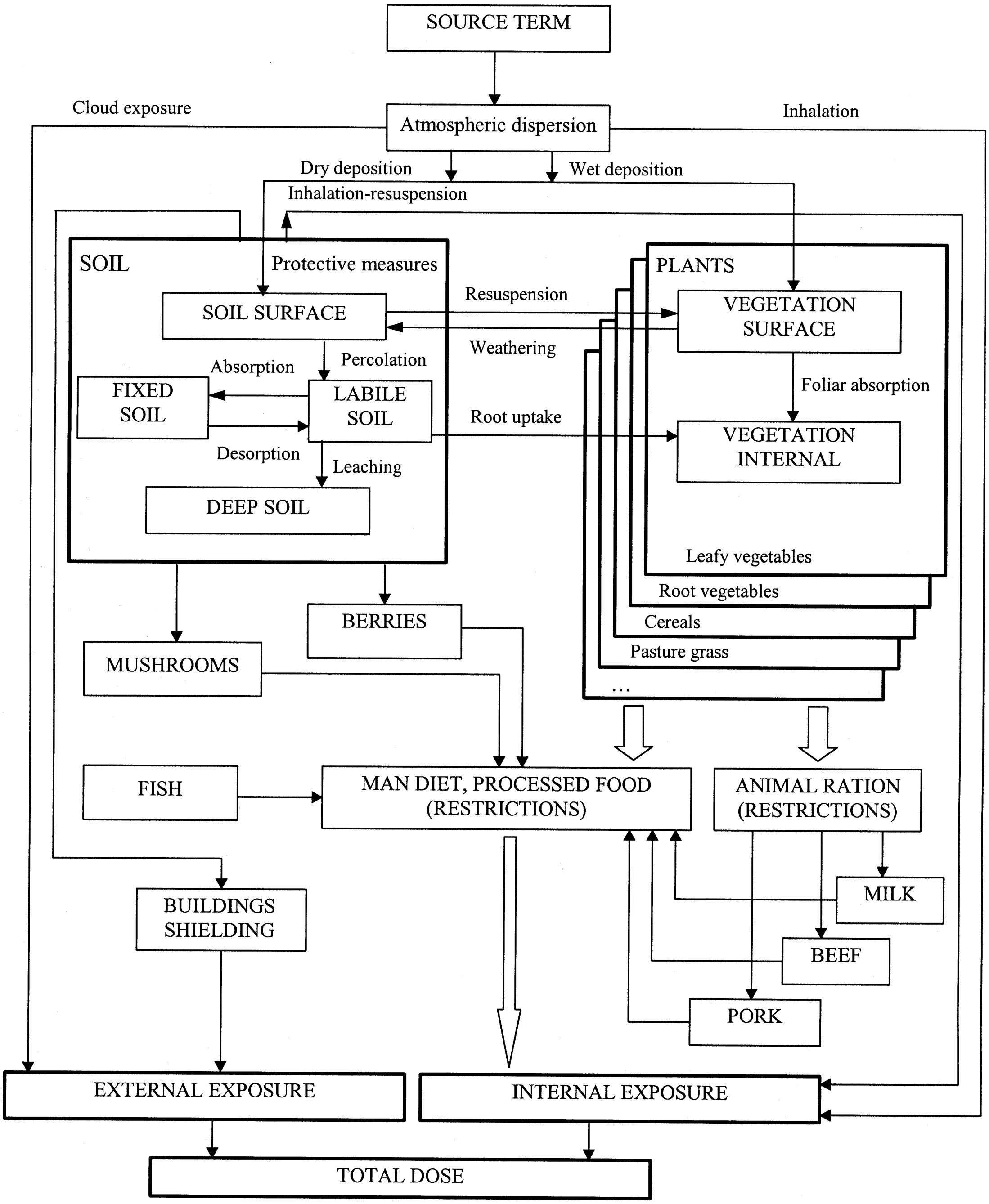

FIG. II-1.1. LIETDOS model structure and flow chart.

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[1] In the case of IPUT RIVER scenario exercise this LIETDOS-FILTSEG submodel was not used.

LIETDOS biosphere submodel contains a suite of models, which simulate radionuclide transfer through different parts of the foodchain. Air concentration/deposition values are needed to run the calculations. The main primary products and food considered are green vegetables, grain products, root vegetables, milk, meat and seminatural products. The model is flexible to be adjusted to desirable region site-specific conditions and the release scenario. Default transfer parameter values in the model are selected for the Ignalina NPP region.

LIETDOS human exposure assessment submodel includes the following exposure pathways: external irradiation from the passing cloud, external irradiation from deposited materials, inhalation taking into account resuspension and ingestion of contaminated food. The population lifestyle and consumption habits are taken into account. As in the previous case, default transfer parameter values are selected for the Ignalina NPP region. LIETDOS biosphere and human exposure submodels are described by the first order differential equation systems and solved numerically using Adams-Moulton Gear BDF method.

The flowchart indicating the structure of the LIETDOS and radionuclide migration pathway is presented in Figure II-1.1.

- The end points of the calculations can be selected from the following list:
- spatial distribution of the integrated air concentration and/or ground deposition;
- plant contamination;
- forage, primary products and food contamination;
- the prognosis of agricultural countermeasures and consumption restriction efficiency (this file was created additionally for the Iput River scenario exercise);
- external and internal exposure dose assessment of selected human critical groups.

Isotopes of iodine, cesium and strontium are treated in greatest detail. The LIETDOS code is still being developed although the validation study has been performed (IAEA, BIOMASS, Hanford scenario exercise).

LIETDOS model is deterministic. The latter versions of LIETDOS will include possibilities for probabilistic calculations.

II–1.1.3. LIETDOS modifications for the Iput River scenario

The purpose of LIETDOS involvement in the Iput River scenario exercise has been to test the generic LIETDOS model (predictions to tests data). However, additionally some files were created for the evaluation of agricultural countermeasures and the consumption restriction influence on human exposure as well as for the assessment of the distribution function of whole body cesium content. Attempt has been made to have each compartment or term in a model as accurate and as site-specific as possible.

II–1.1.4. Method used for deriving uncertainty estimates

All statistical information given to modellers in the scenario description was taken into account. The probabilistic LIETDOS code is under development. In this connection the deterministic code was run repeatedly to generate the distribution of predictions. Uncertainties in the model output were estimated statistically using Monte Carlo sampling for all parameters. The intended accuracy of the model predictions is to within a half order of magnitude. The work is currently in progress.

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II–1.2. DESCRIPTION OF PROCEDURES, EUQATIONS AND PARAMETERS USED IN THE MODEL PREDICTIONS

II–1.2.1. The contamination density

The density of contamination and vertical distribution of ^{137}Cs in Novozykov area soils were used for the evaluation of contamination density distribution with the following initial assumptions:

- the soil activity, mostly measured in 1991, was regarded as the inventory of 1986 taking into account the radioactive decay;
- the average mean of contamination density has been calculated on the basis of data for each district of Novozybkov region and vertical distribution of ^{137}Cs in Novozybkov area soils. The rough estimate concerning the triangular soil activity distribution of separate districts and Monte Carlo generation procedure serve as initial assumption for the evaluation of average soil activity values and confidence intervals.

These evaluations have been performed separately for the controlled area (with the ^{137}Cs soil contamination density above 555 kBq m^{-2}) and the non-controlled area (with the^{137}Cs soil contamination density below 555 kBq m^{-2}). The contamination density distributions in the case of controlled and non-controlled areas as well as the regional distribution pattern are presented in Figure II-1.2. These distributions were used as the basis in the case of uncertainty estimation of the other test data.

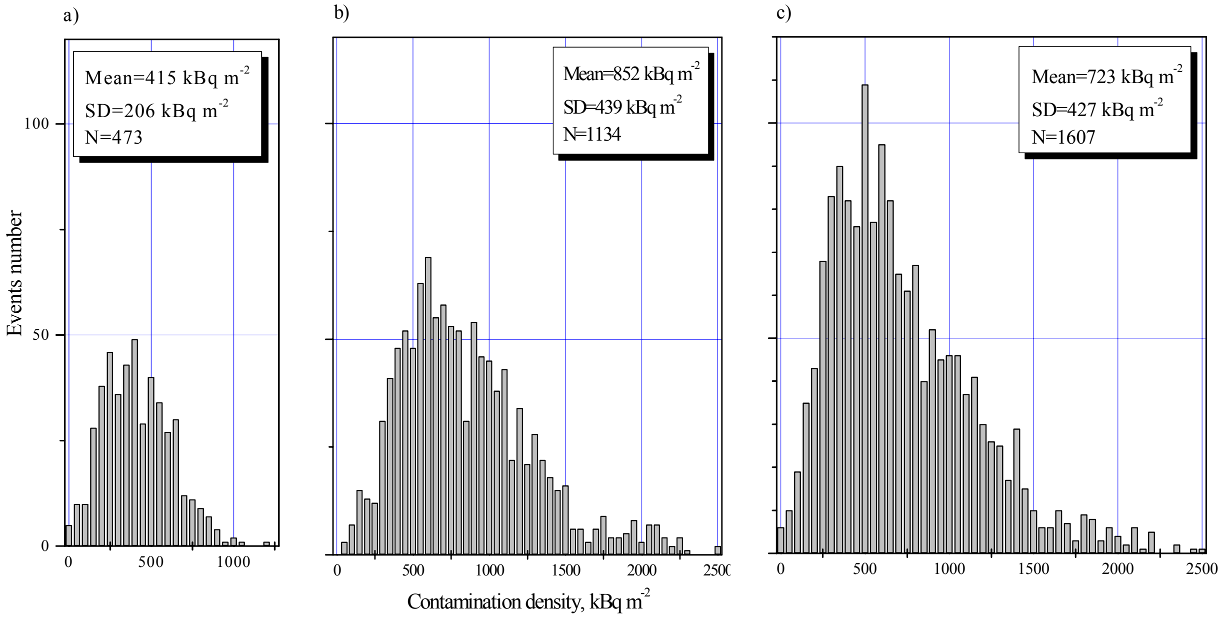

FIG. II-1.2. The distribution of ^{137}Cs contamination density: a) controlled area; b) non-controlled area; c) Novozybkov district.

II–1.2.2. Soil contamination density and agricultural countermeasures

LIETDOS soil compartment was divided into the upper 0.1 cm height soil surface layer, the root layer (0.1 – 30 cm) and the deep soil layer. The root zone of the pasture and crops extends up to the 10 cm and 20 cm depths respectively. Labile and fixed fractions of cesium in the root zone soil were considered. Radionuclide migration in soil layers was evaluated using the following equations:

$$\frac{dC_{SS}(t)}{dt} = \{[1 - R_d(t)]v_D + [1 - R_w(t)]w_o I_w(t)\}C_{air}(t) + \lambda_w C_{VS}(t) - (\lambda_r + f_{res} v_D + \lambda_{per})C_{SS}(t)$$

$$\frac{dC_{LS}(t)}{dt} = \lambda_{per} C_{SS}(t) + \lambda_{des} C_{FS}(t) - \left[\lambda_r + \lambda_s + \lambda_{abs} + \frac{B_v}{L_s \rho_s}\frac{dY(t)}{dt}\right]C_{LS}(t)$$

$$\frac{dC_{FS}(t)}{dt} = \lambda_{abs} C_{LS}(t) - (\lambda_r + \lambda_{des})C_{FS}(t)$$

where

$C_{SS}(t)$ = soil surface layer contamination (Bq m^{-2});
$C_{VS}(t)$ = plant activity (Bq m^{-2});
$C_{LS}(t)$, $C_{FS}(t)$ = labile and fixed soil contamination (Bq m^{-2});
$C_{air}(t)$ = air activity (Bq m^{-3});
$I_w(t)$ = precipitation rate (mm d^{-1});
$R_d(t)$, $R_w(t)$ = dry and wet interception factors [1];
v_D = dry deposition velocity = 173 m d^{-1} [2];
w_o = washout ratio = 6.2 × 10^5 Bq m^{-3} [rain]·(Bq m^{-3} [air])$^{-1}$) [2];

$Y(t)$ = yield of pasture (kg [f.w.] m^{-2});
λ_r = radioactive decay constant (d^{-1});
λ_w = weathering constant = 5.0×10^{-2} d^{-1} [2];
λ_s = leaching constant = 1.0×10^{-5} d^{-1} [3];
λ_{abs} = labile soil absorption constants = 9.5×10^{-4} d^{-1}; for grass = 1.9×10^{-3} d^{-1} [4,5];
λ_{des} = labile soil desorption constants = 3.8×10^{-4} d^{-1}; for grass = 2.1×10^{-4} d^{-1} [4,5];
λ_{per} = percolation constant = 2.0×10^{-2} d^{-1} [3];
f_{res} = resuspension constant = 1.0×10^{-6} Bq m^{-3} [air] (Bq m^{-2} [soil])$^{-1}$ [6];
B_v = transfer parameter from soil to plant = 2.0×10^{-2} Bq kg^{-1} [plant f.w.] (Bq kg^{-1} [soil d.w.])$^{-1}$ [2];
L_{root} = root zone depth (m);
ρ_s = soil density (assumed to be 1.46×10^3 kg m^{-3}).

According to the scenario, agricultural use of arable land was subjected to the following restrictions. The area contaminated up to 185 kBq m^{-2} was the threshold for stopping farming activities. The protective measures have been used in many applications in agricultural areas with intermediate contamination density (especially from 555 to 1480 kBq m^{-2}). Agricultural use of plough land and hay pasture subjected to contamination densities exceeding 1480 kBq m^{-2} was terminated by 40% in 1987 and by 100% in 1988.

The following protective measures for the reduction of ^{137}Cs uptake by plants were applied during 1987–1989:

- greater amounts of mineral and organic fertilisers (up to 1.5-2.0 usual dose) were used for agricultural land, which contributed to decrease uptake by plants 2-4 times;
- lime materials with low pH which decrease ^{137}Cs uptake by plants 2-4 times;
- ploughing of pasturelands effected a decrease of its activity in plants up to 2 times.

The applied agricultural countermeasures are presented in Table II-1.1.

TABLE II-1.1. AGRICULTURAL COUNTERMEASURES FOR THE REDUCTION OF ^{137}Cs UPTAKE BY PLANTS

Contamination density, kBq m^{-2}	Year	Recultured pasture, %	^{137}Cs uptake by plant decrease factor	
			Plough land*	Pasture
185-555	1986	6.4	1	2
	1987	14.0	1	2
	1988	35.7	1	2
	1989	64.6	1	2
555-1480	1986	6.4	2	2
	1987	14.0	2	2
	1988	35.7	2	2
	1989	64.6	2	2
>1480	1986	6.4	2	2
	1987	14.0	2	2

* Contaminated area of plough land was evaluated according data presented in Table I.XL.

II–1.2.3. The contamination of plants

The time dependent activity in the k-type plant $C_k(t)$ (Bq kg^{-1} [f.w.]) due to deposition from the air, resuspension from the contaminated soil surface on the vegetation surface, radionuclide translocation from the vegetation surface to internal parts of plants and the radionuclide root uptake from soil to vegetation was calculated by means of equation:

$$C_k(t) = \frac{C_{VS,k}(t) + C_{VI,k}(t)}{Y(t)},$$

where

$$\frac{dC_{VS,k}(t)}{dt} = \left[v_D R_d(t) + w_p I_w(t) R_w(t)\right] C_{air}(t) + f_{res} v_D C_{SS}(t) - (\lambda_r + \lambda_w) C_{VS,k}(t)$$

$$\frac{dC_{VI,k}(t)}{dt} = \frac{B_v}{L_s \rho_s} \frac{dY(t)}{dt} C_{LS}(t) + \lambda_{fabs} C_{VS,k}(t) - \lambda_r C_{VI,k}(t)$$

and

$C_{VS,k}(t)$ = k-type plant surface activity (Bq m^{-2});

$C_{VI,k}(t)$ = k-type internal plant activity (Bq m^{-2});

$R_d(t)$ = time dependent dry interception factor for grass and leafy vegetables $R_d(t) = 1 - \exp[-\mu \cdot DMC \cdot Y(t)]$, and constant interception factors for potatoes $R_d = 0.4$, cereals $R_d = 0.3$ [7];

$R_w(t)$ = time dependent wet interception factor $R_w(t) = 1.0$ for light rain ($I_w < 7.3$ mm d^{-1}) and $R_w(t) = 0$ for heavy rain [7];

μ = absorption coefficient (m^2 kg^{-1}); (Chamberlain's constant 2.8 m^2 kg^{-1} [d.w.]);

DMC = dry matter contents of the biomass [8];

$Y(t)$ = yield of pasture (kg m^{-2} [f.w.]);

L_s = root zone deep (m);

λ_{fabs} = foliar absorption constant (assumed to be 3.4 × 10^{-2} d^{-1} for cereals, green vegetables and grass; and 5.8 × 10^{-2} d^{-1} for potatoes) [3,7];

$I_w(t)$ = precipitation rate (mm d^{-1}).

For potatoes additional differential equation was used:

$$\frac{dC_T(t)}{dt} = \lambda_{Trans} C_{VI}(t) + \lambda_{RootTr} C_{LS}(t) - \lambda_r C_T(t)$$

In the case of cereals, the following additional equations were introduced:

$$\frac{dC_{SE}(t)}{dt} = p(v_D + R_w w_p I_0(t)) C_{air}(t) - (\lambda_r + \lambda_w) C_{SE}(t)$$

$$\frac{dC_{SI}(t)}{dt} = \lambda_{Trans} C_{VI}(t) - \lambda_r C_{SI}(t),$$

where

$C_T(t)$ = potato tuber activity (Bq m^{-2});
$C_{SE}(t)$ = cereal grain surface activity (Bq m^{-2});
$C_{SI}(t)$ = cereal grain internal activity (Bq m^{-2});
λ_{Trans} = transfer constant from internal plant to tuber (assumed to be 5.8×10^{-5} d^{-1}); to cereal grain $6.4 \cdot 10^{-2}$ d^{-1} [7];
λ_{RootTr} = transfer constant for root uptake to tuber (assumed to be 8.0×10^{-7} d^{-1}) [7];
p = retention on grain surface coefficient (assumed to be 0.012) [7].

The comparison of leafy vegetables, cereals, hay (grass) and potatoes activities, in the cases of applied protective measures and without protective measures, as well as the test data and change in provisional limits is presented in Figure II-1.3.

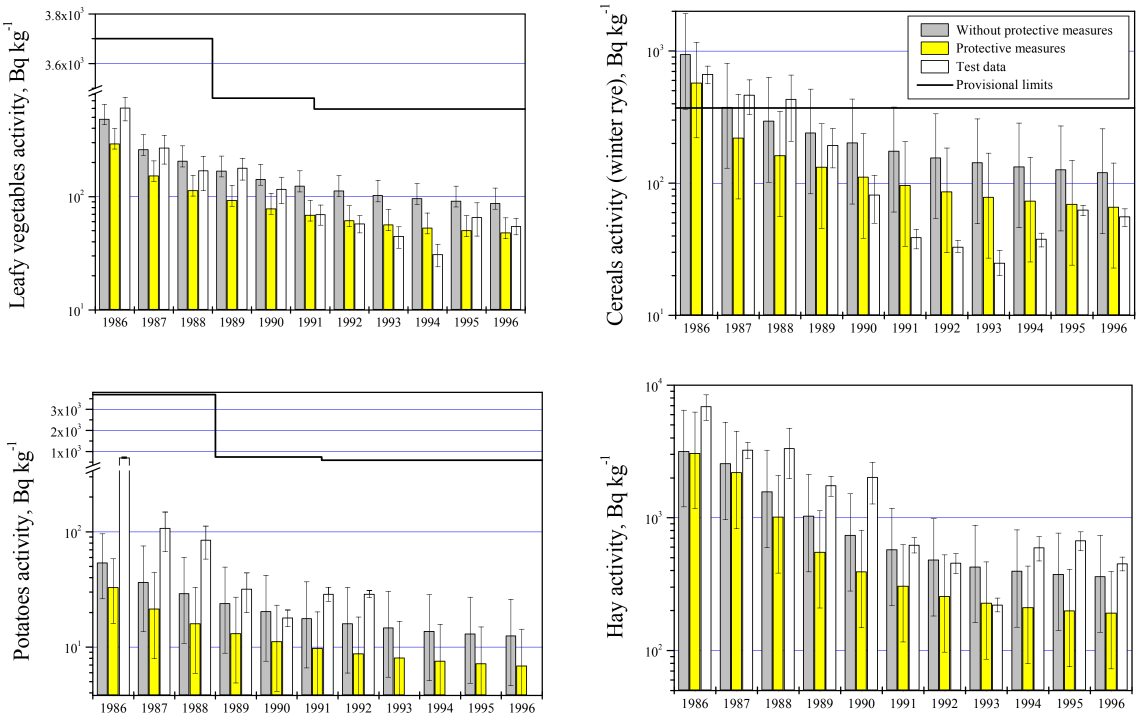

FIG. II-1.3. The comparison of leafy vegetables, cereals, potatoes and hay activities in the case of applied protective measures and without protective measures.

II–1.2.4. The contamination of forage, primary products and food

The contamination of primary products, due to ingestion of contaminated forage was evaluated as follows:

$$C_k(t) = F_k \sum_r C_{forage,r}(t) u_{kr}(t),$$

where

$C_k(t)$ = specific activity of *k*-type primary product (Bq kg^{-1}; Bq L^{-1});
F_k = equlibrium transfer parameter from forage to beef 2.0×10^{-2} d kg^{-1}, pork 0.24 d kg^{-1} and milk 7.0×10^{-3} d L^{-1} [2];
$C_{forage,r}(t)$ = specific activity of *r*-type forage (Bq kg^{-1});
u_{kr} = rations for bulls, dairy cows and pigs (according to the scenario Tables 34–36), (kg d^{-1}).

The contamination of food was evaluated as follows:

$$C_{food,k}(t) = F_{rk} C_k(t)\,,$$

where

$C_{food,k}(t)$ = *k*-type food product specific activity (Bq kg^{-1});
F_{rk} = remaining activity fraction after processing of *k*-type food product [10].

Assumptions for forage, primary products and food contamination:

- activity losses due to storage of forage and food were not considered;
- only locally produced forage and food were used;
- the radionuclide intake via the inhalation pathway by animals was not considered;
- soil consumed by cow during grazing was not taken into account.

The temporal changes in beef contamination are qualitatively closely related to the contamination of milk. The essential differences between the milk and beef activity include different infiltration factors and metabolic time constants related to the activity of forage. Milk, beef and pork activity values in the cases of applied protective measures and without protective measures, as well as the test data and change of provisional limits, are presented in Figure II-1.4. The presented data concerning the beef activity demonstrate that the recommendation to feed the cattle using uncontaminated forage at least 1.5-2 months prior to slaughtering is highly useful.

II–1.2.5. Human intake and whole body content evaluation

Human diet was as close as possible to that provided in the scenario descriptions (Tables 7a and 7b, second scenario version) for controlled and non-controlled areas separately. Processing losses are factored as reduction in the daily-ingested activity. The radionuclide human daily intake at the time *t* arising from the consumption of contaminated food was calculated as follows:

$$Q_{intake}(t) = \sum_i u_i(t) C_{food,i}(t)\,.$$

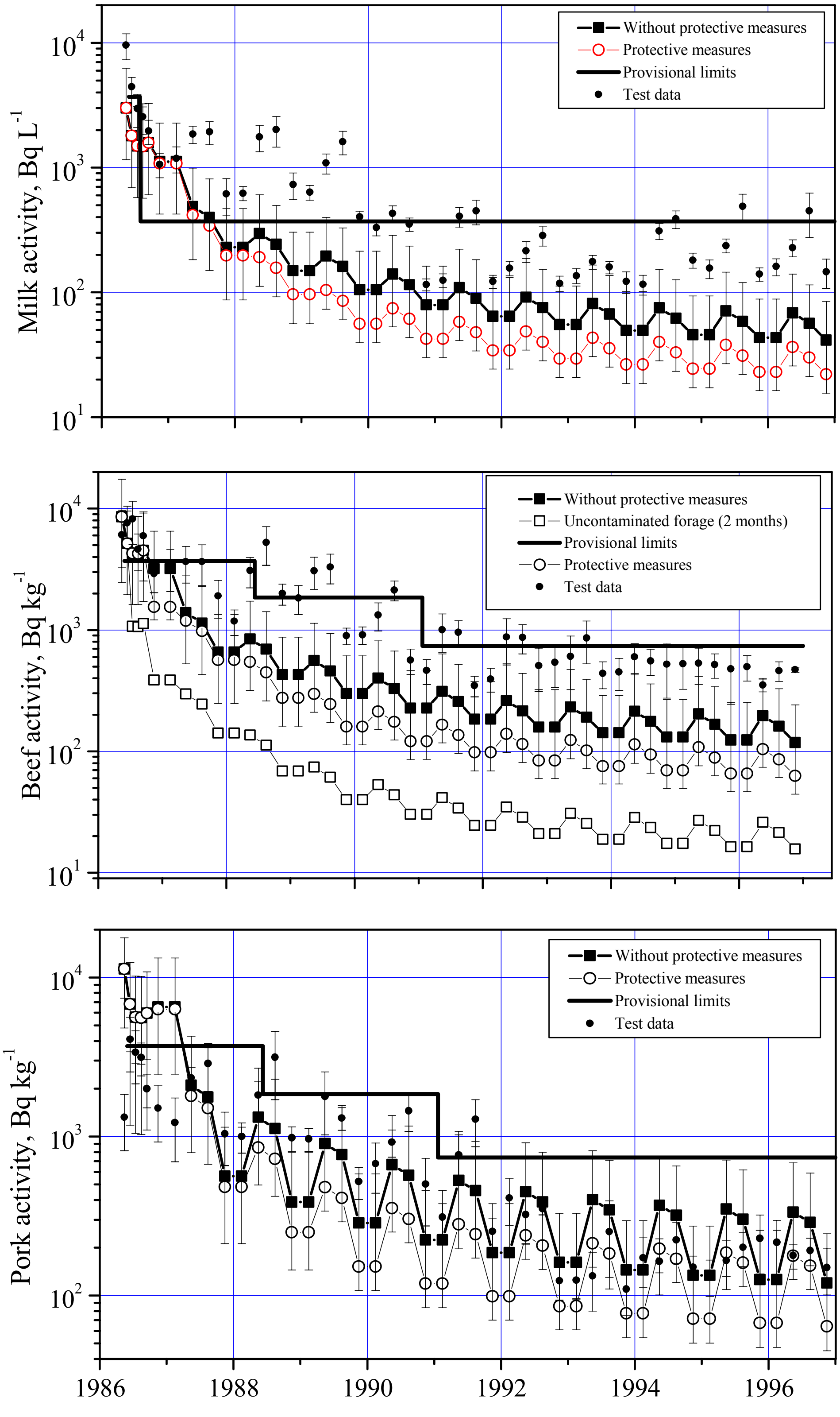

FIG. II-1.4. The temporal changes of milk, beef and pork contamination (beef contamination in the case of protective measures and in the case of uncontaminated forage for 2 months before the slaughtering).

Whole human body content at time *t,* due to food contaminated by ^{137}Cs consumption, was calculated by means of the following equations:

$$C_{wb}(t) = C_{wb,1}(t) + C_{wb,2}(t)$$

$$C_{wb,n}(t) = C_{wb,n}(t_0)\exp[-\lambda_{eff,n}(t-t_0)] + \frac{f_n}{m}\int_{t_0}^{t} Q_{\mathrm{int}\,ake}(\tau)\exp[-\lambda_{eff,n}(t-t_0-\tau)]d\tau\,,$$

where

$\lambda_{eff,n}$ = $\lambda_r + \lambda_{b,n}$ (n = 1, 2);
Q_{intake} = human daily intake of ^{137}Cs activity (Bq d^{-1});
$C_{wb,n}$ = separate fraction concentration in the whole body (Bq kg^{-1});
u_i = human consumption rate of I-th foodstuffs (kg d^{-1});
$\lambda_{b,1}$ = long term retention constant = 0.00815 d^{-1} [9];
$\lambda_{b,2}$ = short term retention constant = 0.347 d^{-1} [9];
f_1 = long term retention fraction = 0.9 [9];
f_2 = short term retention fraction = 0.1 [9];
m = whole body mass (assumed to be 70 kg).

Applied restrictions for food consumption were taken from the scenario. The comparison of human intake and the whole body ^{137}Cs activity content for men living in controlled and non-controlled regions is presented in Figures II-1.5 and II-1.6, respectively.

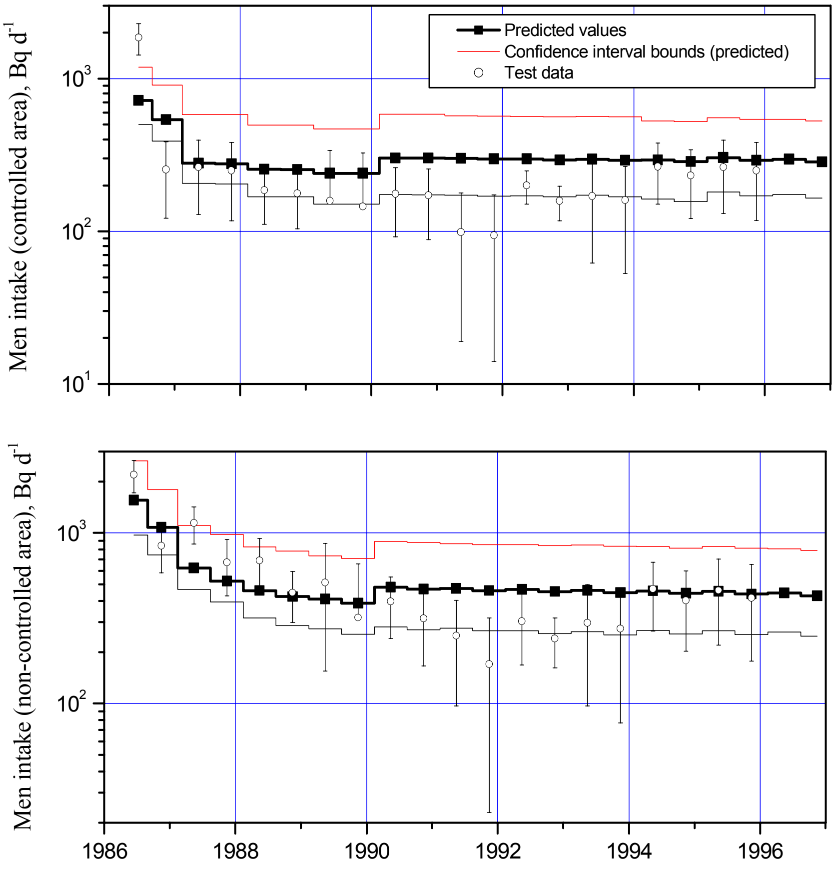

FIG. II-1.5. The comparison of human intake of ^{137}Cs activity for men living in controlled and non-controlled area.

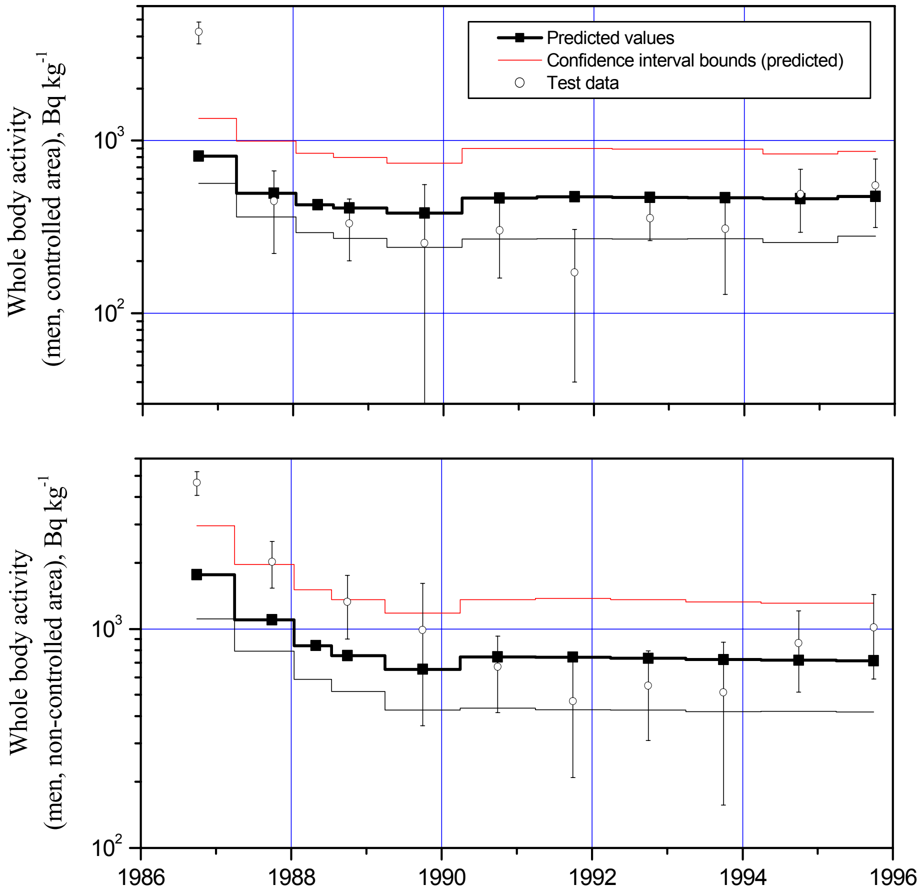

FIG. II-1.6. The comparison of the whole body activity concentration for men living in controlled and non-controlled area.

II–1.3. DOSE CALCULATIONS

Radiation exposure of people via different pathways (external exposure from cloud activities and ground shine, internal exposure from inhalation and ingestion) was evaluated separately for controlled and non-controlled regions.

II–1.3.1. The mean external dose from the cloud shine for adult men

The effective dose from the cloud shine has been estimated using the time-integrated concentration of ^{137}Cs in the air during the cloud passage. The following assumptions were used for external dose from the cloud evaluation:

- external dose evaluation was based on the 1 m height air volumetric activity value;
- external dose evaluation was based on gamma radiation only;
- shielding factors for gamma radiation were considered outside and for three types of buildings: outside – 1.0; wood-frame house – 0.9; masonry house – 0.6; industrial building – 0.2 [10].

The uncertainties in the case of external dose from cloud were suggested to be the same as in the case of the integrated ^{137}Cs air activity concentration. The external effective dose from cloud was evaluated by means of the equation:

$$H_{cloud} = S_{cloud} H^{0}{}_{cloud} \int_{0}^{t_e} C_{air}(t)dt \, ,$$

where

t_e = exposure time period (d);
C_{air} = ^{137}Cs activity concentration in air (Bq m^{-3});
S_{cloud} = shielding factor [10];
$H^{0}{}_{cloud}$ = dose-rate conversion factor for ^{137}Cs, when ^{137}Cs and ^{137m}Ba nuclide in air are at equilibrium: $H^{0}{}_{cloud} = H^{0}{}_{cloud,Cs-137} + f_{Cs-137 \rightarrow Ba-137m} H^{0}{}_{cloud,Ba-137m}$ = 2.35 × 10^{-9} Sv (Bq d m^{-3})$^{-1}$ [11];
$f_{Cs-137 \rightarrow Ba-137m}$ = the fraction of the ^{137}Cs transformations forming ^{137m}Ba = 0.946 [11];
$H^{0}{}_{cloud,Cs-137}$ = effective dose coefficients for radionuclide ^{137}Cs submersion in air = 6.69 × 10^{-13} Sv (Bq d m^{-3})$^{-1}$ [11];
$H^{0}{}_{cloud,\ Ba-137m}$ = effective dose coefficients for radionuclide ^{137m}Ba submersion in air = 2.49 × 10^{-9} Sv (Bq d m^{-3})$^{-1}$ [11].

II–1.3.2. The mean external dose from the ground shine for adult men

For external dose from ground shine exposure evaluation, the diffusion-convection model describing ^{137}Cs migration in soil has been used.

The following assumptions were used for the evaluation of the external dose from the ground:

- ground shine exposure was evaluated at 1 m height above the ground surface level;
- ground shine exposure evaluation was based on gamma radiation only;
- shielding factors from gamma ground shine evaluation were considered for two types of buildings: wood-frame house – 0.4; masonry house – 0.2 and outside – 1.0 [10].

Diffusion coefficient and convection parameter values were taken from [12]. Dose-rate conversion factors for the photon emitters in soil were taken from [13].

The mean external dose for adult men from contaminated ground was given as follows:

$$H_{ground}(T) = S_{ground} H^{0}{}_{ground} D_0 \int_{0}^{t_e} k_{DRFrel}(t)dt \, ,$$

where

H_{ground} = maximal dose at 1 m above ground (Sv);
t_e = exposure time period (s);
D_0 = initial average deposition (Bq m^{-2});
$H^{0}{}_{ground}$ = dose-rate at 1 m above ground per unit of deposited activity for ^{137}Cs = 2.8712 × 10^{-11} Sv d^{-1} Bq^{-1} m^{2} [11];
S_{ground} = integrated shielding factor for groundshine (assumed to be 0.45);

S_{ground} = integrated shielding factor for groundshine (assumed to be 0.45);
$k_{DRFrel}(t)$ = relative external dose rate at time t for photon emitters in soil.

$$k_{DRFrel}(t) = \frac{\int_0^1 Q(x,t) \cdot DRF_\gamma(x, E_\gamma)dx}{D_0 \cdot DRF_\gamma(0, E_\gamma)},$$

where

$Q(x,t)$ = radionuclide specific activity in soil at any depth x and time t (Bq m^{-3});
x = soil depth (m);
$DRF_\gamma(x,E_\gamma)$ = dose-rate conversion factor ((Gy a^{-1}) (Bq $m^{-2})^{-1}$) [13].

Activity migration in soil was calculated using convection-diffusion model (the Fokker-Planck equation):

$$\frac{\partial Q}{\partial t} = D\frac{\partial^2 Q}{\partial x^2} - V_k \frac{\partial Q}{\partial x} - \lambda_r Q,$$

where

$Q(x,t)$ = radionuclide specific activity in soil at any depth x an d time t (Bq m^{-3});
D = diffusion coefficient = 0.172 (SD=0.113) cm^2 a^{-1} [12];
V_k = Darcy velocity = 0.135 cm a^{-1} [12];
λr = decay constant (a^{-1});
$\delta(x)$ = delta function.

The solution of the equation was obtained under the following initial and boundary conditions:

initial condition $Q|_{t=0} = 0$ at $x = 0$,

boundary condition $D\frac{\partial Q(x,t)}{\partial x} - V_k Q(x,t) = D_0 \delta(t) \quad when \quad x > 0, \quad t = 0,$

$$Q(x,t) = D_0 \exp(-\lambda_r t)\left\{\frac{1}{\sqrt{\pi D t}}\exp\left[-\frac{(x - V_k t)^2}{4Dt}\right] - \frac{V_k}{2D}\exp\left(-\frac{V_k x}{D}\right) erfc\left(\frac{x + V_k t}{2\sqrt{Dt}}\right)\right\},$$

where

$erfc(x)$ = complementary error function of x.

The correction function for shielding due to leaching of the radionuclide in soil is presented in Figure II-1.7. The comparison of predicted and tests data for ground exposure is presented in Figure II-1.8.

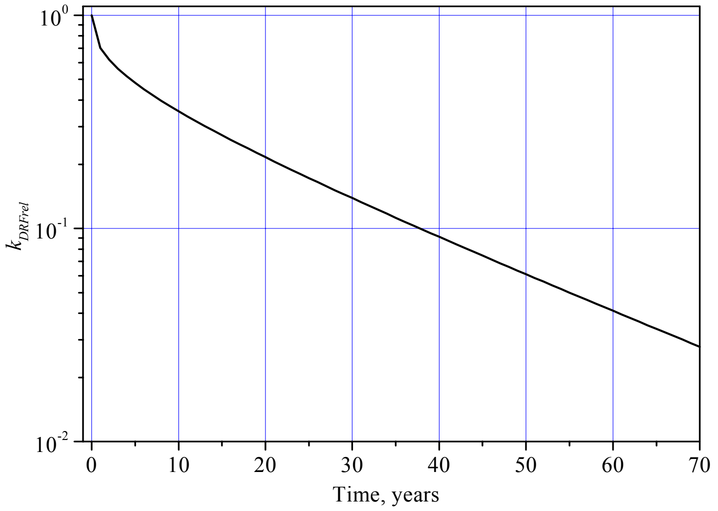

FIG. II-1.7. Time dependent changes of relative external dose rate in soil k_{DRFrel} *in the case of* ^{137}*Cs and* ^{137m}*Ba nuclide photon emitters in equilibrium.*

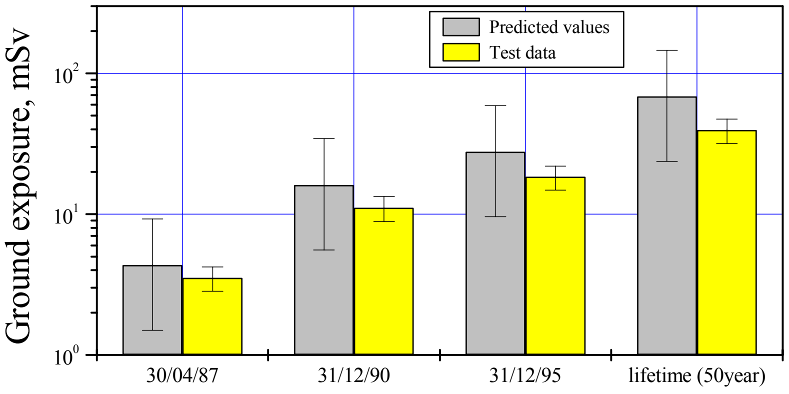

FIG. II-1.8. The comparison of predicted and tests data for ground exposure.

II–1.3.3. The inhalation dose due to cloud activity and resuspension

For the estimation of inhalation dose due to cloud activity, the measured air concentration was available for only one sampling station. The time-integrated air concentration during the period of cloud passing and human exposure dose due to inhalation were evaluated by means of equation:

$$H_{inhalation} = F \cdot H^0{}_{inhalation} v_{inh} \int_0^T C_{air}(t)dt \, ,$$

where

$H^0_{inhalation}$ = dose conversion factor for ^{137}Cs = 8.620×10^{-9} Sv Bq^{-1} [14];
v_{inh} = inhalation rate for adult man = 24.0 m^3 d^{-1} [15];
F = filtering factor (assumed to be = 1) [10].

The inhalation dose due to resuspended ^{137}Cs ($H_{resuspensio}$) was given as follows:

$$H_{resuspension}(t) = F \cdot H^0{}_{inhalation} v_{inh} \int_0^T f_{resuspension}(t) D_{eff}(t) dt \,,$$

where

$f_{resuspension}(t)$ = $1.2 \cdot 10^{-6}$ $(t\text{-}t_0)^{-1}$ (Bq m^{-3}) (Bq m^{-2})$^{-1}$; t in days [6].

II–1.3.4. The ingestion dose for adult

The internal exposure due to ingestion of contaminated food was evaluated by means of equation:

$$H_{ingestion}(t_e) = H^0{}_{ingestion} \sum_i \int_0^{t_e} u_i(t) C_{food,i}(t) dt \,,$$

where

$H^0_{ingestion}$ = dose conversion factor (ingestion) = 1.40×10^{-8} Sv Bq^{-1} [13].

The comparison of predicted and tested ingestion dose data for men and women living in controlled and non-controlled areas of Novozybkov region is presented in Figure II-1.9.

In spite of application of protective measures and food restrictions, milk and meat were the main irradiation contributors in 1986 and 1987. Consumption of natural food derived from the forest ecosystem progressively increases and becomes a major dose contributor after 1988. It must be noted that the restrictions for mushrooms and berries produce little effect on the internal annual dose value.

II–1.3.5. Total doses

Comparisons between evaluated and tested values of total doses are presented in Figure II-1.10.

It must be noted, that the differences between predicted and test data for total dose could be explained mainly by external (ground shine) exposure overestimation due to imprecise interpretation of scenario data concerning lifestyle, and occupancy, as well as shielding factors.

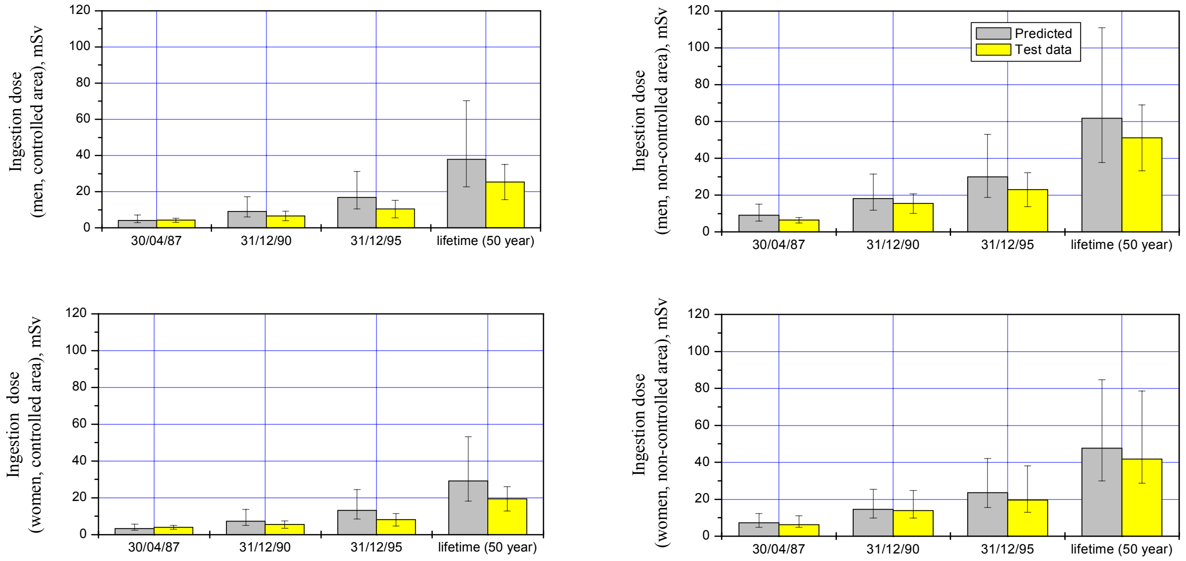

FIG. II-1.9. The comparison of predicted and test data of ingestion doses for men and women living in controlled and non-controlled areas of Novozybkov region.

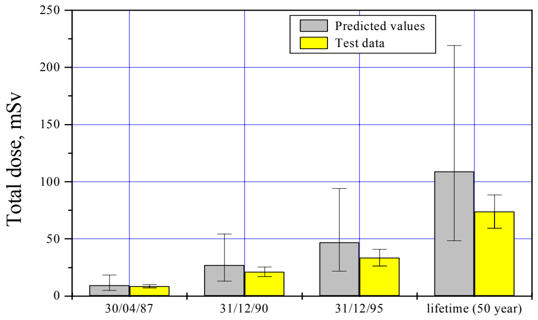

FIG. II-1.10. Comparisons between evaluated and tested values of total doses

II–1.4. SUMMARY OF LESSONS LEARNED FROM THE SCENARIO

In most cases LIETDOS model results were in sufficiently good agreement with the test data and differed by no more than a factor of three. An uncertainty in prediction of LIETDOS model arises from many sources. These include the adequacy of the conceptual model, the quality of the model code, the details contained in the scenario description, the quality of the test data, the uncertainty in parameter values, the assumptions made by user, etc. The participation in the Iput River test exercise provided an opportunity to correct errors in LIETDOS computer code, to improve the model structure and equations, to choose the corresponding parameter values, etc. For example, the model used to predict the contamination of leafy vegetables underestimates ^{137}Cs activity concentration. The main reason for such underestimation was attributed to the incorrect pattern of the growth period and yield in the previous LIETDOS version. The attempt has been made to have each compartment or term in a model as accurate and as site-specific as possible.

The Iput River scenario contains unconventional test data concerning administrated human dose restriction countermeasures and a great quantity of ^{137}Cs content in human body test data (especially in the last scenario version). It must be pointed out that the Iput River scenario contains a great number of reliable soil contamination density data, but very few corresponding air concentration and rainfall observation data. The rough approximate calculations disclosed some discrepancies[2] in data presented in this scenario. Integrated air concentration was about 180 Bq d m^{-3}. The mean value of soil contamination density for the Novozybkov district was equal 720 kBq m^{-2}. At the state of equilibrium these data correspond to the weighted average of 6.2 mm d^{-1} for the rainfall value in the case of the dry deposition velocity of 173 m d^{-1} and the washout ratio of 6.2×10^5 (Bq m^{-3} [rain]) (Bq m^{-3} [air])$^{-1}$). Such or similar rainfall data values were not presented in the scenario. That is why soil contamination densities were used as background to run calculations.

The fundamental importance of the possibility to exchange the knowledge and experiences during the discussions among the international BIOMASS project participants should be noted. The comparison between models on the basis of the scenario has given the opportunity to check the model performance and gain additional knowledge about the efficiency of agricultural countermeasures and food restrictions in the case of accidents.

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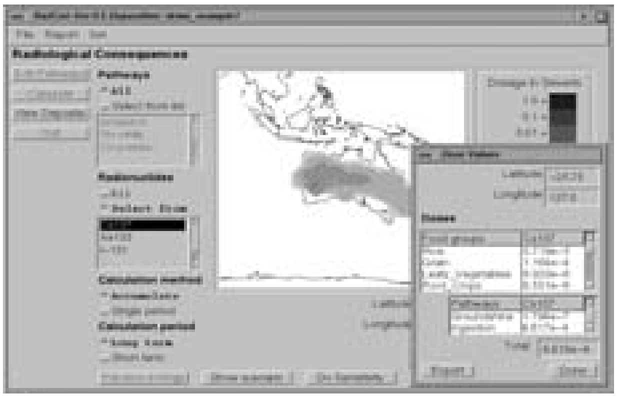

II–2. RADCON – AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

Radiological Consequences Model, A Radiological Consequences Model for use in the Australian and South East Asian Region, Model evaluation for the Iput scenario exercise

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II–2.1. INTRODUCTION

At the Australian Nuclear Science and Technology Organisation (ANSTO), a model – RadCon – was developed to assist in assessing the radiological consequences after an incident in any climate, depending on the meteorological and parameter input. The major areas of interest to the developers are those within tropical and subtropical climates, particularly of South East Asia. This is particularly so, given that nuclear energy use is increasing and may become a mainstay for economies in these regions within the foreseeable future. Therefore, data acquisition and choice of parameter values have been concentrated primarily on these climate types.

The intended use of the model is for assessing consequences in an affected area following an accidental release of radionuclides into the atmosphere. The current RadCon model does not directly implement countermeasures, but these can be addressed through changes to the soil characteristics and food processing parameters.

For use with the RadCon model, atmospheric dispersion and deposition data are currently supplied by the Regional Specialised Meteorological Centre (RSMC, one of five in the world) which is part of the Bureau of Meteorology Research Centre (BMRC) [Puri *et al.* 1992] in Melbourne. A pre-processor has been written to take the output from this model and prepare it in a format suitable for input to RadCon. This process may be applied to any regional atmospheric dispersion model. RadCon combines the time dependent air and ground concentration or measured test data with specific regional parameter values to determine the dose to man via the major pathways of external and internal irradiation.

The results of a wide ranging literature search highlighted that the information required to assess radiological consequences in tropical and sub tropical regions is far from adequate. It was therefore necessary to also acquire the data and parameters provided by researchers for temperate and cold climates. The availability of this data, plus the flexibility of the RadCon model, has allowed participation in the BIOMASS program and the inter laboratory evaluation of the performance of the RadCon model.

The model has also been developed to provide a tool for directing future research and has application as a planning tool for emergency response operations. The user is able to initiate sensitivity analyses within RadCon. This allows the parameters to be ranked in terms of priority of impact within the scenario being investigated.

II–2.1.1. Implementation

Given the wide variability in regions, the model was implemented such that:

- it is able to use inputs from different atmospheric transport models;
- all the required parameter values are separate from the program, thus allowing easy adaptation to new sites;
- it provides a graphical user interface and portability across computer platforms.

RadCon is implemented in the Java programming language and presents a graphical interface to the user. For example, the screen used for carrying out calculations is presented on the title page of this report.

II–2.2. RADCON MODEL DESCRIPTION

II–2.2.1. General asumptions

A large number of simplifying assumptions need to be made for any modelling system. Some assumptions for the implementation of this model are listed below. Others, which are pathway specific, are listed under the specific pathway. In the absence of site specific data, the majority of the assumptions are conservative.

- Effects on food chains in large volumes of water or moving streams are not modelled.
- A local production and consumption approach is considered, *i.e.* food produced in a grid location is consumed in that grid location with no transfer between grids. A factor is included to allow the user to specify what fraction of the food consumed by humans is produced locally.
- Food consumed by animals and humans is assumed to be harvested at the time of consumption, *i.e* no seasonal variation or storage of food or fodder is included.
- Food consumption is considered to be uniform on a daily basis.

II–2.2.2. Pathways

The major pathways used in this model are:

- External irradiation from material in the cloud. (Cloudshine)
- External irradiation from material deposited on the ground. (Groundshine)
- Internal exposure following inhalation.
- Internal exposure from ingestion of contaminated food.

II–2.2.2.1. External Exposure from the Ground (Groundshine)

The dose for time period t_0 to t_1 from radioactive material deposited on the ground is modelled by the following mathematical formula, adapted from Müller and Pröhl (1993):

$$D(r,t_0,t_1) = G(r)S(r)d(r)c\int_{t_0}^{t_1}\left[\alpha(r,s)e^{-(\lambda(r)+\lambda_1(r,s))t} + (1-\alpha(r,s))e^{-(\lambda(r)+\lambda_2(r,s))t}\right]dt \quad (1)$$

Table II-2.1.presents a description of the parameters in this equation, their units and dependencies. In addition to radioactive decay the function under the integral sign accounts for shielding due to migration into deeper soil layers.

TABLE II-2.1. GROUNDSHINE PARAMETERS

Parameters	Description	Unit	Depends on
$D(r,t_0,t_1)$	dose from radionuclide r in the time interval t_0 to t_1	Sv	radionuclide
$G(r)$	total ground concentration	Bq m^{-2}	radionuclide
$S(r)$*	location factor	dimensionless	lifestyle**, radionuclide
$d(r)$	dose conversion factor	$\frac{Sv}{Bqs/m^2}$	radionuclide
$\alpha(r,s)$	mobile component factor	dimensionless	radionuclide, soil
$\lambda(r)$	radionuclide decay rate	d^{-1}	radionuclide
$\lambda_1(r,s)$	migration rate, mobile component	d^{-1}	radionuclide, soil
$\lambda_2(r,s)$	migration rate, fixed component	d^{-1}	radionuclide, soil
$[t_0,t_1]$	time interval, measured after deposition has stopped	d^{-1}	
c	3600 * 24 (to convert days to seconds)	s d^{-1}	exposure period

* *S(r)* = Fraction of Time Out Door × Out Door Shielding Factor + Fraction of Time In Door × In Door Shielding Factor

** Lifestyle combines rural/residential/urban housing types and indoor/outdoor occupancy factors.

For dose calculation in the short term, (*i.e.* while deposition is occurring) the averaging time, Δt, used by the atmospheric transport model, is used as the interval $[t_0,t_1]$ and *G(r)* is the ground concentration for the associated time step, resulting in a dose being calculated for each time step.

II–2.2.2.2. Assumptions for Groundshine

- Gamma radiation only is considered
- Allowance is made for building attenuation by gamma radiation. In the model, three building types are considered – urban, rural and residential.
- Indoor and outdoor occupancy factors are implemented.
- The gamma dose rate is calculated for 1 metre above the ground.

II–2.2.2.3. Exposure from the Cloud (Cloudshine)

External irradiation from radioactive material in the cloud is modelled by the following mathematical formula. This is valid for a semI-infinite cloud, and can be applied without problems at locations far away from the source of emission where the concentration of activity is homogeneous. The description of parameters is given in Table II-2.2.

$$D(r,t_0,t_1) = A(r,t_0,t_1)S(r)d(r)(t_1 - t_0)c \qquad (2)$$

TABLE II-2.2. CLOUDSHINE PARAMETERS

Parameters	Description	Unit	Depends on
$D(r,t_0,t_1)$	dose from radionuclide r	Sv	radionuclide
$A(r,t_0,t_1)$	averaged airborne concentration in time interval $[t_0,t_1]$	Bq m^{-3}	radionuclide
S(r)*	location factor	dimensionless	lifestyle, radionuclide
d(r)	dose conversion factor	$\frac{Sv}{Bqs/m^3}$	radionuclide
c	3600 * 24	s d^{-1}	
$[t_0,t_1]$	interval of exposure	d	exposure period

*S(r) calculated as for Groundshine, but using appropriate values for shielding from the cloud

When an atmospheric transport model has been used to estimate the airborne concentration, the averaging time, Δt, used by the atmospheric transport model is used as the interval $[t_0,t_1]$.

II–2.2.2.3.1. Assumptions for Cloudshine

The model for the Cloudshine pathway has been adapted from Krajewski (1994). It is assumed that:

- The person is immersed in the cloud, therefore ground level air concentration is used (1 metre above the ground).
- Gamma radiation only is considered.
- Allowance is made for the attenuation of gamma radiation by buildings. In the model, three building types are considered, those for the rural, residential or urban areas.
- Indoor and outdoor occupancy factors are implemented.

II–2.2.2.4. Inhalation

Contribution of dose to humans is modelled by the following mathematical formula, with a description of the parameters given in Table II-2.3.

$$D(r,t_0,t_1) = A(r,t_0,t_1)F(r)I(r,a)d(r,a)(t_1 - t_0) \qquad (3)$$

TABLE II-2.3. INHALATION PARAMETERS

Parameters	Description	Unit	Depends on
$D(r,t_0,t_1)$	dose from radionuclide r	Sv	radionuclide
$A(r,t_0,t_1)$	averaged airborne concentration	$Bq\ m^{-3}$	provided
F(r)*	filtering factor	dimensionless	Shielding, radionuclide
I(r,a)**	inhalation rate	$m^3\ h^{-1}$	age, race
d(r,a)	dose conversion factor	$Sv\ Bq^{-1}$	radionuclide
$[t_0,t_1]$	interval of exposure	h	exposure period

* F(r) = Fraction of Time Out Door × Out Door Shielding Factor + Fraction of Time In Door × In Door Shielding Factor

** I(r,a) = Fraction of Time Resting × Resting Inhalation Rate + Fraction of Time Working × Working Inhalation Rate + Fraction of Time Alternate Activity × Alternate Activity Inhalation Rate, for the particular age group

When an atmospheric transport model has been used to estimate the airborne concentration the averaging time, Δt, used by the atmospheric transport model is used as the interval $[t_0,t_1]$.

II–2.2.2.4.1. Assumption for Inhalation

The model for the inhalation pathway has been adapted from Krajewski (1994). It is assumed that:

- The person is immersed in the cloud, therefore the ground level air concentration is used (1 metre above the ground).
- Indoor air concentration may be assumed to be less than the outdoor (Brown *et al.*, 1990). In the model, three building types are included, those for the rural, residential or urban areas. Thus a filtering factor is required for the shielding of building types.
- Indoor and outdoor occupancy factors are required to estimate the overall filtering factor to account for the attenuation.
- Physical activity modifies the breathing rate.
- Dose varies with the age of the individual.

II–2.2.2.5. Ingestion

Ingestion from crops and animals only is considered. These two ingestion pathways account for the major long-term dose following an accidental release to the atmosphere. In estimating the dose to humans from these pathways, the following are considered:

- soil to plant;
- direct deposition on foliage – dry deposition;
- interception by foliage – wet deposition;
- plant to animal and plant to human;
- animal to human.

The mathematical formulae adapted for this model are described in the following sections. Local production/consumption is assumed. A factor is, however, included which the used can specify, indicating what fraction of the food consumed by humans is produced locally. A reduction factor to account for food processing is also included in this model.

II–2.2.2.5.1. Radionuclide concentration in plant products

Contribution to contamination of plants can be included from the following:

- root uptake,
- direct deposit on foliage,
- interception by foliage (including translocation and weathering where appropriate).

II–2.2.2.5.1.1. Contamination due to root uptake

The concentration of radionuclide *r* in plant product *p,* due to transfer from the soil, is modelled by the following equation with the description of the parameters given in Table II-2.4.

$$P_r(r,p,t)=\frac{G(r)T_{sp}(r,p,s)}{P(s)K(s)}\left[\alpha(r,s)e^{-(\lambda(r)+\lambda_f(r,s)+\lambda_1(r,s))t}+(1-\alpha(r,s))e^{-(\lambda(r)+\lambda_f(r,s)+\lambda_2(r,s))t}\right] \tag{4}$$

TABLE II-2.4. PARAMETERS FOR ROOT UPTAKE

Parameters	Description	Unit	Depends on
$P_r(r,p,t)$	concentration of radionuclide r in edible part of plant p, at time t due to root uptake	Bq kg^{-1}	radionuclide, plant, time from deposit
G(r)	ground concentration	Bq m^{-2}	radionuclide
$T_{sp}(r,p,s)$	transfer factor from soil to plant p	Bq kg^{-1} crop per Bq kg^{-1} dry wt soil	radionuclide and plant, soil type
P(s)	initial soil bulk density	kg m^{-2}	soil type
K(s)*	soil reduction factor	dimensionless	migration of radionuclides
$\lambda_1(r,s)$	rate of migration below root zone of mobile component of radionuclide	d^{-1}	radionuclide, soil
$\lambda_2(r,s)$	rate of migration below root zone of fixed component of radionuclide	d^{-1}	radionuclide, soil
$\alpha(r,s)$	mobile component fraction	dimensionless	radionuclide, soil
$\lambda(r)$	radioactive decay	d^{-1}	radionuclide
$\lambda_f(r,s)$	rate of fixation	d^{-1}	radionuclide, soil
t			

* Depends on agricultural practices, e.g. ploughing.

II–2.2.2.5.1.2. Contamination due to direct deposition and interception fraction

Concentration in plant products and grass due to direct deposition and interception is modelled as in Müller and Pröhl (1993). A distinction is made between plants that are used totally (e.g. leafy vegetables) and those that are used only partially (e.g. cereals, potatoes and fruit). For plants with a specific edible part, the translocation of the activity from the foliage to the edible part is modelled, for those used totally a weathering factor is included. Grass forms a third group, where harvesting is continuous. In the implementation, different indicators are used with each crop presented to the model to flag which process (i.e. translocation, weathering as in leafy vegetables, or grass-like behaviour as in Section II–2.2.2.5.1.2.1) should be included in calculating the concentration in the plant product at harvest.

The total deposition onto plants is modelled according to Müller and Pröhl (1993). Total deposition to plants is given by the following equation with a description of the parameters given in Table II-2.5.

$$
\begin{aligned}
A(r,p) &= A_d(r,p) + f_w(r,p)A_w(r,p) \\
A_d(r,p) &= v(r,p)C_a(r) \\
v(r,p) &= v_{\max}(r,p)\frac{LAI(p)}{LAI_{\max}(p)} \\
f_w(r,p) &= \frac{LAI(p)S(p)}{R}\left[1-\exp\left(\frac{-\ln(2)}{3S(p)}R\right)\right]
\end{aligned}
\tag{5}
$$

TABLE II-2.5. PARAMETERS FOR TOTAL DEPOSITION ONTO PLANTS

Parameters	Description	Unit	Depends on
A(r,p)	total deposition onto plant *p*	Bq m^{-2}	radionuclide, plant
A_d(r,p)	total dry deposition onto plant *p*	Bq m^{-2}	radionuclide, plant
f_w(r,p)	interception fraction for plant *p*	dimensionless	radionuclide, plant
A_w(r,p)	total wet deposition onto plant *p*	Bq m^{-2}	radionuclide, plant
v(r,p)	deposition velocity for plant *p*	m s^{-1}	radionuclide, plant
V_{max}(r,p)	maximum deposition velocity for plant *p*, *i.e.* for a fully developed plant	m s^{-1}	radionuclide, plant
LAI(p)*	leaf area index of plant *p* at the time of deposition	m^2 m^{-2}	plant
LAI_{max}(p)	maximum leaf area index of plant *p* at the time of fully developed foliage	m^2 m^{-2}	plant
S(p)	retention coefficient of plant *p*, washoff	mm	plant, rainfall
C_a(r)	time-integrated activity concentration in air	Bq s m^{-3}`	radionuclide
R	amount of rainfall	mm	

* LAI is defined as the area of leaves present on a unit area of ground.

II–2.2.2.5.1.2.1. Modelling of grass

In the absence of further information for local conditions, the ability to express the LAI of grass by use of yield has been implemented, as in Müller and Pröhl (1993). The following equation is used, with a description of the parameters given in Table II-2.6.

$$
LAI(g) = LAI_{\max}(g)\left[1-e^{-kY_1(g)}\right] \tag{6}
$$

The total deposition on grass, *A(r,g)*, is estimated using equation 5 and including the information for grass as the plant type.

TABLE II-2.6. PARAMETERS FOR GRASS

Parameters	Description	Unit	Depends on
A(r,g)	total deposition onto grass (g)	Bq m^{-2}	radionuclide, grass
LAI(g)	leaf area index of grass at the time of deposition	m^2 m^{-2}	grass
LAI_{max}(g)	maximum leaf area index of grass	m^2 m^{-2}	grass
Y_1(g)	yield of grass at the time of deposition	kg m^{-2}	grass
k	normalisation factor	m^2 kg^{-1}	

II–2.2.2.5.1.3. Foliar uptake of radionuclides

Three groups of plants are considered:

- Plants that are used totally, *e.g.* leafy vegetables, where the concentration of the plant at time of harvest ($P_{d,1}$ in equation 7) is determined by the amount deposited, followed by activity loss due to weathering, radioactive decay and dilution due to growth.
- For plants that are only partly consumed, *e.g.* cereals, potatoes, translocation from the deposited material to the edible part is modelled (concentration is given by $P_{d,3}$ in equation 7).
- Grass, due to its continuous harvest. Here concentration ($P_{d,2}$ in equation 7) is decreased due to growth, weathering, radioactive decay and translocation to the root zone.

The following three equations are used (taken from Müller and Pröhl (1993)), with the parameters described in Table II-2.7.

$$
\begin{aligned}
P_{d,1}(r,p,t) &= \frac{A(r,p)}{Y(p)} e^{-(\lambda_w(r,p)+\lambda(r))t} \\
P_{d,2}(r,g,t) &= \frac{A(r,g)}{Y_1(g)} \left\{ (1-\alpha(r,g)) e^{-(\lambda_b(r,g)+\lambda_w(r,g)+\lambda(r))t} + \alpha(r,g) e^{-(\lambda_t(r,g)+\lambda(r))t} \right\} \\
P_{d,3}(r,p,t) &= \frac{A(r,p)}{Y(p)} T(r,p,t) e^{-(\lambda(r))t}
\end{aligned}
\tag{7}
$$

TABLE II-2.7. PARAMETERS FOR FOLIAR UPTAKE BY PLANTS

Parameters	Description	Unit	Depends on
$P_{d,i}(r,p,t)$	concentration of radionuclide r in plant p at time of harvest due to deposition and interception	Bq kg	radionuclide, plant
A(r,p), A(r,g)	total deposition onto plant p, or grass (g)		
Y(p)	yield of plant p at time of harvest	kg m^{-2}	plant
$Y_1(g)$	yield of grass at the time of deposition	kg m^{-2}	
$\lambda_w(r,p)$	loss rate due to weathering for plant p or grass (g)	d^{-1}	radionuclide, plant
$\lambda_b(r,g)$	dilution rate by increase of biomass in grass	d^{-1}	radionuclide, grass
$\lambda_t(r,g)$	rate of activity decrease due to translocation to the root zone in grass	d^{-1}	radionuclide, grass
$\lambda(r)$	radioactive decay	d^{-1}	radionuclide
$\alpha(r,g)$	fraction of activity translocated to the root zone in grass	dimensionless	
T(r,p,t)	time dependent translocation factor for plant p – fraction of the activity deposited on the foliage that is transferred to the edible part of the plants at harvest	dimensionless	radionuclide, plant, t is the time from deposition

II–2.2.2.5.2. Dose to humans due to ingestion of plant products

Dose to humans from radionuclide *r* due to consumption of plant product *p* over a time period $[t_0, t_1]$ is modelled by the following mathematical formula, with a description of parameters given in Table II-2.8. In this version of RadCon, harvest at time of consumption is assumed, *i.e.* all foodstuff is consumed at harvest (no storage).

$$
D_p(r,p,t_0,t_1) = \int_{t_0}^{t_1} (P_r(r,p,t) + P_d(r,p,t)) d(r,a) Q_p(p) F(p) P(p) dt \tag{8}
$$

TABLE II-2.8. PARAMETERS FOR CROP INGESTION BY HUMANS

Parameters	Description	Unit	Depends on
$D_p(r,p,t_0,t_1)$	committed effective dose from radionuclide r due to consumption of plant p from time t_0 to t_1	Sv	radionuclide, plant, time from deposit
$P_r(r,p,t)$	concentration of radionuclide r in plant p due to root uptake	Bq kg^{-1}	radionuclide, plant
$P_d(r,p,t)$	concentration of radionuclide r in plant p due to deposition and interception, and translocation where appropriate	Bq kg^{-1}	radionuclide, plant
d(r,a)	dose conversion factor	Sv Bq^{-1}	radionuclide, race, age
$Q_p(p)$	intake of food p	kg day^{-1}	diet
F(p)	fraction of total food consumed which is local	dimensionless	
P(p)	remainder of activity after food processing	dimensionless	

II–2.2.2.5.2.1. Assumptions for dose to humans due to radionuclide uptake from plants

- only the specified local fraction, F, of the food is contaminated
- a local production/consumption model is assumed
- dose is calculated assuming the plants are harvested at the time of consumption

II–2.2.2.5.3. Radionuclide contamination in animal products

Contamination to animals due to consumption of contaminated soil and crops is considered. Inhalation by animals and water intake is not taken into account. Research from the temperate climate studies had demonstrated minimal dose from these two pathways, in the case of atmospheric release (Safety Series 57, IAEA, 1982).

The concentration of radionuclide *r* in animal product *m* at time *t* is modelled by the following equation:

$$M_c(r,m,t) = M_{cs}(r,m,t) + \sum_{i=1}^{P} A_c(r,m,t,i) \tag{9}$$

where:

$M_c(r,m,t)$ is the concentration at time *t* of radionuclide *r* in animal product *m* (Bq kg^{-1});
$M_{cs}(r,m,t)$ is the concentration at time *t* of radionuclide *r* in animal product *m* due to soil ingestion;
$A_c(r,m,t,i)$ is the concentration at time *t* of radionuclide *r* in animal product *m* due to ingestion of plant product *i*;
P is the number of plant products in the animal diet.

II–2.2.2.5.3.1. Animal contamination due to plant product ingestion

Concentration in meat product *m* due to the consumption of feed crop *p* is modelled by the following equation, with a short description of parameters given in Table II-2.9.

$$A_c(r,m,t,p) = T_{pm}(r,m)Q(p,m)\int_{t-T}^{t}\left([P_r(r,p,x) + P_d(r,p,x)]f(r,m,t,x)\right)dx \tag{10}$$

where:

$$f(m,r,t,x) = \left(\alpha_m(m,r)\lambda_{m1}(m,r)e^{-(\lambda_{m1}(m,r)+\lambda(r))(t-x)} + (1-\alpha_m(m,r))\lambda_{m2}(m,r)e^{-(\lambda_{m2}(r,m)+\lambda(r))(t-x)}\right)$$

TABLE II-2.9. PARAMETERS FOR PLANT TO ANIMAL TRANSFER

Parameters	Description	Unit	Depends on
$A_c(r,m,t,p)$	concentration of radionuclide r in meat m from ingestion of plant p	Bq kg^{-1}	radionuclide, animal, plant
$P_r(r,p,t)$	concentration of radionuclide r in feed crop p due to root uptake	Bq kg^{-1}	radionuclide, plant
$P_d(r,p,t)$	concentration of radionuclide r in feed crop p due to deposition and interception	Bq kg^{-1}	radionuclide, plant
T	age of animal	d	
$\lambda_{m1}(m,r)$	removal rate constant (fast)of radionuclide concentration in an animal due to physiological processes	d^{-1}	animal, radionuclide
$\lambda_{m2}(m,r)$	removal rate constant (slow)of radionuclide concentration in an animal due to physiological processes	d^{-1}	animal, radionuclide
$\alpha_{m1}(m,r)$	fast removal component fraction	dimensionless	
$T_{pm}(r,m)$	transfer factor for radionuclide r from plants to animal m	d kg^{-1}	radionuclide, animal
Q(p,m)	quantity of feed crop p consumed by animal m	kg day^{-1}	plant, animal

II–2.2.2.5.3.1.1. Assumptions for radionuclide uptake by animals from plants

- Seasonal variation in diet is not considered, *i.e.* animals are fed uniformly throughout the year
- Animal feed is harvested at the time of consumption.

II–2.2.2.5.3.2. Animal contamination due to soil ingestion

The available soil concentration is modelled in the following equation, with the description of the parameters as given in Table II-2.4.

$$C_s(r,t) = \frac{G(r)}{P(s)K(s)}\left[\alpha(r,s)e^{-(\lambda(r)+\lambda_f(r,s)+\lambda_1(r,s))t} + (1-\alpha(r,s))e^{-(\lambda(r)+\lambda_f(r,s)+\lambda_2(r,s))t}\right] \tag{11}$$

Concentration in meat product *m* due to consumption of soil is given in the following equation with the parameters as defined in Table II-2-10.

$$M_{cs}(r,m,t) = C_s(r,t)Q(m)T_{pm}(r,m) \tag{12}$$

TABLE II-2.10. PARAMETERS FOR SOIL TO ANIMAL TRANSFER

Parameters	Description	Unit	Depends on
$M_{cs}(r,m,t)$	concentration of radionuclide r in meat m	Bq kg^{-1}	meat and radionuclide
$C_s(r,t)$	concentration of radionuclide r in soil	Bq kg^{-1}	radionuclide
$T_{pm}(r,m)$	transfer factor for radionuclide r to meat m	day kg^{-1} of meat or soil	radionuclide, animal
Q(m)	quantity of soil consumed by animal m	kg day^{-1}	animal

II–2.2.2.5.3.2.1. Assumptions for radionuclide uptake by animals via soil ingestion

- the transfer coefficient from soil-to-animal is the same as the one used for plant ingestion, again presenting the most conservative situation.

II–2.2.2.5.4. Dose to humans due to ingestion of animal products

Dose to humans from radionuclide *r* due to consumption of animal product *m* is modelled by the following mathematical formula, with a description of the parameters given in Table II-2.11.

$$D_m(r,m,t) = \int_{t_0}^{t_1} M_c(r,m,t)d(r,a)Q(m)F(m)P(m)dt \tag{13}$$

TABLE II-2.11. PARAMETERS FOR ANIMAL PRODUCT INGESTION BY HUMANS

Parameters	Description	Unit	Depends on
D_m(r,m,t)	committed effective dose from radionuclide r due to consumption of meat m, at time t	Sv	radionuclide, meat, time from deposit
M_c(r,m,t)	concentration of radionuclide r in animal product m	Bq kg^{-1}	radionuclide, meat
d(r,a)	dose conversion factor	Sv Bq^{-1}	radionuclide, age, race
Q(m)	quantity of food m consumed	kg day^{-1}	diet
F(m)	fraction of food m consumed which is local	dimensionless	
P(m)	fraction of activity remaining after food processing	dimensionless	

II–2.2.2.5.4.1. Assumptions for dose to humans due to ingestion of animal products

- only the specified fraction, F, of the meat is contaminated;
- a local production/consumption model is assumed;
- there is no long term storage of food.

II–2.2.2.5.5. Total dose to humans from the ingestion pathway

The contribution from consumption of crop and animal products is considered. The total dose to humans from the ingestion pathway at time *t* is given by:

$$TotalDose(t) = \sum_{r} \left[\sum_{p=1}^{P} D_p(r,p,t) + \sum_{m=1}^{M} D_m(r,m,t) \right] \tag{14}$$

Where *P* and *M* are the number of crop and animal products consumed respectively.

II–2.3. APPLICATION OF RADCON TO THE IPUT SCENARIO

For the Iput scenario, intermediate results and end points have been calculated using average conditions over the region. Where appropriate, weighted averages have been used, for example, for the calculation of external exposure.

The parameter values and adjustments used in applying RadCon to the Iput test scenario are described in the following sections. In addition, propagation of parameter uncertainty was implemented to obtain 95% confidence intervals for the estimates. This was achieved by assigning a distribution to each parameter (Section II–2.3.12) and propagating the uncertainty to the estimated result using Monte Carlo sampling.

II–2.3.1. Initial ^{137}Cs inventory

The average initial inventories used are as follows:

- 724 kBq/m^2 for arable land, i.e. used in the calculation of all agricultural products and grass contamination. In addition this initial value is used for the calculation of external exposure from the ground. Taking agricultural land out of production was not considered.
- 980 kBq/m^2 for forest, and the calculation of contamination in mushrooms and berries. As RadCon does not implement a separate model for mushrooms, radioactive decay as well as radionuclide soil fixation and removal from the soil is modelled as for agricultural products and grass.
- 62680 m Bq/m^3 for the air concentration, Table I.I in scenario description. This value is used in the calculation of external exposure from the cloud and inhalation, as well as the initial value for the calculation of deposition onto grass and plants, where appropriate, based on the biomass of plants above the ground at the time of the accident.

II–2.3.2. Radionuclide decay rates

The half-life of Cs-137 – 30 years, or 10957.266 days.

A factor of 365.2422 was used to convert years to days.

$$\text{Decay rate, } \lambda_r = \frac{\ln(2)}{half\_life_r} = \frac{0.693}{10957.266} = 6.3e^{-5}\,/\text{d}$$

Half-life obtained from ICRP 68 (1994).

II–2.3.3. Dose conversion factors

For the current calculations, dose conversion factors used were those presented in the test scenario description. The dose conversion factors used for ^{137}C are as follows:

- Inhalation – 8.6 × 10^{-9} Sv/Bq
- Ingestion – 1.4 × 10^{-8} Sv/Bq
- External radiation from the deposition – 1.3 × 10^{-12} Sv Bq^{-1} m^2 h^{-1}
- External radiation from the cloud – 9.3 × 10^{-11} Sv Bq^{-1} m^3 h^{-1}

II–2.3.4. Lifestyle information

It was assumed that the entire population was rural. The percentage of time spent indoors and outdoors (occupancy factors) were taken from those presented in Tables I.XLIV, I.XLV, and I.XLVI of the test scenario. In calculating the exposure from the cloud and dose from inhalation, the fraction of time spent in buildings (living and working) was that of April-October, i.e. inclusive of the time the plume was passing in April-May 1986. The annual average occupancy factors, Table I.XLVI, were used in calculating the exposure from the ground. The occupancy factors and the modified occupancy factors are presented in Tables II-2.12 and II-2.13, respectively.

TABLE II-2.12. OCCUPANCY FACTORS

	Indoor workers	Outdoor workers	Pensioners
April-May 1986			
Inside buildings	0.67	0.49	0.6
Outside buildings	0.33	0.51	0.4
Annual average			
Inside buildings	0.73	0.56	0.7
Outside buildings	0.27	0.44	0.3

It was further assumed that the *relative units*, specified in the table were those for the day light hours and the people were indoors for the remainder of the day. A value of 14 daylight hours was used for April-October and 12.5 daylight hours for the annual calculations (Handbook on the climat of the USSR). The implication of this is that the values in the tables are used for 0.583 (14 hr / 24 hr) of the 24 hour day and the additional 0.417 of time is assumed to be spent indoors, for the April-May time frame. For the annual calculations, the values in the tables are used for 0.52 (12.5 hr / 24 hr) of the 24 hour day and the additional 0.48 of the time is assumed to be spent indoors. Thus the actual values used in the calculations are as follows, Table II-2.13.

TABLE II-2.13. MODIFIED OCCUPANCY FACTORS

	Indoor workers	Outdoor workers	Pensioners
April-May 1986			
Inside buildings	0.67*0.583+0.417 (0.81)	0.49*0.583+0.417 (0.7)	0.6*0.583+0.417 (0.767)
Outside buildings	0.33*0.583 (0.19)	0.51*0.583 (0.3)	0.4*0.583 (0.233)
Annual average			
Inside buildings	0.73*0.52+0.48 (0.86)	0.56*0.52+0.48 (0.77)	0.7*0.52+0.48 (0.84)
Outside buildings	0.27*0.52 (0.14)	0.44*0.52 (0.23)	0.3*0.52 (0.16)

The final results presented for the exercise were generated using the modified occupancy factors. From discussions at the workshop it was concluded that the unaltered values should have been used, in which case the resulting dose will be higher than those reported for the inhalation and external exposure from the cloud and ground contamination.

II–2.3.5. Human inhalation information

An inhalation rate for the standard Caucasian adult male was used (ICRP 71, 1995).

Inhalation rate, m^3h^{-1} = fraction working × inhalation during work
+ fraction resting × inhalation during resting
+ fraction alternate (sitting, light exercise) × inhalation during the alternate types of activity.

Activity	Fraction	Inhalation, m^3h^{-1}
Working	0.41	1.5
Resting	0.25	0.54
Alternate	0.34	0.45

Total Inhalation Rate = 0.903 $m^3h^{-1} \pm 0.0903$

SD = standard deviation, was set at 10% (due to sufficient precision for calculational purposes, ICRP 71, 1995).

The air concentration used was that presented in Table I.I of the Iput River test scenario and given in Bq m^{-3}. The type of distribution and error presented was not indicated. It was assumed that the distribution was normal and that it was an arithmetic mean with 95% confidence intervals about that mean.

An indoor to outdoor airborne concentration ratio of 0.25 for ^{137}Cs was used (Roed and Godddard in EUR 13013/1, 1990), giving an inhalation dose reduction of 1.1 to 1.5.

The final calculations for the indoor and outdoor fractions of the inhabitants' lifestyle are calculated by relating to the information presented in Table I.XLV. Using the values in Table I.XLV:

- Fraction of indoor workers (*fi*) = 0.26
  0.18 indoor workers living in wooden houses + 0.08 indoor workers living in brick houses
- Fraction of outdoor workers (*fo*) = 0.47
  0.33 outdoor workers living in wooden houses + 0.14 outdoor workers living in brick houses
- Fraction of pensioners (*fp*) = 0.27
  0.19 pensioners living in wooden houses and 0.08 pensioners living in brick houses

The weighted attenuation for the airborne concentration ratio indoors was calculated in the following manner:

Weighted attenuation for indoor workers (*ai*) = airborne factor for indoors × *fi*
= 0.25 × 0.26 = 0.065

Weighted attenuation for outdoor workers (*ao*) = airborne factor for indoors × *fo*
= 0.25 × 0.47 = 0.118

Weighted attenuation for pensioners (*ap*) = airborne factor for indoors × *fp*
= 0.25 × 0.27 = 0.068.

Indoor contribution = indoor workers (*ai* × fraction indoors) + outdoor workers (*ao* × fraction indoors) + pensioners (*ap* × fraction indoors)
= 0.065 × 0.67 + 0.118 × 0.49 + 0.068 × 0.6 = 0.142. (using Table II-2.12)
= 0.065 × 0.81 + 0.118 × 0.70 + 0.068 × 0.767 = 0.187. (using Table II-2.13)

Outdoor contribution = indoor workers (fraction people × fraction outdoors) + outdoor workers (fraction people × fraction outdoors) + pensioners (fraction people × fraction outdoors)
= 0.26 × 0.33 + 0.47 × 0.51 + 0.27 × 0.4 = 0.434. (using Table II-2.12)

= 0.26 × 0.19 + 0.47 × 0.3 + 0.27 × 0.233 = 0.253. (using Table II-2.13)

The indoor and outdoor contribution fractions are added and the final result used in RadCon to calculate the dose from this pathway. Using the values in Table II-2.13, a value of 0.187 + 0.253 = 0.44 is used for F(r) in Table II-2.3 for the calculation of the inhalation dose. If the data in Table II-2.12 were used, a value of 0.142+0.434=0.576 would have been implemented for F(r), resulting in a higher dose.

II–2.3.6. External exposure from cloud (cloudshine)

The shielding factor for cloudshine (i.e. external exposure from the passage of the plume) depends on the wall thickness of the buildings and the type of building material. Attenuation for wooden and brick buildings was presented in the scenario description:

- for wooden buildings, a shielding factor of 0.48
- for brick houses a shielding factor of 0.125.

The weighted attenuation for cloudshine indoors was calculated in the following manner:

Weighted attenuation for indoor workers (*Iwa*) = indoor workers in wood × wood shielding + indoor workers in brick × brick shielding
= 0.18 × 0.48 + 0.08 × 0.125 = 0.0964

Weighted attenuation for outdoor workers (*Owa*) = outdoor workers in wood × wood shielding + outdoor workers in brick × brick shielding
= 0.33 × 0.48 + 0.14 × 0.125 = 0.1759

Weighted attenuation for pensioners (*Pwa*) = pensioners in wood × wood shielding + in brick × brick shielding
= 0.19 × 0.48 + 0.08 × 0.125 = 0.1012.

Indoor contribution = indoor workers (*Iwa* × fraction indoors) + outdoor workers (*Owa* × fraction indoors) + pensioners (*Pwa* × fraction indoors)
= 0.0964 × 0.67 + 0.1759 × 0.49 + 0.1012 × 0.6 = 0.2115. (using Table II-2.12)
= 0.0964 × 0.81 + 0.1759 × 0.7 + 0.1012 × 0.767 = 0.28. (using Table II-2.13)

Outdoor contribution = indoor workers (fraction people × fraction outdoors) + outdoor workers (fraction people × fraction outdoors) + pensioners (fraction people × fraction outdoors)
= 0.26 × 0.33 + 0.47 × 0.51 + 0.27 × 0.4 = 0.434. (using Table II-2.12)
= 0.26 × 0.19 + 0.47 × 0.3 + 0.27 × 0.233 = 0.25. (using Table II-2.13)

The indoor and outdoor contribution fractions are added and the final result used in RadCon to calculate the dose from this pathway. Using the values in Table II-2.13, a value of 0.28 + 0.25 = 0.53 is used for S(r) in Table II-2.2 for the calculation of the cloudshine dose. If the values in Table II-2.12 were used, a value of 0.2115+0.434=0.65 would have been used for S(r), resulting in a higher dose.

II–2.3.7. External exposure from the ground (groundshine)

A shielding factor of 0.23 was used for outdoor groundshine received indoors (Peterson, AECL 11089, 1994). From the scenario description there are:

- 0.18 indoor workers living in wooden houses and 0.08 indoor workers living in brick houses = 0.26
- 0.33 outdoor workers living in wooden houses and 0.14 outdoor workers living in brick houses = 0.47
- 0.19 pensioners living in wooden houses and 0.08 pensioners living in brick houses = 0.27.

The weighted attenuation for groundshine indoors, while in the plume, was calculated in the following manner:

Weighted attenuation for indoor workers (*Iwa*) = groundshine factor for indoors × fraction indoor workers
= 0.23 × 0.26 = 0.0598

Weighted attenuation for outdoor workers (*Owa*) = groundshine factor for indoors × fraction outdoor workers
= 0.23 × 0.47 = 0.1081

Weighted attenuation for pensioners (*Pwa*) = groundshine factor for indoors × fraction pensioners
= 0.23 × 0.27 = 0.0621.

Using the annual occupancy factors:

- indoor workers are indoors 0.73 of the time
- outdoor workers are indoors 0.56 of the time
- pensioners are indoors 0.7 of the time.

Indoor contribution = indoor workers (*Iwa* × fraction indoors) + outdoor workers (*Owa* × fraction indoors) + pensioners (*Pwa* × fraction indoors)
= 0.0598 × 0.73 + 0.1081 × 0.56 + 0.0621 × 0.7 = 0.148. (using Table II-2.12)
= 0.0598 × 0.86 + 0.1081 × 0.77 + 0.0621 × 0.84 = 0.187. (using Table II-2.13)

Outdoor contribution = indoor workers (fraction people × fraction outdoors) + outdoor workers (fraction people × fraction outdoors) + pensioners (fraction people × fraction outdoors)
= 0.26 × 0.27 + 0.47 × 0.44 + 0.27 × 0.3 = 0.358. (using Table II-2.12)
= 0.26 × 0.14 + 0.47 × 0.23 + 0.27 × 0.16 = 0.188. (using Table II-2.13)

The indoor and outdoor contribution fractions are added and the final result used in RadCon to calculate the dose from this pathway. Using the values in Table II-2.13, a value of 0.187 + 0.188 = 0.375 is used for S(r) in Table II-2.1 for the calculation of the groundshine dose. If the values in Table II-2.12 were used, a value of 0.148+0.358=0.506 would have been used for S(r), resulting in a higher dose.

A reduction in the availability of ^{137}Cs in the soil to contribute to external exposure from ground deposition is implemented in RadCon using two exponentials (see Section II–2.2.2.1).

A value of 0.36 was used for α and 0.00146 and 0.0000387 for λ_1 and λ_2 respectively. Reference for these values: Müller and Pröhl, 1993.

II–2.3.8. Information on soil concentrations

In the scenario description, information related to soil was presented for year 1 and year 2 after the accident in which a 5-6 fold higher exchangeable ^{137}Cs was noted (Section I–1.3.1.2 Soil Contamination). In this report, year 1 was taken as April 1986 to December 1986 and year 2 as January 1987 to April 1987. However, a decreased transfer to plants by a factor of 3 to 6 was noted from 1987 to 1990 (Section I–1.3.3.7, Change of Biological Availability and Vertical Migration of ^{137}Cs in Agricultural Soils). Thus, from May 1987 to 1990 and onwards, the ^{137}Cs transfer to plants was regarded as decreasing by the average factor for the implementation of countermeasures.

RadCon was not intended to implement countermeasures; however, to account for some of the countermeasures in this scenario, a decision was made to use the soil concentration parameter K (see Table II-2.4) to alter the soil to plant transfer factors. As K is not time dependent, time dependence could not easily be simulated, thus a simple step function was used (Table II-2.14) to simulate the higher soluble fraction of ^{137}Cs in the period immediately after the accident (Section I–1.3.1.2) and then a decrease after countermeasures were applied. The change in K relates mainly to the crops and the pastures, not to mushrooms and berries (‘nature’s gifts’). The model does not accommodate more than one soil concentration factor per run, so averages were used. This was also the case for soil density. Soil density is presented at a depth of 3cm. The K value from May 1987 onwards presents an average value and a range accounting for the effectiveness of agrochemical and agrotechnical countermeasures as described in Tables I.LIV and I.LV in the scenario description. The K value for 1986-1987 was calculated at an increased value by a factor of 6 to account for the decreased transfer to plants after that date (Section I–1.3.3.7, Change of Biological Availability and Vertical Migration of ^{137}Cs in Agricultural Soils).

For mushrooms and berries, the model was run separately to allow the implementation of the relative soil density and concentration factor for natural soils, i.e. no countermeasures applied to forest areas. Table II-2.14 lists the information required for the soil.

Initial soil bulk density is site specific, and the authors did not present this data. The above values are representative for sand/loam and peat soils for Polish agricultural lands (Krajewski, 1994). For agricultural land, the soil bulk density is calculated to a depth of 3 centimetres

The soil concentration factor, K, is used to account for the concentration/dispersion of ^{137}Cs and is also site specific, depending on soil type and agricultural practices. In ploughed lands, ^{137}Cs is dispersed according to the size of the ploughed furrow. This information was not presented by the authors, so the plough depth for Polish soils was used – a depth of around 20 cm.

For natural systems, such as those for mushrooms and berries, K is a concentration, not a dispersion value. The initial 1986 to 1987 K value is also a concentration when the increased, non-equilibrium ^{137}Cs transfer is taken into consideration.

Time varying concentration in soil was modelled by one exponential, i.e. using a value of 0.0 for α in Table II-2.4. A value of 0.000003 (1/d) was used for λ_2 and 0.00024 (1/d) was chosen for the fixation parameter, λ_f, based on work by M.J. Frissel.

TABLE II-2.14. SOIL INFORMATION

Soil type (crop)	Soil bulk density - Initial (kg m $^{-2}$)	Soil concentration (K) 1986-1987	Soil concentration (K) 1988 onwards (range)
Sand – loam (grains, vegetables, fruit)	40 (at 3cm depth)	0.38	2.3 (1.2 to 3.5)
Sand – loam with some organic (pasture)	40 (at 3cm depth)	0.38	2.3 (1.2 to 3.5)
Organic (mushrooms)	20 (at 3cm depth)	0.65	0.65
Organic (berries)	20 (at 2cm depth)	0.65	0.65

II–2.3.9. Deposition on the vegetation

This function required additional data, some of which was not presented by the authors. This additional data included: deposition velocity in m s^{-1}; leaf area index (LAI) at the time of deposit and the maximum LAI at time of harvest, as m^{2} m^{-2} and retention on the crop in mm – presented in Table II-2.15. The data used was that presented for the southern German environment (Müller and Pröhl, 1993). Where dry weight was given for the yields, this was converted to fresh weight using dry weight content of fresh products from TRS No. 364, IAEA (1994). Where the crop yield was given in the test scenario this information was used, i.e. Tables I.XXI, I.XXII and I.XXXII (scenario description). The LAI used for mushrooms and berries was based on personal judgement, and was determined for the time of harvest.

II–2.3.9.1. Loss due to weathering and dilution rates

For vegetables which may be consumed totally (leafy vegetables), a loss rate due to weathering was calculated and a value equivalent to a half-life of 25 days was assumed. The value for the weathering factor, λ_w, of ln(2)/25 = 0.027726 was used in the RadCon model for all crop types.

For grass, a dilution rate of 0.0116 was used, assuming a half-life of 60 days. The fraction of activity translocated to the root zone of 0.05 was used from measurements of grass contamination after the accident at Chernobyl. A dilution rate at the maximum growing period (June) of 0.035 was used.

Reference for these values: Müller and Pröhl, 1993.

II–2.3.9.2. Translocation factors

For fruit, vegetables and grain, translocation factors for mobile and immobile elements, as a function of time before harvest, were used. These factors were referenced from Müller and Pröhl (1993) from the data provided in their Table II-2.7 and II-2.8. As all the data in the tables was accessed, the tables were not reproduced here.

TABLE II-2.15. LEAF AREA INDEX (LAI) AND YIELD FOR THE VEGETATION

Crop/vegetation	Deposition velocity[a] ms^{-1}	LAI (at time of deposit)[a] m^2m^{-2}	Max. LAI (at time of harvest)[a] m^2m^{-2}	Retention mm	Yield kgm^{-2}	Yield fresh wt. kgm^{-2}
Fodder M (fresh cut maize)	0.002	0 (not growing)	6	0.3	4.05	
Fodder (straw)	0.002	2	7	0.3	0.19*	0.61
Grass (dry hay)	0.0015	1	7	0.2	0.308*	1.6
Grass L (legumes for fodder)	0.0015	1	7	0.2	0.6*	3.16
Root vegetables	0.002	2.5	5	0.3	2.8	
Cereals, grain	0.002	2	7	0.2	0.19*	0.61
Leafy vegetables	0.002	0	5	0.3	2.3	
Vegetables (includes ground and fruit veg.)	0.002	0	5	0.3	2.3	
Fruit	0.005	2	5	0.3	2.0[a]	
Potato	0.002	0	4	0.3	2.0	
Wild berries	0.002	0.5	5	0.3	1.5[a]	
Wild mushrooms	0.0015	1	5	0.3	1.5[a]	

* dry weight yield

[a] Reference: Müller and Pröhl, 1993.

II–2.3.10. Transfer Rates

Two types of transfer rates were required. These were soil-to-crop transfers as shown in Table II-2.16 and crop-to-animal transfer rates as shown in Table II-2.18. Where necessary, the soil-to-crop transfer rates were converted to fresh weight in Table II-2.17. The values in the tables were listed as *Bq* kg^{-1} *of dry crop per Bq* kg^{-1} *dry soil* for the soil to plant parameter and *day* kg^{-1} or *day* L^{-1} for meat and milk respectively. It was assumed that the transfer factor from soil-to-plant depends on the plant type and the radionuclide. The transfer factor from plant-to-animal depends on the animal and the radionuclide. The transfer factor and range for the wild mushrooms were an average of those presented for the given species in published literature (Rühm, et al., 1998; Rühm, et al., 1999; TRS No. 364, IAEA, 1994). For the wild berries, the transfer parameter was averaged from data in published literature.

The tables include food groups consumed by people and animals, as provided by the authors. The transfer parameter values given were those for temperate data and averaged for sand and loam, where this was available in the literature ([a]Müller and Pröhl, 1993; [b]Nisbet, et al., 1998). Where no upper and lower 95% limits were provided, a range was sought and documented here as a guide.

For the leafy vegetables, cereals and potatoes, the concentration for 1986 was calculated as having all accumulated in the one growing season:

- for June, concentration was calculated at 2 months after accident
- for July, concentration was calculated at 3 months after accident and so on.

For the years to follow, the concentrations for the leafy vegetables, cereals and potatoes were calculated at 1.25, 2.25, 3.25 years, and so on.

For the mushrooms and wild berries, the concentrations were calculated at the end of October for each year.

Table II-2.20 includes only the animal products consumed by the humans as identified in the test scenario.

TABLE II-2.16. SOIL-TO-CROP TRANSFER RATES FOR ^{137}Cs (UNITS AS DESCRIBED ABOVE, SECTION II–2.3.10)

Crop/vegetation	Recom. value*	95% Confidence interval lower	95% Confidence interval upper
Fodder M (fresh cut maize)	0.02[a]		
Fodder (straw)	0.02[a]		
Grass (hay)	0.05[a]		
Fruit	0.02[a]		
Grass L (legumes for fodder)	0.029[b]	0.002	0.4025
Root Vegetables	0.045[b]	0.0036	0.545
Cereals, Grain	0.017[b]	0.0009	0.324
Leafy Vegetables	0.159[b]	0.0177	1.4283
Vegetables (includes ground and fruit veg.)	0.041[b]	0.004	0.399
Potato	0.056[b]	0.0064	0.4992
Wild Berries	0.02[a]		
		Range	
Wild Mushrooms	10.2	0.003 to 30	

* dry weight

[a] Müller and Pröhl (1993), values given as fresh weight

[b] Nisbet, et al., 1998

TABLE II-2.17. TRANSFER FACTOR CONVERSION FOR DRY WEIGHT TO FRESH WEIGHT

Crop/vegetation	Average* (% d.w.)	Recomm. value fresh wt.	95% Conf. range lower	95% Conf. range upper
Fodder M (green cut maize)	20+	as in Table II-2.16		
Fodder (straw)	31	as in Table II-2.16		
Grass (hay)	10	as in Table II-2.16		
Fruit	6	as in Table II-2.16		
Grass L (legumes for fodder)	19	0.0055	0.00038	0.077
Root vegetables	13	0.006	0.0005	0.07
Cereals, grain	86	0.015	0.00077	0.279
Leafy vegetables	8	0.013	0.0014	0.114
Vegetables (incl. ground fruit veg.)	10	0.0041	0.0004	0.04
Potato	21	0.012	0.0013	0.105
Wild Berries	50++	as in Table II-2.16		
			Range	
Wild Mushrooms	10	1.02	0.04 to 5.1	

*Ref: TRS No. 364, IAEA, 1994

[+] Reference: test scenario tables

[++] Ref: Drissner et al., 1998

TABLE II-2.18. CROP-TO-ANIMAL TRANSFER RATES FOR ^{137}Cs (UNITS AS DESCRIBED ABOVE, SECTION II–2.3.10)

Animal	Expected transfer rates	Range
Dairy, (cow milk)	0.0079	0.001 to 0.027
Beef (veal)	0.2	0.04 to 0.6
Pig	0.24	0.03 to 1.1
Eggs	0.4	0.06 to 2
Fowl	10	0.3 to 10

Reference: TRS No. 364, IAEA, 1994

TABLE II-2.19. BIOLOGICAL HALF-LIVES AND THE FRACTIONS CONTRIBUTING TO THE BIOLOGICAL TRANSFER RATES FOR THE CS RADIONUCLIDE

Product	Biological half-life 1. (day)	Fraction 1.	Biological half-life 2. (day)	Fraction 2.
Milk	1.5	0.8	15	0.2
Beef (cow), veal	30	1		
Beef (bull)	50	1		
Pork	35	1		
Lamb, roe deer, chicken	20	1		
Eggs	3	1		

Reference for these values: Müller and Pröhl, 1993.

TABLE II-2.20. FOOD CONSUMPTION BY ADULTS CALCULATED AS THE AVERAGE OF THAT FOR CONTROLLED AND OBSERVED AREAS

	Milk	Meat	Meat	Meat	Potatoes	Vegs	Bread	Mush-rooms	Berries
Year (and gender studied)		Chicken	Beef	Pork		Root veg., ground fruit/veg.			
1985 (M)	0.76	0.035	0.099	0.042	0.64	0.3	0.39	0.05	0.025
1985 (F)	0.56	0.034	0.095	0.041	0.56	0.27	0.29	0.03	0.025
10 May 1986 (M+F)	0.525	0.020	0.057	0.024	0.6	0.28	0.34		
20 May 1986 (M+F)	0.325	0.019	0.054	0.023	0.6	0.28	0.34		
June 1986 (M+F)	0.3	0.019	0.054	0.023	0.6	0.28	0.34		
July1986 (M+F)	0.29	0.019	0.054	0.023	0.6	0.28	0.34		
August1986 (M+F)	0.28	0.019	0.054	0.023	0.6	0.28	0.34		
September 1986	0.215	0.016	0.044	0.019	0.6	0.28	0.34		
Average 1986 (M+F)	0.323	0.019	0.053	0.023	0.6	0.28	0.34	0.014	0.004
1987 (M+F)	0.14	0.011	0.030	0.013	0.55	0.28	0.34	0.018	0.004
1988 (M+F)	0.1	0.005	0.015	0.006	0.475	0.245	0.315	0.009	0.004
1990 (M)	0.1	0.005	0.015	0.006	0.475	0.23	0.325	0.018	0.004
1990 (F)	0.075	0.007	0.021	0.009	0.425	0.22	0.28	0.009	0.004
1993 (M)	0.24	0.030	0.083	0.036	0.84	0.275	0.385	0.015	0.004
1993 (F)	0.25	0.021	0.059	0.025	0.645	0.285	0.305	0.011	0.004
1995 (M)	0.405	0.032	0.091	0.039	0.79	0.25	0.47	0.033	0.012
1995 (F)	0.405	0.022	0.060	0.026	0.645	0.19	0.41	0.025	0.012

Notes: Meat proportioned: pork eaten – 56%, poultry eaten – 20%, beef eaten – 24%

II–2.3.11. Human and animal diet data

II–2.3.11.1. Human Diet

The conservative assumption was made that all the food produced in the region of deposition was eaten in the region. Food consumption for the test region assumed continuous harvest. Seasonality of consumption was not included in the estimation of dose to man – the diet was averaged over the whole year.

Consumption was presented in *kg day^{-1}* (Table II-2.20) and was averaged from Tables I.XLIX and I.L in the scenario description for estimated consumption rates for adult rural inhabitants of the test area in both the 'controlled' and 'observed' areas (as described in the scenario description). The meat was proportioned as provided in the test scenario and also as discussed at the workshop. For mushrooms and berries, the consumption rate presented in Table I.XLVII of the scenario description was used.

A scaling factor for the processing of food was included. The processing scaling factor relates to the modification of the radionuclide concentration to account for the activity remaining after agricultural countermeasures and food processing prior to consumption as presented in Table II-2.21 of this report. The written account for fruit and berries, table greens and mushrooms (I.1.3.5.1 Countermeasures – General information) was taken into consideration. Milk processing takes into account processing to make other dairy products, as described in Tables I.LIV, I.LVI to I.LVIII of the scenario description. Processing for crops (vegetables and grains) takes into account agricultural countermeasures as described in Tables I.LIV, I.LVI to I.LVIII of the scenario description.

Consumption of fruit and leafy vegetables was taken as that presented in Table 45 of the original scenario description: fruit – 0.15 kgd^{-1}, leafy vegetables – 0.05kgd^{-1} for both male and female. For these products, no consumption reduction was presented in the scenario description, for the periods 1986-1987. However, the effect of agricultural countermeasures and processing in the kitchen was taken into account in Table II-2.21 of this report.

Fresh weight was assumed in the consumption data. The average uncertainty for consumption of natural food products was taken, as presented in the test scenario at 40–60%.

II–2.3.11.2. Animal diet

The animal diets were those presented in the scenario tables and description. Where the consumption by animals is presented by seasonally, an averaged value was used. The RadCon model does not implement seasonality of diet so the food concentrations for the two different feeding periods were averaged and used in the calculations. Soil ingestion was a highly variable factor dependent on the animal, climate and topography. It can account for a large proportion of total daily intake but in most cases will not be an important source of the bio-available radioisotope (TRS No. 364, IAEA, 1994).

II–2.3.11.2.1. Cow and beef diet

Examples of two types:

- Dairy cow
- Beef: bull-calves (assumed for veal)

Tables II-2.22 and II-2.23 present the amount of feed consumed by each beef type in kg day^{-1}, as given in Tables I.XXXIV and I.XXXVII of scenario description.

TABLE II-2.21. FOOD PROCESSING: RADIONUCLIDE ACTIVITY REMAINING AFTER PREPARATION FOR COOKING AND AFTER AGRICULTURAL COUNTERMEASURES

Food group	Processing (radionuclide activity remaining)
Dairy (cow milk)	0.5
Meat (pork, poultry, beef)	0.7
Egg	0.8
Grain	0.6
Leafy vegetables	0.4
Vegetables	0.4
Fruit	0.8
Potatoes	0.6
Fish	0.9
Wild berries	0.9
Wild mushrooms	0.5

TABLE II-2.22. FOOD CONSUMPTION BY DAIRY COWS

Feed type	Amount consumed (kg day^{-1})	Amount consumed (kg day^{-1}) converted to fresh weight
Soil	0.16	
Pasture period – summer		
Green	50	
Concentrates	2*	2.33
Stable period – winter		
Hay and straw	4 and 2*	46.5
Silage^{+}	15	
High grade feed		
Root crop beet	3	
Concentrates^{++}	2.2*	2.6

*dry weight assumed

$^{+}$Main component of silage is green-cut maize, content of dry matter is 20%

$^{++}$Concentrates include grain of barley, rye, wheat with mineral and vitamin supplements, phosphorus acid, ammonium salts.

TABLE II-2.23. FOOD CONSUMPTION BY BULL-CALVES (BEEF)

Feed type	Amount consumed (kg day^{-1})	Amount consumed (kg day^{-1}), converted to fresh weight	Amount consumed (kg year^{-1}) from test scenario
Soil	0.072		
Poor grade feed			
Green	7.5		2724
Hay	1.5*	15	532
Silage^{+}	8.7		3163
High grade feed			
Root crop	0.4		146
Potato	0.3		125
Concentrates^{++}	1.1		815

* dry weight

Note: fresh weight assumed, but the feed quantities are then inconsistent with the slaughter weights of the beef cattle given in the test scenario.

II–2.3.11.2.2. Pig diet

Table II-2.24 presents the amount of feed and soil consumed by a pig in kg day^{-1} – Table I.XXXVI of the scenario description. The reported results were generated using annual average consumption rates. The concentrates include meals (barley, oats, wheat, pea), bran (wheat), meat, meat+bone or fish meal, and mineral supplements.

TABLE II-2.24. FOOD CONSUMPTION BY PIGS

Feed type	Amount consumed (kg day^{-1})	Amount consumed (kg day^{-1}) fresh weight
Soil	0.024	
Winter period		
Concentrates (cereals mainly)	2*	2.33
Beet roots	6	
Ground hay (dry)	0.2*	2
Summer period		
Concentrates (cereals mainly)	2.8*	3.3
Grass (legumes)	5.5	

* dry weight

II–2.3.11.2.3. Fowl diet

Table II-2.25 presents the amount of feed consumed by fowl in kg day^{-1} as presented in Table I.XXXVII, of the scenario description. No seasonality of feeding was assumed. The component of the ration is described in Table II-2.26.

TABLE II-2.25. FOOD CONSUMPTION BY FOWL (BATTERY)

Feed type	Amount consumed (kg day^{-1})	Amount consumed (kg day-1) fresh weight
Soil	0.0007	
Ration	0.12*	0.14

TABLE II-2.26. RATION COMPONENTS, %

Feed type	% feed in ration
Grain (whole barley, oats, rye)	35-40*
Grain, crushed of ground	30-35*
Animal feed, dry	7-8*
Green or succulent	20
Mineral supplements	3

*dry weight

The concentrations in the beef, chicken and pork were calculated as a proportion of the meat – see Section II–2.3.11.1 above.

II–2.3.12. Parameter distribution

In order to provide the 95% confidence intervals for the assessment results, it was necessary to know the distributions for the parameters selected for the model. Many of these parameters do not have information on the distributions of the underlying data and some do not present ranges. It was decided to allocate normal distributions to all the physical data and log normal distributions to all the biological data. A 25% standard deviation was chosen for all parameters that did not have a standard deviation provided. A Monte Carlo sampling technique from the parameter distribution was applied to generate a distribution for the estimated dose. Where a range for a parameter is presented in the tables above, it was ensured that no values outside of that range were sampled, otherwise a restriction on the range was made to 2 standard deviations from the mean, (for those parameters with a log-normal distribution, the sampling and restrictions were applied to the log transformed data). For the dose conversion factors, a single value was used.

Aside from the transfer factors, i.e. soil to plant transfer and crop to animal transfer, a 25% standard deviation was chosen. The transfer factors were assigned a log-normal distribution with the following standard deviation.

TABLE II-2.27. STANDARD DEVIATION FOR SOIL-TO-CROP TRANSFER RATES FOR ^{137}Cs

Crop/vegetation	Standard deviation
Fodder M (fresh cut maize)	2.0
Fodder (straw)	2.0
Grass (hay)	2.0
Fruit	2.0
Grass L (legumes for fodder)	4.0
Root vegetables	3.0
Cereals, grain	4.0
Leafy vegetables	3.0
Vegetables (includes ground and fruit veg.)	3.0
Potato	2.0
Wild berries	4.0
Wild mushrooms	3.0

TABLE II-2.28. STANDARD DEVIATION FOR CROP-TO-ANIMAL TRANSFER RATES FOR ^{137}Cs

Animal	Standard deviation
Dairy, (cow milk)	1.8
Beef (veal)	1.8
Pig	2.0
Eggs	3.0
Fowl	2.0

II–2.3.13. Earlier results

The model equations and parameter values used for the third and final calculations have been described in the previous sections of this document. The differences between these and earlier results were due to a number of factors, which can broadly be grouped into:

- model enhancements,
- scenario interpretation, and
- additional information in the revised scenario.

At the time of joining the working group, the RadCon model was under developed and a number of enhancements have been implemented since the first results for the Iput scenario were reported. Following is a list of enhancements implemented in the RadCon model and modifications to parameter values since the first reported results.

- External exposure from the ground
    - In the generation of the first reported results, radioactive decay was the only implemented depletion from the soil, although the effective soil concentration was halved after 10 years. For the second and third set of calculations the equation in Section II–2.2.2.1 was used.
    - The indoor and outdoor occupancy factors were not given in the earlier versions of the scenario description, thus for the first two reported results these values were referenced from the literature. For the final calculations the factors stated in the scenario have been used.
- External exposure from the cloud
    - Changes between the last reported results and the first two were those of including the new occupancy and shielding factors, provided in the revised scenario description.
- Inhalation
    - Changes between the last reported results and the first two were those of including the new occupancy factors.
- Ingestion
    - For the initial calculations only plant contamination due to root uptake from contaminated soil was considered. Subsequently, deposition onto plants was implemented. The second set of reported results considered plant contamination due to deposition onto the plants and subsequent translocation where appropriate, in addition to contamination by root uptake from the soil.
    - Animal product contamination was implemented using a simple equilibrium transfer which was used in the generation of the first two sets of reported results. For the final estimates the equation in Section II–2.2.2.5.3 was used.
    - Soil-to-plant transfer factors were modified from using those for sandy soils (for first reported results) to using an average from sandy and loamy soils (for last two reported results). This choice was based on the description of soil types in the Iput scenario. In addition, for the second set of results a number of soil-to-plant transfer factors were assumed to be wet weight while they were dry weight. This was corrected for the final set of results.
    - The diet composition for animals, both quantities consumed and composition, evolved over the duration of the exercise. Changes were mainly due to clarifications and discussions at the workshops.
    - As RadCon was not intended to be used in estimating effects of countermeasures, but rather to calculate the effect from an accident without intervention, no effort was made to model any of the countermeasures in reporting early results. For the first and second set of calculations, the amount of food consumed by individuals was kept at the same level for all years of the simulation.

- In the final estimates, countermeasures were considered and have been described in this report. In addition the diet of people varied over the years, as shown in Table II-2.20. For the lifetime dose, the diet for 1995 was used.
- Initial inventory – the initial ground concentration remained unchanged for the three sets of results reported, although for the final set of results, the higher forest contamination was used to calculate concentration in mushrooms and berries. In addition, as the revised scenario description detailed the species of these products, the soil-to-plant transfer factors were altered (an average value, researched from the literature, was used). The combination of higher initial soil concentration and lower soil bulk density resulted in higher final estimates for these products.
- Reduction in effective soil concentration – the first reported results implemented radioactive decay and reduction in available contamination due to soil fixation. For subsequent calculations, reduction in effective soil concentration due to radionuclide migration in the soil was also implemented.
- Reduction in effective concentration due to food processing was altered for the generation of the final estimates due to additional information being made available.

II–2.3.14. Estimates generated by RadCon

RadCon was intended to be used in the estimation of dose to humans following an accidental release of radionuclides in the atmosphere without considering intervention. The Iput test scenario was an opportunity for the model developers to test model predictions using field data, and to identify important processes not implemented or not implemented adequately.

In the period of the exercise, the model evolved and the results generated at all stages of the exercise were very encouraging and the performance against the test data was very gratifying to the developers. The opportunity to discuss modelling approaches, scenario interpretation and choice of parameter values was invaluable both with the Dose Reconstruction group and subsequently with the RadCon project team members.

The most obvious difference between the final results and the previously reported results was the effect of the addition of the step function to alter the soil-to-plant transfer factor between the first and subsequent years. The effect was that of increasing the soil-to-plant transfer by a factor of 2.6 for the first year to account for the higher exchangeable ^{137}Cs (Section I–1.3.1) and decreasing the soil-to-plant transfer by a factor of 2.3 for subsequent years to account for the effect of countermeasures. As the calculations were carried out as separate runs for year 1 and then for the subsequent years, the step function is obvious in the results, where a smooth transition is not seen. This was an expected behaviour, because a parameter without time-dependence was used to simulate a time-dependent function.

A comparison of the RadCon estimates and test data for each of the end points is presented in the following sections. A general trend is that RadCon's estimates demonstrate a sharper decline in the early period followed by better agreement in the following years. This could be due to the step function used to alter the soil-to-plant transfer function, an area that needs more investigation for future applications. In the case of animals, average annual feed consumption is used (i.e. no seasonality) and no account for fresh feed before slaughter is made. As such, the dynamic behaviour is not observed in the graphical representation. However, the average results are acceptable. Given the intended use of the model, the RadCon developers are satisfied with these averaged results.

II–2.3.14.1. Leafy vegetables

The final estimated concentration of ^{137}Cs in leafy vegetables is in reasonable agreement with the test data. The main change between successive estimates was the choice of the soil-to-plant transfer factors from that of sandy soil to a mixture of sandy and loamy soils.

II–2.3.14.2. Hay

The ^{137}Cs concentration in hay shows a sharp decline in the first year. This decline reflects the decline in the estimated concentration in crops because the same initial soil inventory was used and the effective availability of ^{137}Cs in the soil for root uptake was calculated in the same way as that for crops. Because deposition onto grass was modelled followed by dilution, a second source of misprediction could be the choice of the dilution rate. After 1990, the estimations are comparable with the test data.

II–2.3.14.3. Potatoes

The comparison of the estimations with the test data show a higher estimation for the first year by a factor of 2. This could be an indication that choice of a factor of 2.6 higher soil-to-plant transfer factor in the first year could be too high. The results of the test data are comparable with the RadCon estimates for the following years.

II–2.3.14.4. Cereals (winter wheat)

In the comparison with the test data, the estimations are higher by a factor of 1.7 for the first year. This could be due to a higher soil-to-plant transfer factor, or the assumed amount of deposition onto the plant, and subsequent translocation to the edible part. For 1987 to 1989, the RadCon estimations are comparable with the test data. From 1990 to 1996, the dip in the test data is not reproduced in the estimates. The test data and estimations for the 1990 to 1996 are comparable.

II–2.3.14.5. Milk

Aside from the seasonal dynamics, which have been discussed previously, estimated concentration in milk is a factor of 2 to 3 times lower than the test data. This could be due to the transfer factor used from feed to milk, which could have been higher due to the lower milk yield. RadCon does not relate the transfer parameter to the yield.

II–2.3.14.6. Beef (calves)

In comparison with the test data, the RadCon estimations are higher by a factor of 3 for the first year and the first quarter of 1987, and then by a factor of 2 for the following periods. This could be due to the use of a transfer factor for veal. Also, RadCon does not have a mechanism to allow for the 1.5 months feeding on uncontaminated fodder prior to slaughter, thus overestimating the concentration in the meat products.

II–2.3.14.7. Pork

In comparison with the test data, the estimated ^{137}Cs concentration in pork is higher by a factor of 2 (approximately). This may be due to interpretation of diet components (wet/dry weight) and under estimation of the loss from soil.

II–2.3.14.8. Wild mushrooms

The final estimations are higher by a factor of 4 compared to those previously reported. Higher soil concentration and lower soil bulk density were used for the final calculations.

The comparison of the estimated concentrations in the mushrooms with the test data, demonstrated a factor of 6 higher for the 1986 RadCon estimations, but decreasing estimations for the following years to be a factor of 2 higher for 1994 onwards. Whereas, the test results demonstrated a decrease only in 1991 and 1992, and the same high concentration as in the first year for 1994 to 1996. The decreased estimates with time in the RadCon model can be accounted for by the implementation of the same pathway as used for the grains, fruit and vegetables. No separate pathway has been implemented to deal with mushrooms and wild berries, thus activating ^{137}Cs leaching and immobilisation in the soil, which seems not be the true situation in this natural environment.

II–2.3.14.9. Wild berries

The final estimations are higher by a factor of 10 compared to those previously reported. Higher soil concentration and lower soil bulk density were used for the final calculations.

The final estimates are compatible with the test data for the years 1987 to 1991 (a factor of 0.4). In the first year RadCon implemented deposition onto the plants, followed by translocation to the fruit, which could contribute to the higher estimate for this period. For the years 1993, 1995 and 1996 other factors may be responsible such as re-suspension from the roadside, which was not included in the RadCon model.

II–2.3.14.10. ^{137}Cs Intake in the test area

Estimates did not distinguish between the ‘controlled’ and ‘non-controlled’ areas. RadCon is capable of implementing these differences but it would require many more runs, and time did not allow this additional work. The estimations are an average of the total test area and are comparable (slightly higher) with the test data for the ‘non controlled’ areas and higher by a factor of 3 over the ‘controlled’ areas for the years 1987 onwards. For 1986, the RadCon estimations are higher by a factor of 2, being a reflection of the higher concentrations in the food estimations for that year.

II–2.3.14.11. External dose for man

In the final estimates, the occupancy factors provided in the revised Iput scenario description were used, whereas in previous estimates these were obtained from the literature.

In comparison with the test data, the RadCon estimations for exposure from the cloud and ground are comparable, with a variation of approximately 0.7 to 0.9. However, the RadCon estimate would have been higher had the occupancy factors in Table II-2.12 been used, as opposed to those in Table II-2.13.

II–2.3.14.12. Inhalation dose

In the final estimates, the occupancy factors provided in the revised Iput scenario description were used, whereas in previous estimates these were obtained from the literature.

In comparison with the test data, the RadCon estimations are comparable, with a variation of approximately 0.9 higher for these estimations. However, the RadCon estimate would have been higher had the occupancy factors in Table II-2.12 been used, as opposed to those in Table II-2.13.

II–2.3.14.13. Average dose from ingestion

In comparison with the previous estimations, the final estimations for dose from the ingestion pathway are comparable with variations by factors of 0.8 to 0.9. The most important food components were altered by the inclusion of beef in these current estimations.

The test data for the 'non-controlled' areas indicate lower doses from the ingestion pathway than those estimated by the RadCon model, by an approximate factor of 2, particularly for the first 3 time peiods. This is a reflection of the over-estimation of ^{137}Cs concentration in the food. This reflects the more conservative approach taken by the modeller and assessor driving the RadCon model. For the 'controlled' areas, the test doses are lower again, by factors of 3 to 4 from the RadCon estimations. Time prevented the additional to distinguish between the two different areas.

The RadCon estimations agreed with two of the food categories (mushrooms and beef) which contributed the major ^{137}Cs concentration to the dose. This was exclusive of the contribution from milk. The RadCon estimations for milk had been much lower than the test data (discussed earlier under Section II–2.3.14.5 of the results).

II–2.3.14.14. Total dose

The total dose estimations were comparable for the current and previous drafts, with a variation by a factor of 0.9 between the 4 time periods.

In comparison with the test data, the RadCon estimations for the total dose at the 4 time periods were higher by factors between 1.1 to 1.4.

II–2.3.15. Discussions and reasons for mispredictions

The results for the final dose and for many of the intermediate end points have demonstrated differences no larger than a factor of 10 (mostly for 1986 estimations) between the RadCon estimations and the test data, with most being within a factor of 2 to 3 or closer. The RadCon estimations had tended towards the conservative in applying transfer parameters and countermeasures. This agreed with the intentions of the model developer and assessor.

For the final reported estimates, a step function was used to alter the plant-to-animal transfer factors. However, a number of additional parameter changes for the current estimations, such as soil density and soil concentration factors, ameliorated any potential impact. It was interesting to note that the final estimates are also within a factor or 2 to 3, and/or closer, to the previous estimates, not including those for 1986. The underestimation of concentration in milk could very well be due to the lower transfer factor from feed.

Effectiveness of Countermeasures – a reduction of a factor of 2.3 was used for the availability of the ^{137}Cs for soil uptake. This reduction, in addition to radioactivity removal by processing, were reflected in the total dose from the ingestion pathway.

The three main areas contributing to misprediction are:

- Countermeasures were not implemented in full detail.
- The transfer factor for milk was taken from the literature without adjustment for the lower milk yield in the test region.
- The mushrooms and berries pathways need further attention. These pathways were not considered significant in the initial intended use of RadCon.
- Composition of animal feed, as interpreted from the scenario description, as well as no inclusion of the seasonality of the animal feed.

Some aspects not yet implemented in RadCon, which may impact on the final dose:

- an aquatic pathway, but the additional ^{137}Cs intake from fish was not a major dietary component and so did not have a major impact on the final dose;
- biological half-life of ^{137}Cs in humans – its implementation may reduce the final dose, and would also allow whole body distribution of the radionuclide estimations to be made;
- re-suspension;
- a separate pathway for the estimation of natural foods such as mushrooms and berries;
- ability to provide clean fodder to animals before consumption.

Other possible improvements to RadCon include:

- implementation of a more elegant approach to modelling a time-dependent transfer from soil-to-plants – at present a step-function has been implemented;
- seasonality of food consumption by animals to present more detail in the form of seasonal fluctuations for radioisotope concentration – at present RadCon presents an average over the whole year which has proven to be a reasonable estimation.

II–2.3.16. Experiences and lessons learnt

- The importance of knowing the situation at the site and choosing appropriate transfer factors cannot be over emphasised.
- Discussions with workshop participants was invaluable in this exercise.

II–2.3.17. Conclusions

This exercise has clearly demonstrated the importance of well-defined data for the test scenario in order to align the estimations closely to that data and so be able to produce realistic predictions. Good predictions are particularly important in the assessment of the impact of countermeasures and the time required for these to be applied to minimise the long-term dose to humans.

The RadCon model has performed well in the estimations of intermediate end points and final dose. A need was identified for well-defined transfer parameters including ranges and/or distributions, particularly related to environmental factors such as soil. This should include factors for transfer parameters for the initial period after deposition, when the radioisotopes are not in equilibrium and are more bio-available.

This evaluation of the RadCon model has been a worthwhile exercise and of great benefit in understanding the requirements for radiological assessments, both for the test data and the model being evaluated. The workshops have been a valuable source of information, discussion and net working.

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II–3. SENES MODEL

Predictions for the IPUT River Scenario

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II–3.1. INTRODUCTION

Multiple pathways dose assessment is a complex exercise that requires application of mathematical equations describing natural processes to a particular exposure situation. A computer model contains sets of these equations in a fixed structure. It is often cumbersome to adapt the computer model structure for the purpose of the given assessment exercise. It is easier, sometimes, to use the individual mathematical equations to make predictions of the transport and bioaccumulation of the contaminant in the environment, than to use off-the-shelf computer models. Such an exercise was performed below. Thus, no particular pre-packaged computer model was used to produce the results presented below, but individual processes were modeled starting from basic principles. Calculations were performed in EXCEL, and uncertainties were propagated using *Crystal Ball* software (Decisioneering, 1995).

II–3.2. EXTERNAL EXPOSURE TO CONTAMINATED SOILS

The following relationships were used to calculate effective dose equivalents from external exposure to contaminated soils:

$$\dot{D}(t) = C_S(t) \cdot DRF(z(t)) \tag{1}$$

where:

$\dot{D}(t)$ = dose rate at time t [Sv yr^{-1}];
$C_s(t)$ = concentration of ^{137}Cs in a soil layer of depth z at time t [Bq kg^{-1}]; and
$DRF(z(t))$ = the effective dose-rate factor [Sv yr^{-1} per Bq kg^{-1}] for a given uniform contamination of the soil up to a depth $z(t)$.

The dose-rate factor can be calculated as (Apostoaei et al. 2000):

$$DRF(z) = a \cdot \exp\left(-\frac{z}{\mu}\right) + b \tag{2}$$

where:

z = depth of the uniform contaminated soil slab (cm);
μ = the mean free path of ^{137}Cs/^{137m}Ba gamma radiation in soil ($\mu = 7.72$ cm); and
a and b = empirical fit coefficients ($a = -7.98 \times 10^{-7}$, and $b = 8.86 \times 10^{-7}$) for effective dose from exposure to ^{137}Cs. When using these values of the fit coefficients, the resulting DRF is measured in Sv yr^{-1} per Bq kg^{-1}.

The concentration of ^{137}Cs in the soil layer of depth z depends on the inventory of ^{137}Cs in that layer at time t after a single deposition event.

$$C_S(z) = \frac{C_A(0)}{\rho \cdot z} \cdot \exp(-\lambda \cdot t) \tag{3}$$

where:

$C_A(0)$ = the areal concentration of ^{137}Cs [Bq m^{-2}] at the time of deposition;
ρ = the soil density [kg m^{-3}];
λ = radioactive decay of ^{137}Cs [yr^{-1}];
z = depth of the uniform contaminated soil slab [m]; and
t = time [yr].

The effective dose received from time t_1 to time t_2 is obtained by integrating equation 1.

$$D_{t_2 - t_1} = \frac{C_A(0)}{\rho \cdot z} \cdot \exp(-\lambda \cdot t_1) \cdot \frac{1 - \exp(-\lambda \cdot (t_2 - t_1))}{\lambda} \cdot DRF(z(t)) \tag{4}$$

During the time interval (t_1, t_2), the depth of the contaminated layer z is considered to be constant. The time after April 28, 1986 was divided in five broad intervals where the depths was considered constant: 1) April 28, 1986 to May 28, 1986, 2) May 29, 1986 to April 28, 1987, 3) April 29, 1987 to December 31, 1990, 4) January 1, 1991 to December 31, 1995, and 5) January 1, 1996 to April 28, 2036 (for 50-years lifetime exposure). The effective dose received during two or more intervals were obtained by summing the doses for each time interval.

Effective doses were estimated separately for exposure to undisturbed soils and for exposure to cultivated soils. The total dose was calculated by adding the two doses weighted by the fraction of time spent on each type of soil. Occupancy factors (i.e. the fraction *f* of time spent indoor vs. outdoors), shielding factors (*SF*) for the construction materials, and the fractions of the population (*F*) performing outdoor and indoor work, respectively were also used in estimation of the total dose. The resulting dose estimate is considered representative for an average individual in the population living in the study area.

$$\begin{aligned}
TD = {} & D_{undisturbed} \times \\
& \times \left\{ \begin{array}{l}
F_{indoor}\left[f_{home}\left(f_w SF_w + f_b SF_b\right) + f_{outdoor-work} SF_{soil} + f_{indoor-work} SF_{work}\right]_{indoor-workers} + \\
F_{outdoor}\left[f_{home}\left(f_w SF_w + f_b SF_b\right) + f_{outdoor-work} SF_{soil} + f_{indoor-work} SF_{work}\right]_{outdoor-woreker s} + \\
F_{outdoor}\left[f_{home}\left(f_w SF_w + f_b SF_b\right) + f_{outdoor} SF_{soil} + f_{indoor} SF_{work}\right]_{pensioners}
\end{array} \right\} + \\
& + D_{cultivated} \times \\
& \times \left\{ \begin{array}{l}
\left[f_{outdoor-work} SF_{soil}\right]_{indoor-workers} + \left[f_{outdoor-work} SF_{soil}\right]_{outdoor-workers} + \\
\left[f_{outdoor} SF_{soil}\right]_{pensioners}
\end{array} \right\}
\end{aligned}$$

The subscripts *w* and *b* denotes *wood* and *brick*, respectively, as the material of construction for the houses in the area of interest. The factors f_w and f_b represents the fraction of the population living in wood or brick houses respectively. The factors *f* represent the fraction of time spent at home, working indoors or outdoors. The description and the value of each occupancy factor (*f* and *F*) are given in Table II-3.1. The shielding factors (*SF*) used to estimate the total dose are presented in Table II-3.2.

An initial set of values for the occupancy factors was obtained from Tables 43, 44 of version 1.06 of the scenario (October 1997). Using these values a set of initial predictions was obtained (these predictions were reported in October 1999). A set of revised predictions was obtained using data given in Tables I.XLIV, I.XLV, and I.XLVI of the revised version of the scenario (Version 1.07, January 2000).

The soil density for cultivated soils was taken to be 1300 kg m^{-3}, with a range of values from 1200 to 1500 kg m^{-3}. For undisturbed soils, the soil density was set to 1400 kg m^{-3}, ranging from 1300 to 1600 kg m^{-3}. Triangular probability distribution functions were used to describe the uncertainty in this parameter for the two types of soil.

The contamination was considered to be uniform in a layer of a given depth z. This is obviously not the case in reality. The depth z can be considered as that depth of a uniform contaminated top layer of soil that would produce the same dose as the actual distribution of activity in soil, given that the entire amount deposited onto the soil is found within the layer of depth z. This method was chosen because it is convenient (i.e. dose-rate factors for uniform contaminated layers are available for different depths z (Eckerman et al. 1993), and they can be easily interpolated between depths (Apostoaei et al. 2000).

A difference between the cultivated and uncultivated (undisturbed) soils was made in terms of the depth of the contamination. For cultivated soils, the activity mixes in a top layer at the time of tillage. The depth of the contaminated layer z can be obtained from measurements or it can be derived by modeling the transport of radioactivity in a soil column. In this exercise, an initial choice was made for the depth of the contamination z (Table II-3.3), and based on this choice initial predictions were made. The initial predictions were larger than the observations[3] (about a factor of 2), especially for the longer periods of time (Figure II-3.1), indicating a underestimation of the contaminated depth z. Additional revised predictions were obtained by increasing the contaminated depths for the longer periods of time.

Finally, two sets of revised predictions (Table II-3.4 and Figure II-3.1) were made. In the first set, the depth of the contaminated layer was kept the same as in the initial predictions, and only the occupancy factors were changed. In the second set of revised predictions, both the occupancy factors and the depth of the contamination were changed. The last revision produces results much closer to the observed values, than the initial predictions.

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[3] "Observations" are actually estimates of the lifetime dose based on measurements, provided by the authors of the Scenario.

TABLE II-3.1. OCCUPANCY FACTORS USED IN THE CALCULATION OF THE TOTAL DOSE

Occupancy factor	Outdoor workers	Indoor workers	Pensioners
Time spent			
HOME (f_{home})			
Indoor	0.47	0.49	0.68
Outdoor (undisturbed)	0.20	0.23	0.32
WORK (f_{work})			
Indoor (building)	0.08	0.23	0.00
Outdoor (cultivated)	0.25	0.04	0.00
TOTAL	1.00	1.00	1.00
Type of house			
Wooden house (f_w)	70%	70%	70%
Brick house (f_b)	30%	30%	30%
Population ($F_{indoor,\ outdoor\ or\ pensioners}$)	52%	34%	14%

TABLE II-3.2. SHIELDING FACTORS (*SF*) FOR THE ^{137}Cs/^{137m}Ba GAMMA RADIATION FOR DIFFERENT BUILDING STRUCTURES. VALUES ARE TAKEN FROM THE SCENARIO AND FROM MODEL DESCRIPTIONS OF VARIOUS PARTICIPANTS IN THE IAEA-VAMP SCENARIO CB AND SCENARIO S EXERCISES

	Uncertainty range for shielding factor[a]		
	min	mode	max
Wooden house	0.1	0.25	0.35
Brick house	0.05	0.15	0.25
Building (at work)	0.01	0.05	0.1
Outdoor (open field)[b]	0.85	0.95	1

[a] A triangular probability distribution function was used to describe the uncertainty in the shielding factor.

[b] Due to vegetation coverage.

TABLE II-3.3. DEPTHS OF THE UNIFORMLY CONTAMINATED TOP LAYER OF SOIL USED TO OBTAIN THE INITIAL AND THE REVISED PREDICTIONS. THE DEPTH WAS TREATED AS AN UNCERTAIN VARIABLE. TRIANGULAR DISTRIBUTION FUNCTIONS WITH THE MINIMUM, MODE, AND MAXIMUM VALUES REPORTED BELOW WERE USED TO DESCRIBE THE UNCERTAINTY

UNDISTURBED SOILS		Depth (cm) used for the initial predictions			Depth (cm) used for the revised predictions		
Exposure period							
Begin date	**End date**	min	mode	max	min	mode	max
April 28, 1986	May 28, 1986	0.1	0.2	0.3	0.1	0.2	0.3
May 29, 1986	April 28, 1987	0.5	2	4	0.5	2	4
April 29, 1987	Dec 31, 1990	1	3	5	2	4	7
Jan 1, 1991	Dec 31, 1995	2	5	8	4	8	12
Jan 1, 1996	April 28, 2036	5	10	15	15	20	25
CULTIVATED SOILS							
Exposure period							
Begin date	**End date**	min	mode	max	min	mode	max
April 28, 1986	May 28, 1986	0.1	0.2	0.3	0.1	0.2	0.3
May 29, 1986	April 28, 1987	5	10	15	5	10	15
April 29, 1987	Dec 31, 1990	5	10	15	7	12	17
Jan 1, 1991	Dec 31, 1995	7	12	17	10	15	20
Jan 1, 1996	April 28, 2036	7	15	20	10	30	40

TABLE II-3.4. ESTIMATED EXTERNAL EFFECTIVE EQUIVALENT DOSE (mSv) FROM EXPOSURE TO CONTAMINATED GROUND SURFACES. THESE RESULTS ARE FOR BOTH GENDERS COMBINED, THEY ARE PRACTICALLY IDENTICAL WITH THE VALUES PREDICTED FOR MALES AND FOR FEMALES

	95% confidence interval		
	Lower bound	Central value	Upper bound
OBSERVATIONS[a]			
27 April 1986 – 30 April 1987	2.8	3.5	4.2
27 April 1986 – 31 Dec 1990	8.9	11.1	13.3
27 April 1986 – 31 Dec 1995	14.8	18.4	22.0
27 April 1986 – lifetime	31.8	39.6	47.4
INITIAL PREDICTIONS			
27 April 1986 – 30 April 1987	3.2	4.1	5.6
27 April 1986 – 31 Dec 1990	10.6	13.6	17.7
27 April 1986 – 31 Dec 1995	19.0	23.3	29.6
27 April 1986 – lifetime	48.8	60.4	75.6
REVISED PREDICTIONS (I)			
27 April 1986 – 30 April 1987	3.4	4.3	6.0
27 April 1986 – 31 Dec 1990	11.4	14.3	18.7
27 April 1986 – 31 Dec 1995	20.1	24.5	30.6
27 April 1986 – lifetime	50.9	62.3	77.6
REVISED PREDICTIONS (II)			
27 April 1986 – 30 April 1987	3.4	4.2	5.7
27 April 1986 – 31 Dec 1990	10.2	12.6	16.1
27 April 1986 – 31 Dec 1995	16.9	20.7	25.4
27 April 1986 – lifetime	35.4	43.3	53.9

[a] "Observations" are actually estimates of the lifetime dose based on measurements, provided by the authors of the Scenario.

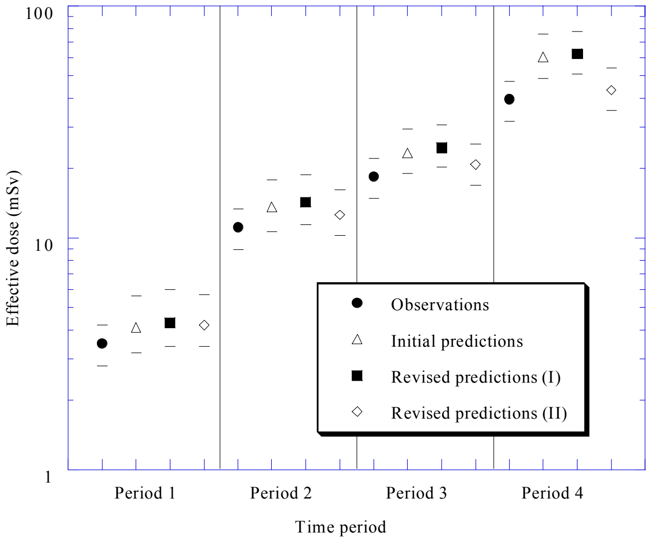

FIG. II-3.1. Comparison between the "observed" and predicted doses from exposure to contaminated ground surfaces. The time periods are: Period 1 = April 28, 1986 – April 30, 1987; Period 2 = April 28, 1986 – December 31, 1990; Period 3 = April 28, 1986 – December 31, 1996; Period 2 = April 28, 1986 – lifetime. In the first set of revised predictions, the occupancy factors were changed. In the second set of revised predictions, both the occupancy factors and the depth of the contaminated layer were changed. The upper and lower bound for each dose estimate encompass a 95% confidence interval.

II–3.3. INGESTION OF FISH FROM THE IPUT RIVER

The concentration of ^{137}Cs in fish (C_f, Bq kg^{-1}$_{\text{fresh wt.}}$) from the Iput River in a given year was calculated using bioconcentration factors:

$$C_f(t) = \left(C_w(t) / b_{wet/dry}\right) \cdot BCF \tag{5}$$

where:

C_w = concentration of ^{137}Cs in water [Bq L^{-1}] at time *t*. An annual time step was used;

$b_{dry/wet}$ = bias factor accounting for the differences in the concentration in water between the dry and the wet season [unitless]; and

BCF = bioconcentration factor [Bq kg^{-1}$_{\text{fresh wt.}}$ per Bq L^{-1}].

The concentration in water used in the calculation was obtained from the Scenario. The information provided in the revised version of the scenario (January 2000) is very similar to the information provided in the initial version of the scenario (October 1997). Thus, the results reported here were not changed when the updated scenario was released. The concentration in water for the years 1987-1991 was fitted with an exponential equation ($y = 3.33 * \exp(-0.52 \times x)$), where *x* is the number of years from 1986. That is, x=1 for 1987, x=2 for 1988, etc. The value for 1986 was obtained by setting *x* to zero in the above fit equation. The values for years after 1991 were obtained by extrapolation, using the fit equation for *x* larger than 5.

Even though the Scenario states that the reported concentration in water represents an annual average for a given location, the reported values match closely the values reported for the wet season (data for April 1991 in Table I.VI of the Scenario description). During the wet season, the concentration in water is larger than the concentration during the dry season by a factor of about 1.5. This effect is observed by comparing the data provided in Table I.VI and I.VII of the Scenario. A possible explanation for this effect is the presence of runoff. During a rain event or during snowmelt, the runoff water collects ^{137}Cs and transports it into the river. Even though more water is also added to the river (leading to dilution), the overall effect is a concentration of ^{137}Cs in water larger than that observed during the dry season. During the dry season, little or no ^{137}Cs is added to the water by runoff; the concentration in water is given by resuspended sediment, or by ^{137}Cs brought from other regions.

In this exercise, the reported water concentrations were adjusted by a bias factor that accounts for the differences between the wet and the dry season. Given that the reported concentrations are for the wet season (assumed to last 6 month per year) and the difference between the wet season and the dry season a factor of about 1.5, the bias factor ($b_{wet/dry}$) was assumed to range between 1 and 1.5 with a best estimate of 1.3. The concentration in water was reduced by this bias factor before being used to estimate the concentration in fish.

For the years 1987-1991, for which reported water concentrations were available, the uncertainty in the estimated water concentration was taken to be a factor of 2 (i.e. a geometric standard deviation of 1.5; Table II-3.5). Since the rest of the years are based only on extrapolation using the fit equation discussed above, an uncertainty factor of 4 was used (i.e. a GSD = 2.0). Lognormal distributions were chosen to describe the uncertainty in the water concentration in each year.

The bioconcentration factor was taken from the dose reconstruction study performed for assessing the health effects of historical ^{137}Cs releases into the Clinch River in Tennessee, U.S.A. (Thiessen et al. 1998). The values used (a range of 120 to 3000, with a central value of 600 Bq $kg^{-1}_{\text{fresh wt.}}$ per Bq L^{-1}) are representative for all types (i.e. predator and not predator) of river water fish. A log-triangular distribution was used to describe the uncertainty.

A comparison of the predicted and observed concentration of ^{137}Cs in fish from the Iput River is shown in Figure II-3.2. The central values of the predictions are about a factor of two lower than the central values of the observations, but the observations are contained within the predicted uncertainty ranges. These differences may be due to a lower bioconcentration factor and/or due to the effect of the $b_{wet/dry}$ (the wet vs. dry season adjustment factor).

The predicted trend is somehow different than the observed trend. First, the observed values for 1986 are lower than those observed in 1987. The possible reason for this difference is the time lag usually observed between the concentration in fish and the concentration in water. That is, when the concentration in water increases, the concentration in fish will increase too, but only after a period of time determined by the dynamics of the uptake of ^{137}Cs in fish. The use of a bioconcentration factor is based on the assumption of equilibrium between the concentration in water and the concentration in fish. Cesium-137 concentrations in the Iput River and fish were not in equilibrium in 1986.

In the last years (1994, 1995), the observed concentrations seem to level off, while the predicted values continue to decrease. A possible explanation for these differences is that the model uses an extrapolation of the fit equation for concentration in water in early years. Cesium-137 is mainly brought into the river by water runoff from slopes adjacent to the river. In the early years after the accident, ^{137}Cs is available to be carried by runoff, but the available amount decreases with time. After a number of years, either the rate of this decrease changes with time, or the amount of ^{137}Cs brought into the river by runoff becomes comparable with the amount resuspended from the bottom sediments of the river (deposited in the previous years). The extrapolation used in this exercise does not specifically take into account such physical processes.

TABLE II-3.5. CONCENTRATION OF ^{137}Cs IN THE WATER OF IPUT RIVER USED IN THE CALCULATIONS

	C_w [Bq L^{-1}]		
	Ver. 1.06[a]	Ver 1.07[a]	
Year	Average	Average[b]	GSD[c]
1986		3.3	2.0
1987	2.0	1.9	1.5
1988	1.4	1.4	1.5
1989	0.6	0.54	1.5
1990	0.55	0.52	1.5
1991	0.23	0.23	1.5
1992		0.24	2.0
1993		0.15	2.0
1994		0.086	2.0
1995		0.051	2.0

[a] Version of the scenario: Ver 1.06 is dated October 1997; Ver 1.07 is dated January 2000.

[b] The scenario provided values for 1987-1991. The values for other years were obtained by extrapolation (see text). [c] GSD is the geometric standard deviation used to define the uncertainty in the average values.

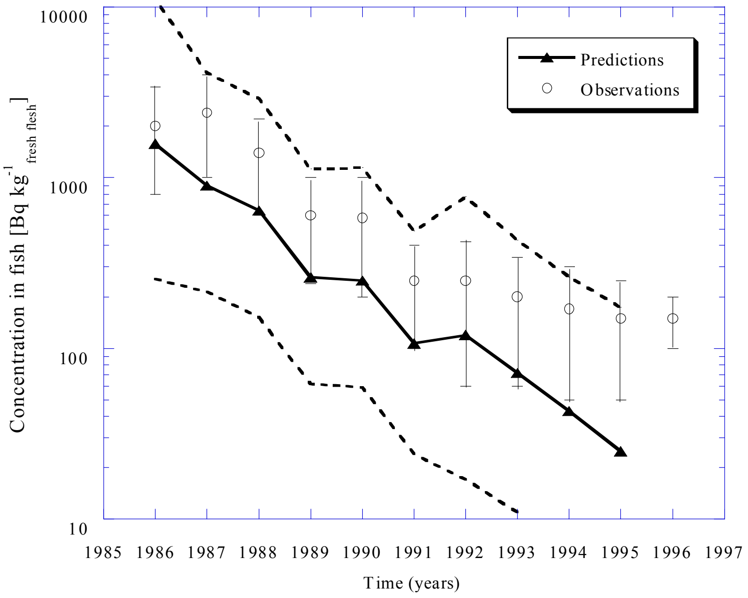

FIG. II-3.2. Comparison between the observed and predicted concentrations of ^{137}Cs in fresh water fish from the Iput River. The upper and lower bounds for both observations and predictions represent 95% confidence intervals. (For predictions, the confidence interval is based on propagation of uncertainties assigned to individual parameters by professional judgment).

II–3.4. CONCENTRATION ^{137}Cs IN POTATOES

The concentration of ^{137}Cs in potatoes was calculated starting from the concentration of ^{137}Cs in soil, by using two methods, both based on soil-to-plant transfer factors.

Approach 1 $$C_p(t) = C_{s,mass}(t) \cdot R_F \cdot B_v / W \tag{6}$$

Approach 2 $$C_p(t) = C_{s,surface} \cdot \exp(-\lambda_R t) \cdot B_s(t) / W \tag{7}$$

$$C_{s,mass}(t) = \left(C_{s,surface}(0) / \rho \cdot z(t)\right) \cdot \exp(-\lambda_R t) \tag{8}$$

where

$C_p(t)$ = concentration of ^{137}Cs in potatoes at time *t* [Bq kg$^{-1}_{\text{fresh}}$]. Time is measured in years from 1986;

$C_{s,\ surface}(t)$ = surface concentration of ^{137}Cs [Bq m^{-2}] at time *t*;

$C_{s,\ mass}(t)$ = mass concentration of ^{137}Cs [Bq kg^{-1}] at time *t*, within a uniformly contaminated layer of soil of thickness *z* [m]

R_F = reduction of available activity due to fixation of cesium in soil. The fixation is 15% per year, which corresponds to a half-life of 4.3 yrs (IAEA 1994)[4];

---

[4] The fixation of 15% per year was applied as follows: $C_n = C_{n-1} \times (1-0.15) = C_{1986} \times (0.85)^n = C_{1986} \times \exp(-0.16 \times n)$; where *n* is the number of years after 1986. Thus, $\lambda = 0.16$ yr^{-1}, and $T_{1/2} = 4.3$ yr.

W = wet mass to dry mass conversion factor [$\mathrm{kg_{dry}\ kg^{-1}_{fresh}}$]. Values for this parameter vary from 0.15 to 0.35 $\mathrm{kg_{dry}\ kg^{-1}_{fresh}}$;

B_v = volumetric soil-to-plant transfer factor [$\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ kg^{-1}_{dry\ (soil)}}$];

B_s = surface soil-to-plant transfer factor [$\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ m^{-2}_{soil}}$];

λ_R = radioactive decay constant [$\mathrm{y^{-1}}$];

ρ = soil density [$\mathrm{kg\ m^{-3}}$]; and

z = depth of the contaminated layer [m]; (10 cm for 1986, 12 cm for 1987–1991, 15 cm after 1991).

The two approaches make use of the data on soil-to-plant transfer factors from two different sources: (a) B_v from Frissel (1992) (which are the same with the ones in IAEA 1994), and (b) B_s reported by Shutov (1992). The data reported by Shutov (1992) are obtained from measurements performed after Chernobyl accident in areas close to Novozybkov region.

The scenario indicates that the soil in the test area is mostly sandy or sandy loam (Tables 27 and 29 of the Scenario). The values for B_v recommended by Frissel (1992) and IAEA (1994) for sandy soils vary from 1.7×10^{-2} to 1.7 $\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ kg^{-1}_{dry\ (soil)}}$, with a central value of 1.7×10^{-1} $\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ kg^{-1}_{dry\ (soil)}}$. For clay soils, the same sources indicate values for B_v of 7.2×10^{-2} $\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ kg^{-1}_{dry\ (soil)}}$ with a range from 7.2×10^{-3} to 7.2×10^{-1} $\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ kg^{-1}_{dry\ (soil)}}$. The initial predictions were obtained using the coefficients for sandy soils (Figure II-3.3). However, the predictions highly overestimate the observed concentration (more than a factor of 10). A second set of predictions was obtained using the coefficients for clay soils. These predictions were also large overestimates (by more than a factor of 5).

Shutov (1992) expressed the soil-to-plant transfer per unit area of soil rather than the volume of soil. This method has the advantage of relating the total amount of the contaminant located below 1 $\mathrm{m^2}$ of soil to the concentration in the edible part of the plant.

The values reported by Shutov (1992) for sandy soil for years 1987-1991 are 1.3×10^{-4}, 6.8×10^{-5}, 3.3×10^{-5}, 1.8×10^{-5}, and 9.0×10^{-6} $\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ m^{-2}_{soil}}$, respectively. These values were fitted using an exponential decay function, and it was found that they decrease with a half-life of about 14 months. Using the fitted exponential decay function, values for 1986 and for years after 1991 were obtained. A geometric standard deviation of 3.5 was assigned for all values (Shutov, 1992) for the purpose of uncertainty analysis. For clay soil, the coefficients reported by Shutov (1992) for years 1986-1991 are 5.3×10^{-5}, 3.4×10^{-5}, 2.0×10^{-5}, 1.4×10^{-5}, 9.04×10^{-6}, and 6.1×10^{-6} $\mathrm{Bq\ kg^{-1}_{dry\ (edible\ plant)}}$ per $\mathrm{Bq\ m^{-2}_{soil}}$, respectively. These values can be fitted using an exponential decay function with a half-life of 19 month.

The results (Figure II-3.3) show extremely large differences between the predictions using the two sets of transfer factors. These differences cannot be easily explained. As expected, the predictions based on the data reported by Shutov (1992) are closer to the observed data. However, the decreasing pattern of the predictions based on Shutov (1992) is much steeper than the observed decreasing pattern. A possible explanation is that Shutov obtained data from areas where intensive agricultural countermeasures were applied during 1988-1991.

The decrease pattern recommended by the IAEA (1994) accounts for general processes that reduce the bioavailablility of $^{137}\mathrm{Cs}$ in soil, such as soil adhesion. This pattern, however, matches closely the observed decreasing pattern.

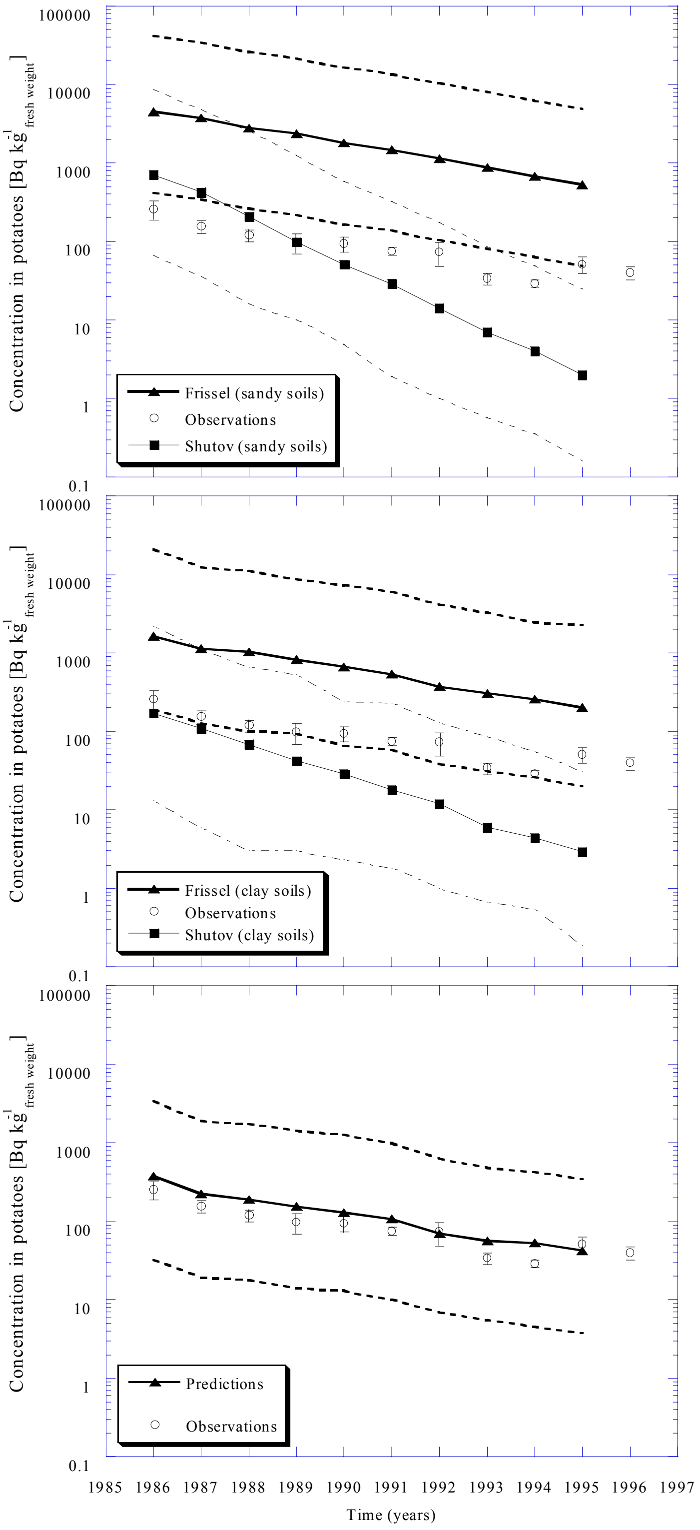

FIG. II-3.3. Comparison between the predicted and the observed concentration in potatoes in the Novozybkov region.

Generally, the predictions using coefficients for clay soil gave results closer to the observed concentration in potatoes, even though the scenario indicates that the soil is mostly sandy loam. One possible explanation is related to gardening techniques. Potatoes may have been planted on areas with more clay soils (which are of limited surface in the test area), or better soils were added to the potatoes cultivated areas. Also, deep ploughing brings clay soil from the lower soil layers to the surface, increasing the clay component and thus, the absorption of cesium.

The final predictions (lower panel of Figure II-3.3) were obtained by combining the information from Shutov (1992) and from Frissel (1992). Equation 6 was used with a decrease pattern of available ^{137}Cs in soil recommended by IAEA (1994) (15% per year), but by using a transfer coefficient (B_v) derived from the values reported by Shutov (1992) for 1986: $B_v = B_s$ * soil thickness [0.2 m] * soil density [1400 kg m^{-3}] = 1.47×10^{-2}. An uncertainty of a factor of 10 was used for this coefficient. No countermeasures were taken into account in any of the presented predictions.

II–3.5. DOSE FROM INHALATION OF ^{137}Cs DURING PASSAGE OF THE CLOUD

The effective dose from inhalation ^{137}Cs during the passage of the cloud was calculated as follows:

$$D_{inh} = \sum C_a \cdot \left[f_{outdoor} + \left(1 - f_{outdoor}\right) \cdot R_{io} \right] \cdot BR \cdot N_{days} \cdot DCF_{inh} \qquad (9)$$

where:

D_{inh} = effective dose equivalent from inhalation of ^{137}Cs [Sv]. Summation is done over all periods of time, each of N_{days} in length;
C_a = average concentration of ^{137}Cs in air in each period of time lasting N_{days} [Bq m^{-3}];
$f_{outdoor}$ = fraction of time spent outdoors [unitless]
R_{io} = indoor/outdoor reduction fraction [unitless]
BR = breathing rate for adults [m^3 d^{-1}] (23 m^3 d^{-1} for males; 18 m^3 d^{-1} for females, with a geometric standard deviation of 1.3);
= number of days over which the concentration in air is averaged [days];
DCF_{inh} = the inhalation dose conversion factor for effective dose [Sv Bq^{-1}]. The value of 8.6×10^{-9} Sv Bq^{-1} recommended by ICRP (Eckerman et al. 1988) was used. A geometric standard deviation of 1.8 was used to describe the uncertainty in the inhalation dose factor (Thiessen et al. 1998).

The equation above was applied for each gender and for each population category (indoor or outdoor workers, pensioners) by using the appropriate parameter values. Population average doses were obtained for males and females separately by taking the average over all population groups, weighted by the relative number of individuals in each population group (52% outdoor workers, 34% indoor workers, 14% pensioners). Pensioners and indoor workers are assumed to spend the same amount of time outdoors.

The concentration in outdoor air (C_a) and the number of days (N_{days}) were taken from Table 1 of the Scenario. The concentration in indoor air was assumed to be lower ($R_{i/o}$ = 70%; ranging from 40% to 100%) than the concentration in outdoor air (Apostoaei et al. 1998a). The indoor workers are assumed to spend at least 2-4 hours per day outdoors, while outdoor workers are assumed to spend 9-11 hours per day outdoors.

The doses estimated here (Table II-3.6) are about a factor of two larger than the doses estimated by the authors of the Scenario (1.3×10^{-2} mSv), chiefly because of the differences between the inhalation dose factors ($DCF_{inh} = 8.6 \times 10^{-9}$ Sv Bq^{-1} used here, as opposed to $DCF_{inh} = 4.6 \times 10^{-9}$ Sv Bq^{-1} used by the authors of the scenario).

TABLE II-3.6. ESTIMATED EFFECTIVE DOSES FOR CLOUD INHALATION

		Effective dose from cloud inhalation [mSv]					
Time Period			Females			Males	
from	to	2.5%-ile	Central	97.5%-ile	2.5%-ile	Central	97.5%-ile
28-Apr-86	30-Apr-86	4.2×10^{-3}	1.9×10^{-2}	8.4×10^{-2}	5.3×10^{-3}	2.6×10^{-2}	1.1×10^{-1}
01-May-86	10-May-86	4.3×10^{-4}	2.2×10^{-3}	1.1×10^{-2}	5.7×10^{-4}	2.8×10^{-3}	1.2×10^{-2}
11-May-86	20-May-86	1.1×10^{-4}	4.2×10^{-4}	1.8×10^{-3}	1.3×10^{-4}	5.3×10^{-4}	2.2×10^{-3}
21-May-86	31-May-86	5.2×10^{-5}	2.4×10^{-4}	8.9×10^{-4}	6.4×10^{-5}	3.0×10^{-4}	1.1×10^{-3}
01-Jun-86	30-Jun-86	6.4×10^{-5}	2.7×10^{-4}	9.6×10^{-4}	7.3×10^{-5}	3.3×10^{-4}	1.3×10^{-3}
	TOTAL	5.6×10^{-3}	2.3×10^{-2}	9.4×10^{-2}	6.6×10^{-3}	3.1×10^{-2}	1.2×10^{-1}

II–3.6. CONCENTRATION OF ^{137}Cs IN WINTER WHEAT AND RYE

Winter cereals are planted in the fall; thus, the soil is not disturbed by tillage in the spring. In the spring and summer of 1986, ^{137}Cs was contained in the first few centimeters of soil. Also, the accident occurred only shortly after the vegetation period started. Due to the small leaf area, direct deposition and interception of ^{137}Cs by the plants was considered to be small compared to contamination by soil uptake, and it was neglected. In the absence of countermeasures, the concentration in winter wheat was calculated by using simple soil-to-plant transfer factors:

$$C_w = \left(C_{s,mass} \cdot R_f\right) \cdot \left(B_v \cdot K\right) / W \tag{10}$$

where:

C_w = concentration in winter wheat [Bq kg$^{-1}_{\text{fresh wt}}$];

$C_{s,\,mass}$ = mass concentration in soil [Bq kg^{-1}];

R_f = reduction factor because of fixation of ^{137}Cs (15% per year; IAEA 1994);

B_v = soil-to-plant transfer factor [Bq kg$^{-1}_{\text{dry wt}}$ per Bq kg$^{-1}_{\text{soil}}$] ($B_v = 3.7 \times 10^{-2}$ for sandy soils, with a factor of 10 uncertainty on both sides; IAEA 1994; Frissel 1992);

K = factor accounting for an increase in the transfer from soil to plant due to a low potassium level in soil [unitless] (K=1.5, Frissel 1992); and

W = wet mass to dry mass conversion factor [kg$_{\text{dry}}$ kg$^{-1}_{\text{fresh}}$]. Values for this parameter vary from 0.75 to 0.95 kg$_{\text{dry}}$ kg$^{-1}_{\text{fresh}}$.

The concentration in soil was calculated (see Eq. 3) assuming that ^{137}Cs was found in the first 10 cm of soil in 1986 and 1987, and in the first 12, 13, and 14 cm in 1988, 1989, and 1990 respectively. After 1990, the contamination is found in the first 15 cm of soil. These assumptions are similar to those made for the depth of the contamination in soil in the case of external exposure (for cultivated soils).

In the revised version of the predictions, I also took into account the effect of the following agricultural countermeasures: liming, application of organic fertilizers, and taking land out of production.

According to the scenario, increased quantities of lime and organic fertilizers were applied as countermeasures as early as 1987 in areas where contamination was between 555 and 1480 kBq m^{-2}. Agricultural lands with a soil concentration greater than 1480 kBq m^{-2} were taken out of production. In the calculations, I considered that these measures became fully effective only starting with 1988. Liming and organic fertilizers were applied until early 1990, but I considered that they were fully effective in reducing the root uptake until 1993. When fully effective, the application of lime reduced the root uptake by a factor of 2, while the application of the organic fertilizers reduced the uptake by a factor of 1.5 (Table 55 of the Scenario). The reduced root uptake fraction was applied for all agricultural areas where the average soil concentration was greater than 700 kBq m^{-2}. The agricultural areas that had an average soil concentration greater than 1480 kBq m^{-2} were eliminated from the calculation of the average for the entire region.

For rye, the soil-to-plant transfer factors (B^S_v [Bq $kg^{-1}{}_{\text{dry weight}}$ per Bq $m^{-2}{}_{\text{soil}}$]) reported by Shutov (1992) were used (Table II-3.7). A geometric standard deviation of 3.5 (a factor of 10 on either side) was used to describe the uncertainty around these soil-to-plant transfer factors. The concentration in soil (Bq m^{-2}) is reduced by radioactive decay only.

$$C_r = \left(C_{s,surface} \cdot \exp(-\lambda_R \cdot t)\right) \cdot \left(B_v^s \cdot K\right) / W \qquad (11)$$

where:

C_r = concentration in rye [Bq $kg^{-1}{}_{\text{fresh weight}}$];
$C_{s,\,surface}$ = surface concentration of ^{137}Cs in soil [Bq m^{-2}]; and
λ_R = radioactive decay constant [y^{-1}].
The rest of the variables are defined above.

Predictions using Shutov's transfer factors reproduce the decreasing trend with time of the observed data (Figure II-3.4) Shutov's factors were measured after the Chernobyl accident in areas close to the Novozybkov region, and thus they already contain the effect of countermeasures applied in the area. However, Shutov's factors were reported until 1990 only. After 1990, the countermeasures were not applied at the same rate. Thus, no change was assumed in the soil-to-plant transfer factors after 1990. (Note: some reduction because of processes such as soil adhesion is possible.)

TABLE II-3.7. SOIL TO PLANT TRANSFER FACTORS FOR RYE REPORTED BY SHUTOV (1992)

Year	B_v^S [Bq $kg^{-1}{}_{\text{dry weight}}$ per Bq $m^{-2}{}_{\text{soil}}$]
1987	1.50E-04
1988	8.30E-05
1989	4.50E-05
1990	2.20E-05
1991-1995	1.20E-05

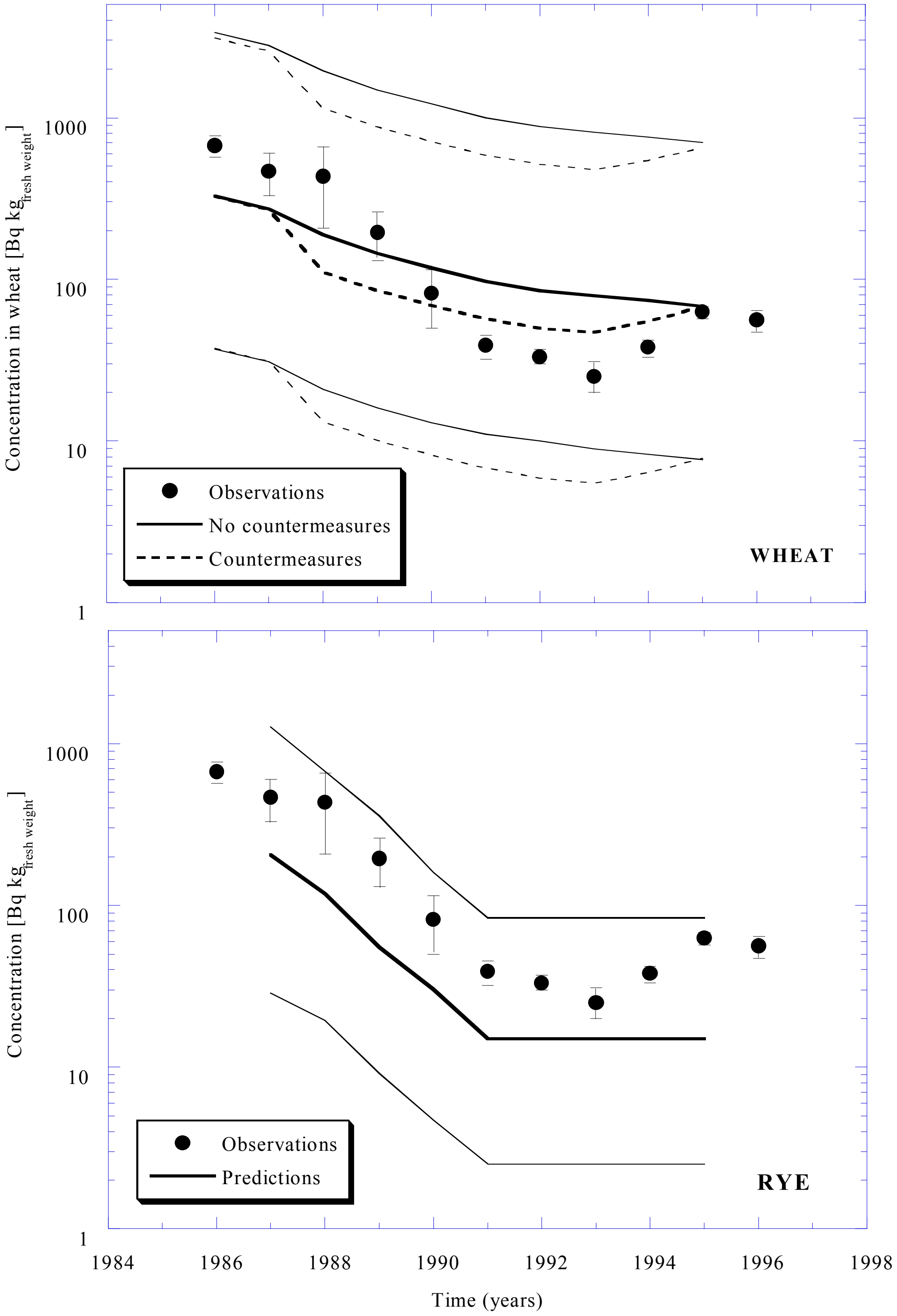

FIG. II-3.4. Comparison between predictions and observations for the concentration in cereals. The effect of agricultural countermeasures was taken into account for wheat.

II–3.7. INTAKE OF ^{137}Cs AND INTERNAL DOSES

The intake of ^{137}Cs and internal doses from ingestion of cereals, potatoes, and fish were calculated. This intake represents a small portion of the total intake of ^{137}Cs that is dominated by ingestion of milk and mushrooms.

The intake of ^{137}Cs from ingestion of fish (*I*; in Bq) was calculated as follows:

$$I = C_f \cdot L_f \cdot \left(\sum_{pop} Q_{pop} \cdot ED \cdot F_{pop} \right) \tag{12}$$

where:

C_f = concentration in fish (Bq kg^{-1})
L_f = loss of ^{137}Cs due to food preparation (0.5, IAEA 1992);
Q_{pop} = ingestion rate for a given population group (kg$_{\text{fish flesh}}$ day^{-1});
F_{pop} = fraction of the total population represented by the given population group (unitless); and
ED = exposure duration (days).

The concentration of ^{137}Cs in water for the wet season was used to calculate the intake of ^{137}Cs from ingestion of fish. Exposure duration was set to 1 day; thus the intake *I* actually represents the daily intake of ^{137}Cs from ingestion of fish (Bq d^{-1}). The population was divided in three groups relative to fish consumption, according to the information provided in Table 47 of the Version 1.06 of the Scenario. This information was updated in the January 2000 version of the Scenario, but the modifications are not important. One percent of the population consists of people who consume the fish they catch at a rate of 1-2 meals/week (average of 1.5 meals/week). Thirteen percent of the population consumes fish at a rate of four meals every three weeks (i.e. 3/4 of a meal/week, ranging from 0.25 to 1 meal/week). The rest of the population (86%) consumes very little or no fish from the Iput River. One meal is about 200 grams of fish flesh (ranging from 100 to 300 grams/meal). The small fraction of the population consuming fish reflects the situation in the years immediately after the accident (1987-1990). These fractions were applied for all years of interest. In future revisions of these calculations, an increase in the proportion of the population fishing and consuming fish from the Iput River should be included.

The intake of ^{137}Cs from ingestion of cereals (*I*, Bq d^{-1}) is calculated as:

$$I = C_w \cdot L_w \cdot Q_c \tag{13}$$

where:

C_w = Concentration in wheat;
L_w = factor accounting for the loss due to food preparation (0.2-0.6, IAEA 1992); and
Q_c = intake rate of all grains (males = 0.23 kg d^{-1}, females = 0.17 kg d^{-1}, with a 35% coefficient of variation).

The intake of cereals in a given year is from the cereals produced in the previous years harvest.

The intake of ^{137}Cs from ingestion of potatoes (I, Bq d^{-1}) is calculated as:

$$I = C_p \cdot L_p \cdot Q_p \tag{14}$$

where:

C_p = concentration in potatoes;
L_p = factor accounting for the loss due to food preparation (0.6-0.8, IAEA 1992); and
Q_p = intake rate of potatoes (0.1 kg d^{-1} for both males and females, with a 20% coefficient of variation).

The estimated intake of ^{137}Cs from ingestion of cereals, potatoes and fish is given in Table II-3.8. Based on this intake, ingestion doses (Table II-3.9) were obtained using a dose factor for ingestion of ^{137}Cs of 1.2×10^{-8} Sv Bq^{-1} (with a geometric standard deviation of 1.2; Apostoaei et al. 1998b). Note that these doses are small because they do not contain the contribution of the dominant sources of ^{137}Cs in the diet (i.e. milk and mushrooms).

TABLE II-3.8. PREDICTED INTAKE OF ^{137}Cs [Bq d^{-1}] FROM INGESTION OF CEREALS, FISH AND POTATOES BY MALES. THE RESULTS FOR FEMALES ARE LOWER, BUT THE DIFFERENCES ARE NEGLIGIBLE

Year	No countermeasures[a] 95% confidence interval			Countermeasures[a] accounted for 95% confidence interval		
	Lower bound	Central value	Upper bound	Lower bound	Central value	Upper bound
1986	3.7	28	279	3.7	28	279
1987	12	93	465	11	91	447
1988	9.1	69	348	8.9	67	341
1989	6.5	53	262	4.6	42	205
1990	4.4	41	212	3.4	32	168
1991	3.9	32	158	3.0	25	135
1992	3.0	27	129	2.3	19	117
1993	2.3	20	96	1.8	15	73
1994	1.8	16	81	1.5	12	64
1995	1.6	13	70	1.3	11	61

[a] Refers to agricultural countermeasures only.

TABLE II-3.9. RADIATION DOSES (mSv) FROM INGESTION OF CEREALS, POTATOES AND FISH CONTAMINATED WITH ^{137}Cs. THE REPORTED VALUES ARE FOR MALES. THE VALUES FOR FEMALES ARE LOWER, BUT THE DIFFERENCES ARE NEGLIGIBLE

	No countermeasures[a] 95% confidence interval			Countermeasures[a] accounted for 95% confidence interval		
MALES	Lower bound	Central value	Upper bound	Lower bound	Central value	Upper bound
April 1986 – April 1987	0.03	0.22	1.48	0.03	0.22	1.48
April 1986 – Dec 1990	0.15	1.17	5.97	0.14	1.07	5.36
April 1986 – Dec 1995	0.20	1.60	8.25	0.18	1.43	7.15
April 1986 – Lifetime						

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II–4. OSCAAR MODEL – DESCRIPTION AND EVALUATION OF MODEL PERFORMANCE

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II–4.1. GENERAL MODEL DESCRIPTION

II–4.1.1. Name of model, model developer and model user

Model name: OSCAAR (Off-Site Consequence Analysis code for Atmospheric Releases in reactor accidents).
Model developer: Toshimitsu Homma and Orihiko Togawa, JAERI
Model user: Toshimitsu Homma, JAERI

II–4.1.2. Intended purpose of the model in radiation assessment

OSCAAR has been developed within the research activities on probabilistic safety assessment (PSA) at the Japan Atomic Energy Research Institute. OSCAAR is primarily designed for use in Level 3 PSA of nuclear reactors in Japan. OSCAAR calculations, however, can be used for a wide variety of applications including siting, emergency planning, and development of design criteria, and in the comparative risk studies of different energy systems.

II–4.1.3. Uncertainties and variability

OSCAAR is coupled with the uncertainty and sensitivity analysis techniques to quantify uncertainty associated with accident consequence assessment and to identify uncertain processes and important parameters contributed to consequences. Among a number of techniques available for propagating parameter uncertainties through complex models, a Monte Carlo method has been implemented to perform uncertainty and sensitivity analyses of OSCAAR. The software package PREP/SPOP is used to allow for an automatic performance of all necessary steps in uncertainty and sensitivity analysis. The different sampling schemes, such as pure random, Latin hypercube and quasi-random sampling, are allowed to be used in PREP(Homma and Saltelli, 1992). SPOP performs the uncertainty and sensitivity analyses on the output of the model. SPOP includes several parametric and non-parametric techniques, based on regression-correlation measures, as well as some “two-sample” tests (Saltelli and Homma, 1992).

In this calculation, the uncertainties in the model results, both due to the uncertainty in model parameter values and due to the variability of contamination in the test area, are determined by Latin hypercube sampling from prescribed distribution of the model parameters and initial contamination. The 95% confidence intervals about the arithmetic mean for all quantities are estimated using Chebychevs theorem.

II–4.2. DETAILED MODEL DESCRIPTION

OSCAAR consists of a series of interlinked modules and data files that are used to calculate the atmospheric dispersion and deposition of selected radionuclides for all sampled weather conditions, and the subsequent dose distributions and health effects in the exposed population. Using the Iput scenario, we have mainly tested the performance of the CHRONIC module, which calculated:

— long-term groundshine dose;

— internal doses via inhalation of radionuclides resuspended from the ground; and

— internal doses via ingestion of contaminated foodstuffs.

The migration of deposited material into soil as well as the radioactive decay is taken into account for the calculation of the long-term groundshine doses. The concentrations of resuspended particles are estimated by the time-dependent resuspension factor. The food chain model in CHRONIC is an extension of the methodology used in WASH-1400 and is available for important Japanese crops. It can reflect their seasonal dependence in probabilistic assessments.

Although OSCAAR does not include the model for aquatic pathways, the empirical model was developed for the Iput scenario to estimate the contribution of fish pathway to the total intake of ^{137}Cs. The detailed model descriptions and assumptions used to calculate the concentration of ^{137}Cs in the river fish are given in Annex II–4.A.

II–4.2.1. External dose

II–4.2.1.1. Cloudshine

The external dose from the passing cloud is estimated in OSCAAR using the air concentrations calculated from the atmospheric dispersion and deposition. In this calculation, however, because of lack of information about the source term and the meteorological conditions at the time of the accident, the atmospheric dispersion and deposition model was not used. Instead the time-integrated concentration of ^{137}Cs in air was used according to the following equation:

$$D_c = TIC \cdot DF_c \cdot \sum_i f_i \cdot (OF_i^{out} + OF_i^{in} \cdot SF) \tag{1}$$

where:

D_c = external dose from the passing cloud (Sv);
TIC = time-integrated concentration of ^{137}Cs in air (Bq s m^{-3});
DF_c = dose conversion factor for cloudshine (Sv s^{-1} per Bq m^{-3});
f_i = fraction of *i*-th occupation group (%);
OF_i^{out} = outdoor occupancy factor for *i*-th occupation group;
OF_i^{in} = indoor occupancy factor for *i*-th occupation group; and
SF = shielding factor for wooden or brick house.

The time-integrated concentration in air was calculated from the ^{137}Cs concentrations in ground-level air of the test area given in Table I.I of the Scenario. The fraction of rural inhabitants and the values of occupancy factor for three occupation groups were used from Table I.XLIV and I.XLV of the Scenario, respectively. The shielding factors for structures were calculated from the attenuation factor for 0.66 Mev gamma radiation in the Scenario description. Data used in the cloudshine dose calculations are given in Table II-4.1.

TABLE II-4.1. PARAMETER VALUES USED IN CLOUD EXPOSURE CALCULATIONS

Variable	Mean	Min	Max	Distribution	Units
SF(wood)	0.52	0.26	0.78	Uniform	-
SF(brick)	0.20	0.10	0.30	Uniform	-
DF_c	2.88×10^{-14}	-	-		Sv s^{-1}/Bq m^{-3}

II–4.2.1.2. Long-term exposure due to groundshine

The dose rate due to long-term groundshine is expressed by:

$$D_g(t) = SD_k \cdot R(t) \cdot E(t) \cdot DF_g \cdot L \cdot \sum_i f_i \cdot (OF_i^{out} + OF_i^{in} \cdot SF) \tag{2}$$

where:

$D_g(t)$ = dose rate on day t after the deposition of a radionuclide onto the ground (Sv s^{-1});
SD_k = total deposition of the radionuclide at place k (Bq m^{-2});
$R(t)$ = factor to account for radioactive decay occurring between the deposition and t;
$E(t)$ = factor to account for the environmental decay of groundshine;
DF_g = dose-rate conversion factor for groundshine (Sv s^{-1} per Bq m^{-2});
L = geometric factor (%);
f_i = fraction of i-th occupation group (%);
OF_i^{out} = outdoor occupancy factor for i-th occupation group;
OF_i^{in} = indoor occupancy factor for i-th occupation group; and
SF = shielding factor for wooden or brick house.

The following exponential functions represent the two factors of $R(t)$ and $E(t)$ as a function of time:

$$R(t) = \exp(-\ln 2 \cdot \frac{t}{T_r}) \tag{3}$$

$$E(t) = d_f \cdot \exp(-\ln 2 \cdot \frac{t}{T_{sf}}) + d_s \cdot \exp(-\ln 2 \cdot \frac{t}{T_{ss}}), \quad d_f + d_s = 1 \tag{4}$$

where:

T_r = half-life for radioactive decay (y);
d_f = fraction of fast decay term for the environmental decay of groundshine;
d_s = fraction of slow decay term for the environmental decay of groundshine;
T_{sf} = half-life for fast decay term for groundshine (y);and
T_{ss} = half-life for slow decay term for groundshine. (y).

The initial deposition of ^{137}Cs at the region was assumed to have the distribution given in Table I.XL of the Scenario. The dose conversion factor for groundshine was calculated by the method of Kocher (1980) in which the exposed individual was assumed to be standing on a smooth, infinite plane surface with uniform source concentration. The value of the geometric factor was determined from the comparison between the model prediction and the observations within the 30-km zone of the Chernobyl plant (Takahashi and Homma, 1999). The parameter values and uncertainty ranges in the environmental decay terms, Eq. (4) of deposited ^{137}Cs on the ground were determined from data in the expert judgement study (NUREG/CR-6526, 1997). The shielding factors for structures are the same as that used in the cloudshine calculation. Data used in the groundshine dose calculations are given in Table II-4.2.

TABLE II-4.2. PARAMETER VALUES USED IN GROUND EXPOSURE CALCULATIONS

Variable	Mean	Min	Max	Distribution	Units
d_s	0.52	0.40	0.71	Uniform	-
T_{Sf}	1.1	0.41	1.4	Uniform	y
T_{Ss}	28	24.3	29.4	Uniform	y
L	0.45	0.2	0.7	Uniform	-
$SF(wood)$	0.52	0.26	0.78	Uniform	-
$SF(brick)$	0.20	0.10	0.30	Uniform	-
DF_g	5.86×10^{-16}	-	-		Sv s^{-1}/Bq m^{-2}

II–4.2.2. Inhalation dose

II–4.2.2.1. Inhalation of passing cloud

Like the external dose from the passing cloud, the internal dose from inhalation of the passing cloud is estimated in OSCAAR using the air concentrations calculated from the atmospheric dispersion and deposition model. In this calculation, however, the time-integrated concentration of ^{137}Cs in air was used according to the following equation:

$$RD_g(t) = SD_k \bullet R(t) \bullet E(t) \bullet DF_g \bullet SF \tag{5}$$

where:

D_i = internal dose from inhalation of the passing cloud (Sv);
DF_i = dose conversion factor for inhalation (Sv Bq-1);
BR = breathing rate of an average individual (m^3 d-1);
f_i = fraction of *i*-th occupation group (%);
OF_i^{out} = outdoor occupancy factor for *i*-th occupation group;
OF_i^{in} = indoor occupancy factor for *i*-th occupation group; and
FF = filtering factor for wooden and brick houses.

The time-integrated ^{137}Cs concentrations in ground-level air of the test area is the same as that used in the external dose. The dose conversion factor for inhalation was calculated by the DOSDAC code system based upon the method of ICRP 30. The filtering factor for structures were determined from data on ^{137}Cs particulate, representative of about 1ƒÊm in the expert judgement study (NUREG/CR-6526, 1997). Data used in the cloud inhalation dose calculations are given in Table II-4.3.

TABLE II-4.3. PARAMETER VALUES USED IN CLOUD INHALATION CALCULATIONS

Variable	Mean	Min	Max	Distribution	Units
$FF(wood)$	0.64	0.43	0.84	Uniform	-
$FF(brick)$	0.64	0.43	0.84	Uniform	-
BR	23.	-	-		$m^3\ d^{-1}$
DF_i	8.63×10^{-9}	-	-		Sv Bq^{-1}

II–4.2.2.2. Inhalation of resuspended materials

The amount of a radionuclide consumed through inhalation of resuspended materials is calculated with:

$$I_r(t) = SD_k \cdot R(t) \cdot K(t) \cdot BR \tag{6}$$

where:

$I_r(t)$ = amount of a radionuclide consumed by an individual through inhalation of resuspended materials on day t after the deposition of the radionuclide onto the ground (Bq y^{-1}); and
$K(t)$ = time-dependent resuspension factor (m^{-1}).

The resuspension factor is defined as the ratio of the air concentration of a resuspended radionuclide to the total deposition onto the ground. The following gives the time-dependent resuspension factor, $K(t)$:

$$K(t) = k_0 \cdot \exp(-\ln 2 \frac{t}{T_{Rf}}) + k_e \cdot \exp(-\ln 2 \frac{t}{T_{Rs}}) \tag{7}$$

where:

k_0 = initial values of fast decay term of the time-dependent resuspension factor (m^{-1});
k_e = initial values of slow decay term of the time-dependent resuspension factor (m^{-1});
T_{Rf} = half-life for fast decay term (y^{-1}); and
T_{Rs} = half-life for slow decay term (y^{-1}).

The parameter values in the resuspension factor, Eq. (7) of deposited ^{137}Cs on the ground were given in Table II-4.4 as default values in CHRONIC (NUREG/CR-4215).

TABLE II-4.4. PARAMETER VALUES USED IN RESUSPENSION CALCULATIONS

Variable	Mean	Min	Max	Distribution	Units
k_0		3.6×10^{-9}	4.9×10^{-8}	Uniform	m^{-1}
k_e	1.0×10^{-9}	-	-		m^{-1}
T_{Rf}	1.35	0.50	2.2	Uniform	y
T_{Rs}	100.	-	-		y

The total intake of a radionuclide through inhalation, CF_r^j (Bq), during time interval *j* can be calculated by integrating Equation (6). The internal dose, D_r^j (Sv), in each time interval can be estimated by:

$$RD_r^j = \sum_{n=1}^{j} DF_{inh}^n \bullet CF_r^{j+1-n} \qquad (j \leq 5) \tag{8}$$

where:

DF^n_{inh} = dose conversion factor for inhalation for time interval n after intake of a radionuclide (Sv Bq^{-1}).

II–4.2.3. Ingestion of contaminated foodstuffs

The food-chain model included in the CHRONIC module takes account of the transfer of radionuclides to cow's milk (including milk products), beef and edible crops. The edible crops are classified into four categories: leafy vegetables, cereals, root crops and fruits (including non-leafy vegetables). It is assumed that dairy and beef cows consume only pasture grass, and pasture grass and edible crops are contaminated both by direct deposition from the atmosphere and by root uptake from the soil. The model deals with the growing periods of the pasture grass and the crops, so that their seasonal dependence on the ingestion dose can be evaluated. To take account of the seasonality, a year is divided into three seasons: dormant season, growing season and grazing season for pasture grass; and dormant season, growing season and harvest season for crops. It is assumed that cows and individuals cannot consume pasture grass and crops during the growing season, respectively. The productivity of pasture grass and crops is also assumed to be constant during the grazing season and the harvest season, respectively.

II–4.2.3.1. Direct deposition

(a) Milk and milk product pathway

It is assumed that pasture grass is grown during a grazing season and dairy cattle consume the pasture grass continuously. The amount of a radionuclide consumed by an individual via milk at a given time can be expressed by:

$$I_{dm}(t) = IC_0 \cdot R(t) \cdot L(t) \cdot A(t) \cdot S_m \cdot V_m \tag{9}$$

where:

$I_{dm}(t)$ = amount of a radionuclide consumed by an individual via milk on day $t+d_m$ after the deposition of the radionuclide onto the ground (Bq d^{-1});

t = days from the radionuclide deposition (d);

d_m = days from milk production to consumption (d);

IC_0 = first days' intake of the radionuclide by an average cow (Bq d^{-1});

$L(t)$ = factor to account for loss of the radionuclide from pasture grass due to weathering;

$A(t)$ = fraction of the radionuclide consumed by a cow that is secreted into a milk sample (d L^{-1});

S_m = factor to account for decay of the radionuclide during the time from milk production to consumption; and
V_m = volume of milk consumed daily by an average individual of the population (L d^{-1}).

The parameter of IC_0 is estimated as follows for a reference deposition of 1 Bq m^{-2}:

$$IC_0 = \frac{RF_g}{Y_g} \cdot J_l \tag{10}$$

where:

RF_g = initial retention factor for pasture grass;
J_l = consumption rate of pasture grass by an average cow (kg d^{-1}); and
Y_g = productivity density of pasture grass (kg m^{-2}).

The mass interception factor was assumed to be 2.0 (m^2 kg^{-1}) and the productivity density Y_g and consumption rate J_l of pasture grass by an average cow were used from Table I.XXXII and Table I.XXXV of the Scenario, respectively.

The parameters of $L(t)$ and S_m can be expressed by the following exponential functions:

$$L(t) = l_1 \cdot e^{-\lambda_w \cdot t} + l_2, \qquad \lambda_w = \frac{\ln 2}{T_w} \tag{11}$$

$$S_m = e^{-\lambda_r \cdot d_m} \tag{12}$$

where:

T_w = half life for weathering (d);
l_1 = initial value of a decay term of the time-dependent retention factor; and
l_2 = constant term of the time-dependent retention factor ($l_1 + l_2 = 1$).

Only exponential decay term was considered ($l_1=1$) in Equation (11).

The following empirical equations are determined to express the parameter of $A(t)$:

$$A(t) = \{TR_1 + TR_2 \cdot t\} \cdot \{1 - e^{-TR_3 \cdot t}\} \tag{13}$$

where:

TR_1 = empirical coefficient of the fraction of the radionuclide consumed by a cow that is secreted in to a milk sample (d l^{-1});
TR_2 = empirical coefficients and have units of l^{-1}; and
TR_3 = empirical coefficients and have units of d^{-1}.

The parameter values of these coefficients were given in Table II-4.4 as default values in CHRONIC.

As the accident has occurred in the growing season, the total intake of ^{137}Cs via milk, CF_{dm} was calculated by:

$$CF_{dm} = FF(t_p) \cdot \int_0^{T_g} I_{dm}(t)dt \tag{14}$$

where:

$FF(t_p)$ = factor to account for loss of a radionuclide from pasture grass due to weathering;

t_p = days from the accident to the beginning of the grazing season (d); and

T_g = period of the grazing season (d).

The factor of $FF(t_p)$ is represented by:

$$FF(t_p) = l_1 \cdot e^{-\lambda_{eff} \cdot t_p} + l_2 \cdot e^{-\lambda_r \cdot t_p} \tag{15}$$

(b) Beef pathway

It is assumed that pasture grass is grown during a grazing season and beef cattle consume the pasture grass continuously. The amount of a radionuclide consumed by an individual via beef at a given time can be expressed by:

$$I_{db}(t) = B_d(t) \cdot S_b \cdot V_b \tag{16}$$

where:

$I_{db}(t)$ = amount of a radionuclide consumed by an individual via beef on day $t+d_b$ after the deposition of the radionuclide onto the ground (Bq/d);

d_b = days from beef production to consumption (d);

$B_d(t)$ = concentration of the radionuclide in beef (Bq/kg);

S_b = factor to account for decay of the radionuclide during the time from beef production to consumption; and

V_b = amount of beef consumed daily by an average individual of the population (kg/d).

The radionuclide concentration in beef, $B_d(t)$, is estimated by the following differential equation:

$$\frac{dB_d(t)}{dt} = G_d 0 \bullet R(t) \bullet L(t) \bullet \tau_{gb} - \{ \lambda_r + \tau_{meta} + \tau_{meat} \} B_d(t) \tag{17}$$

where:

G_{d0} = concentration of a radionuclide in pasture grass at the time of accident (Bq/m^2);

τ_{gb} = transfer rate of the radionuclide from pasture grass to beef (m^2/kg d^{-1});

τ_{meta} = removal rate of the radionuclide from beef due to metabolism (d^{-1}); and

τ_{meat} = average rate at which cows are slaughtered (d^{-1}).

In determining τ_{gb}, equilibrium conditions were assumed in the grass and meat compartments in Equation (17):

$$\tau_{gb} = \tau_{meta} \frac{B_{eq}}{G_{eq}} = \frac{\ln 2}{T_B} \cdot (F_b \frac{J_l}{Y_g})$$

where:

T_B = biological half-life of cesium (d); and

F_b = equilibrium transfer coefficient from feed to meat for cesium (d kg^{-1}).

The biological half-life and the transfer coefficient are given in Table II-4.5. The parameter of G_{d0} for a reference deposition of 1 Bq/m^2 can be estimated to be RF_g where RF_g is an initial retention factor for pasture grass.

TABLE II-4.5. PARAMETER VALUES USED IN INGESTION CALCULATIONS

Variable	Mean	Min	Max	Distribution	Units
T_w	14	1.20	0.24	Lognormal	days
RF_g	0.05	-	-		-
RF_g/Y_g	2.03	0.26	0.29	Lognormal	m^2/kg
TR_1	1.38×10^{-2}	-	-		d/L
TR_2	7.3×10^{-5}	-	-		L^{-1}
TR_3	3.0×10^{-1}	-	-		d^{-1}
τ_{pd}*(plough)*	146	110	186	Uniform	year
τ_{pd} *(pasture)*	73	55	93	Uniform	year
λ_f	2.2×10^{-4}	-	-		d^{-1}
B_V*(vegetable)*		4.6×10^{-2}	4.6×10^{0}	Loguniform	Bq kg^{-1} d.w./ Bq kg^{-1} soil
B_V*(potato)*		1.7×10^{-2}	1.7×10^{0}	Loguniform	Bq kg^{-1} d.w./ Bq kg^{-1} soil
B_V*(cereal)*		2.6×10^{-3}	2.6×10^{-1}	Loguniform	Bq kg^{-1} d.w./ Bq kg^{-1} soil
B_V*(grass)*		2.4×10^{-2}	2.4×10^{0}	Loguniform	Bq kg^{-1} d.w./ Bq kg^{-1} soil
T_G*(vegetable)*	60	50	70	Uniform	days
T_G*(potato)*	140	130	150	Uniform	days
T_G*(cereal)*	95	75	120	Uniform	days
T_G *(grass)*	60	50	70	Uniform	days
F_m	7.9×10^{-3}	1.0×10^{-3}	2.7×10^{-2}	Loguniform	d L^{-1}
τ_{milk}	0.7	-	-		d^{-1}
F_f*(beef)*	2.0×10^{-1}	4.0×10^{-2}	6.0×10^{-1}	Loguniform	d kg^{-1}
F_f*(pork)*	2.4×10^{-1}	3.0×10^{-2}	1.1	Loguniform	d kg^{-1}
T_B*(beef)*	25	13	37	Uniform	days
T_B*(pork)*	21	11	31	Uniform	days
τ_{meat}	$3.8.^{\sim} 10^{-3}$	-	-		d^{-1}
TF_V*(mushroom)*		3×10^{-3}	7	Loguniform	m^2 kg^{-1}
TF_V*(berry)*		2×10^{-3}	2×10^{-1}	Loguniform	m^2 kg^{-1}

It is noted that a radionuclide consumed by cow remains in beef after the grazing season since the metabolism in cow's body is slow. After the grazing season, the amount of the radionuclide consumed by an individual via beef, $I_{d'b}(t)$, can be represented by:

$$I_{d'b}(t) = B_{d0} \cdot V_b \cdot e^{-\lambda_r \cdot d_b} \cdot e^{-\lambda_b \cdot t} \tag{18}$$

where:

B_{d0} = concentration of a radionuclide in beef at the end of the grazing season (Bq/kg).

Total intake of a radionuclide via beef, CF_{db}, can be estimated by the similar methodology to that for milk pathway. As the accident has occurred in the growing season, CF_{db} was calculated by:

$$CF_{db} = FF(t_p) \cdot \left\{ \int_0^{T_g} I_{db}(t)\, dt + \int_0^{\infty} I_{d'b}(t)\, dt \right\} \tag{19}$$

(c) Crop pathway

Crops are assumed to be grown and harvested continuously during the harvest season. The amount of a radionuclide consumed by an individual via an edible crop at a given time can be expressed by:

$$I_{dc}(t) = \frac{C_d(t)}{Y_c} \cdot S_c \cdot V_c \tag{20}$$

where:

$I_{dc}(t)$ = amount of a radionuclide consumed by an individual via an edible crop on day $t+d_c$ after the deposition of the radionuclide onto the ground (Bq/d);
d_c = days from crop production to consumption (d);
$C_d(t)$ = concentration of the radionuclide in the crop (Bq/m^2);
Y_c = productivity density of the crop (kg/m^2);
S_c = factor to account for decay of the radionuclide during the time from crop production to consumption; and
V_c = amount of the crop consumed daily by an average individual of the population (kg/d).

The radionuclide concentration in the crop, $C_d(t)$, can be expressed by:

$$C_d(t) = C_{d0} \cdot R(t) \cdot L(t) \tag{21}$$

where:

C_{d0} = concentration of a radionuclide in the crop at the time of accident (Bq/m^2).

The parameter of C_{d0} for a reference deposition of 1 Bq/m^2 is estimated to be RF_c where RF_c is an initial retention factor for the crop. Equation (23) can be rewritten as follows:

$$I_{dc}(t) = \frac{RF_c}{Y_c} \cdot V_c \cdot e^{-\lambda_r \cdot d_c} \cdot \left\{ l_1 \cdot e^{-\lambda_{eff} \cdot t} + l_2 \cdot e^{-\lambda_r \cdot t} \right\} \tag{22}$$

The total amount of a radionuclide consumed by an individual via a crop, CF_{dc}, can be estimated by the same equation as that for milk pathway. However, the accident has occurred before the sowing of crops, so the direct contamination pathway for crops except winter grain was not considered in the calculation. The parameter values for winter grain used in Equation (22) were given in Table II-4.5.

II–4.2.3.2. Root uptake

After deposition of radioactive material on the soil surface and subsequent mixing in the soil, the only important pathway by which the material can enter food chains is absorption from the soil. Therefore, the soil is important as a reservoir of long-lived radionuclides. The dynamics of a radionuclide in the soil is simply expressed by the following Equation (25) in CHRONIC. The loss of availability of the radionuclide for uptake is represented by the soil sink with a transfer rate of τ_{pd}. Uptake of the radionuclide by grass or crops is governed by a transfer rate τ_{pg}, or τ_{pc}. In estimating the removal rate of ^{137}Cs from the soil of a root zone, the soil migration rate and the process of soil fixation were considered. The available ^{137}Cs in the soil root zone was described by:

$$P(t) = P_0 \cdot e^{-(\tau_{pd}+\lambda_f)t} \cdot e^{-\lambda_r t} \tag{23}$$

The parameter values in Equation (23) are given in Table II-4.5.

(a) Milk and milk product pathway

The amount of a radionuclide consumed by an individual via milk at a given time can be expressed by:

$$I_{um}(t) = M_u(t) \cdot S_m \cdot V_m \tag{24}$$

The radionuclide concentration in milk, $M_u(t)$ (Bq/l), can be calculated by three differential equations as follows:

$$\frac{dP(t)}{dt} = - \left\{ \lambda_r + \tau_{pg} + \tau_{pd} \right\} P(t) \tag{25}$$

$$\frac{dG_u(t)}{dt} = \tau_{pg} \cdot P(t) - \left\{ \lambda_r + \frac{J_l}{A_g \cdot Y_g} \right\} G_u(t) \tag{26}$$

$$\frac{dM_u(t)}{dt} = \tau_{gm} \cdot G_u(t) - \left\{ \lambda_r + \tau_{milk} \right\} M_u(t) \tag{27}$$

where:

$P(t)$ = concentrations of a radionuclide in soil (Bq/m^2);
$G_u(t)$ = concentrations of a radionuclide in pasture grass (Bq/m^2);
τ_{pg} = transfer rate of the radionuclide from soil to pasture grass (d^{-1});
τ_{pd} = removal rate of the radionuclide from the soil of a root zone (d^{-1});
A_g = area of a pasture grass land which is given to single cow (m^2);
τ_{gm} = transfer rate of the radionuclide from pasture grass to milk (m^2/L d^{-1}); and
τ_{milk} = secretion rate of milk (d^{-1}).

In determining the transfer rate of the radionuclide from soil to plant τ_{pg}, a simple assumption was made that the equilibrium concentration ratio reached for a plant growth period:

$$\tau_{pg} = \frac{1}{T_G}\frac{G_{eq}}{B_{eq}} = \frac{1}{T_G}\cdot(B_V \frac{Y_g}{\rho L})$$

where:

T_G = plant growth period (d);
B_V = soil-to-plant transfer factor for grass (Bq/kg dry weight plant to Bq/kg dry weight soil);
ρ = bulk density of soil (kg m^{-3}); and
L = depth of soil root zone (m).

Data on the transfer rate of cesium from soil to grass is given in Table II-4.5.

To derive the transfer rate of cesium from pasture grass to milk τ_{gm}, the same assumption as the transfer rate from grass to meat was made that equilibrium conditions were assumed in the grass and milk compartments in Equation (27):

$$\tau_{gm} = \tau_{milk}\frac{M_{eq}}{G_{eq}} = \frac{V_m}{U}\cdot(F_m \frac{J_l}{Y_g})$$

where:

V_m = production rate of milk per cow (L d^{-1});
U = capacity of the udder (L); and
F_m = equilibrium transfer coefficient from feed to milk for cesium (d L^{-1}).

τ_{milk} was determined assuming V_m of 7.1 L/d taken from Table I.XXXIX of the Scenario and U of 10 L, and the transfer coefficient from feed to milk was taken from IAEA(1994). Data on the transfer rate of cesium from pasture grass to milk is given in Table II-4.5.

(b) Beef pathway

The amount of a radionuclide consumed at a given time by an individual can be expressed by:

$$I_{ub}(t) = B_u(t)\cdot S_b \cdot V_b \tag{28}$$

where:

$I_{ub}(t)$ = amount of a radionuclide consumed by an individual via beef on day $t+d_b$ after the deposition of the radionuclide onto the ground (Bq/d); and
$B_u(t)$ = concentration of the radionuclide in beef (Bq/kg).

The following calculates the radionuclide concentration in beef, $B_u(t)$:

$$\frac{dB_u(t)}{dt} = \tau_{gb}\cdot G_u(t) - \{\lambda_r + \tau_{meta} + \tau_{meat}\}\cdot B_u(t) \tag{29}$$

where:

$G_u(t)$ = concentration of a radionuclide in pasture grass (Bq/kg); and
τ_{gb} = transfer rate of a radionuclide from pasture grass to beef (m^2/kg/d).

The parameter values in Equation (29) are given in Table II-4.5.

The amount of a radionuclide consumed by an individual via beef after the grazing season, $I_{u'b}(t)$, can be represented by:

$$I_{u'b}(t) = B_{u0} \cdot V_b \cdot e^{-\lambda_r \cdot d_b} \cdot e^{-\lambda_{3'} \cdot t} \tag{30}$$

where:

B_{u0} = the concentration of a radionuclide in beef at the end of the grazing season (Bq/kg).

(c) Crop pathway

The amount of a radionuclide consumed at a given time by an individual can be expressed by:

$$I_{uc}(t) = \frac{C_u(t)}{Y_c} \cdot S_c \cdot V_c \tag{31}$$

where:

$I_{uc}(t)$ = amount of a radionuclide consumed by an individual via an edible crop on day $t+d_c$ after the deposition of the radionuclide onto the ground (Bq/d);
$C_u(t)$ = concentration of the radionuclide in the crop (Bq/m^2).

The following calculates the radionuclide concentration in a crop, $C_u(t)$:

$$\frac{dC_u(t)}{dt} = \tau_{pc} \cdot P(t) - \left\{ \lambda_r + \frac{V_c}{A_c \cdot Y_c} \right\} \cdot C_u(t) \tag{32}$$

where:

$P(t)$ = concentration of a radionuclide in soil (Bq/m^2);
τ_{pc} = transfer rate of the radionuclide from soil to a crop (d^{-1}); and
A_c = cultivated area of crops which is given an individual (m^2).

The transfer rate of the radionuclide from soil to crop τ_{pg} was determined by the following same equation as for the transfer rate from soil to pasture grass:

$$\tau_{pc} = \frac{1}{T_G} \frac{C_{eq}}{B_{eq}} = \frac{1}{T_G} \cdot (B_V \frac{Y_c}{\rho L})$$

Data on the transfer rates of cesium from soil to crops are given in Table II-4.5.

II–4.2.4. Countermeasures assumptions

According to the Scenario description, the following agricultural countermeasures were taken into account to estimate the concentrations in foodstuffs:

- In June 1986 to spring 1987, slaughtering of cattle was forbidden in the regions with contamination level exceeding 555 kBq m^{-2}.
- In 1987, about 40% of agricultural land with contamination density higher than 1480 kBq m^{-2} was take out of agricultural production.
- In 1988, all agricultural lands with contamination density higher than 1480 kBq m^{-2} were completely taken out of agricultural production.
- In 1986 to 1989, a reduction of 1.7 in root uptake transfer to crops due to application of agrochemical measures was taken into account for areas with contamination density higher than 555 kBq m^{-2}.
- A reduction of 3 in root uptake transfer to meadows and pastures due to radical amelioration was taken into account for areas with contamination density higher than 555 kBq m^{-2}. Cumulative percentages of the application areas of this measure from 1989 to 1990 were taken from data in Table I.LX of the Scenario.

For restriction in consumption of local food products and forest gifts, temporary permissible levels for ^{137}Cs concentrations in foodstuffs were take into account to estimate the intake of the test persons over the controlled area with contamination density higher than 555 kBq m^{-2}.

II–4.3. COMPARISON OF MODEL PREDICTIONS WITH TEST DATA

Uncertainty in model output was calculated using 500 parameter sets generated by Latin hypercube sampling for prescribed distributions of all uncertain parameters. For the calculation of both external and internal cloud exposure, the initial input values of time-integrated concentrations in air were derived from uniform distribution in the range of 2.09×10^5–1.36×10^5 (mBq d m^{-3}) given in Table I.I of the Scenario. The ground contamination levels were also derived from piecewise uniform distribution with weight factors calculated by contamination areas given in Table I.XL of the Scenario. These levels are used as input for the calculation of ground exposure, resuspension dose, and concentrations in food products. The ground contamination levels for the forest were derived from uniform distribution in the range of 9.80×10^2–4.60×10^2 (kBq m^{-2}). The range was determined from data given in Table I.XX of the Scenario description.

II–4.3.1. Concentrations in food products

Model predictions, obtained with OSCAAR model in comparison with test data on the Iput test area, are presented in Figs. 5.1-5.10, 5.14, 5.22 and 5.23, see Section 5 of the Iput report “Discussion of results” (OSCAAR results).

II–4.3.1.1. Leafy vegetables

The confidence intervals about the mean predictions cover the observations except for 1986 and 1994 although their mean predictions during the first four years underestimate by a factor of within 2, while larger overpredictions can be observed after 1990.

A large underprediction for 1986 is probably due to the neglect of direct deposition onto vegetation because the dates of sowing for cabbage and vegetable given in the Scenario occurred after the accident. The overpredictions after 1990 are due to the neglect of effectiveness of the agrotechnical countermeasures for several years after their application.

II–4.3.1.2. Potatoes

The confidence intervals about the mean predictions cover all the observations. The same comments are valid, as is the case of leafy vegetables. During the first five years the dynamic of predictions shows a good agreement with that of observations and the predictions fall within a factor of 1.5.

II–4.3.1.3. Cereals

The confidence intervals about the mean predictions cover the only observations for 1990, 1995 and 1996. Between 1986 and 1989 OSCAAR underestimated concentrations in cereals by factors between 2.0 and 5.2, while it overestimated the cereal data by factors between 2.3 and 3.9 after 1991.

The underprediction between 1987 and 1989 might be due to higher bioavailability of the deposited ^{137}Cs in the soil during the first few years.

II–4.3.1.4. Milk

OSCAAR calculated the average concentration of ^{137}Cs in milk produced by a cow grazing on the contaminated pasture during the grazing season. So the predictions are compared with observations for August or third quarter. The confidence intervals about the mean predictions cover the observations after 1991. The predictions between 1987 and 1990 are lower than the observation by factors of 2.3 to 14.1. The prediction for 1986 is higher than the observation by a factor of 8.

OSCAAR does not provide the intermediate output for concentrations in pasture grass. So it is difficult to find major sources of mispredictions. The overprediction produced for 1986, however, is probably due to a high empirical coefficient of feed to milk transfer used in the direct deposition pathway. On the other hand, the underpredictions during 1987 to 1990 might be due to lower transfer factor from grass to milk used in the root uptake pathway.

II–4.3.1.5. Beef

OSCAAR also assumes that the beef cow is grazing on the contaminated pasture during the grazing season. As with milk, the predictions are compared with observations for August or third quarter. The same dynamics for beef predictions are observed as for the milk predictions. The underpredictions are observed between 1987 and 1990, while the overpredictions after 1991 fall within a factor 3 of the observations.

The reason for the underpredictions in the early phase is not clear either due to a low feed to meat transfer factor used or due to the unclear description of feeding practice. The overpredictions after 1991 are probably due to the neglect of continuing effectiveness of the agrotechnical countermeasures after their application.

II–4.3.1.6. Pork

OSCAAR does not take into account the pork pathway, but in order to estimate the contribution of this pathway to the total intake of ^{137}Cs, the same model as for beef pathway was applied. So we observed the same behaviour for pork predictions as for the beef predictions. The differences are due to both the amount of feed and the feed to meat transfer factors used.

II–4.3.1.7. Mushrooms and berries

OSCAAR also does not have models for predicting concentrations in natural products. So a simple approach using aggregated transfer coefficients (m^2 kg^{-1}) was used to estimate the ^{137}Cs concentrations in mushrooms and berries. The ecological half-life of ^{137}Cs in natural ecosystems was assumed to be very long in comparison with the physical half-life.

All predictions for mushrooms are higher than the observations by a factor of 3 to 10. The confidence intervals about the mean predictions do not cover any observations. This is probably due to the high aggregated transfer coefficient used or the neglect of forest countermeasures.

On the other hand, the predictions for berries are relatively in good agreement with the observations. The confidence intervals about the mean predictions cover the observations except for 1986, 1993 and 1996. The predictions for these three years are underestimated by a factor of 2, while the other predictions fall within a factor 1.5.

II–4.3.1.8. Fish

The predictions are in good agreement to the observations and all except for 1996 fall within the confidence intervals about the observations.

II–4.3.2. Human intake

The predictions for both women and men over the controlled area are mostly underestimated by a factor of 1.1 to 3.4. The prediction for 1986 is lower than a factor of about 7. The dynamics of the predictions, however, are in quite good agreement with those of the observations.

For the non-controlled area, the predictions for both women and men are in quite good agreement with the observations and fall within a factor of two except for 1997.

II–4.3.3. Dose

The predicted doses both from cloud external exposure and from inhalation of cloud are slightly higher than the test data. This is due to the differences in shielding factor or filtering factor used and in dose conversion factors. The predicted doses from ground deposits are slightly lower than the test data by a factor of within 1.3 till 1995, while the lifetime predicted dose is slightly higher than the test data. This is also due to the differences in shielding factor and in dose conversion factors, and partly due to weathering half-life of deposits on the ground. The predicted doses from inhalation of resuspended ^{137}Cs are lower than test data by an order of magnitude. This is due to the difference in resuspension factors used in the estimation.

II–4.4. MAJOR SOURCES OF MISPREDICTIONS

The underpredictions of concentrations in crops during in 1987-1989 are probably due to lower root uptake factors used in our analysis. Unfortunately the effect of the fixation of cesium on longer term predictions can not be clearly observed because the observations included the effect of agricultural countermeasures at the same time. As described in the previous section, the underprediction of concentrations in vegetables and potatoes for 1986 is probably due to the neglect of direct deposition onto vegetation, although the dates of sowing given in the Scenario occurred after the accident. The overpredictions after 1990 are due to the neglect of effectiveness of the agrotechnical countermeasures for subsequent several years after their application.

The dynamics of concentrations for milk and meet are similar to that for crops. This is because the dynamics for milk and meet in OSCAAR are mostly governed by the dynamics for grass. Comparing between Figure 4 to 6, larger underpredictions of concentrations in milk are clear. This is probably because a lower feed to milk transfer factor is used due to a lower secretion rate of milk assumed.

II–4.5. LESSONS LEARNED FROM THE SCENARIO

We have experienced from many severe accident consequence assessments that ^{137}Cs external ground exposure and ingestion pathways were the two main important contributors to chronic effects to the population. The Iput dose reconstruction scenario, therefore, provided good opportunities to test our chronic exposure sub-models in OSCAAR.

For the external ground exposure model, it was understood that the appropriate determination of not only weathering parameters but also location factors coupled with the corresponding dose rate conversion factor was able to give the accurate predictions.

For the contamination of food, more detailed modeling of the changes of cesium bioavailability with time is considered to be needed for long term predictions about the ingestion pathway.

The OSCAAR food-chain model is primarily designed to estimate the total intake of radionuclides for the population at each district. However, predictions of the contamination in foods are also important to be used as criteria for the food restriction countermeasures in accident consequence assessments. Hence, it is necessary to allow for more animal products and animal feeds for flexible applications of OSCAAR. Although modeling of agricultural countermeasures is a difficult task, at least a simple reduction factor approach should be introduced in OSCAAR to take into account the effects of countermeasures on dose reduction to the population.

This scenario also provides a good example of regional variations in the environment. Accident assessment codes include default values for many of the parameters in the calculations. These default values and also data libraries such as dose conversion factors are applicable to a particular region, and may not be appropriate for other applications and could introduce uncertainties into the predictions. The computer code like OSCAAR should be capable of handling regional differences in one application.

ANNEX II–4.A.
ESTIMATION OF RADIOACTIVE CONCENTRATION OF ^{137}Cs IN FISH

T. Matsunaga (JAERI)

II-4.A.1. GENERAL DESCRIPTION

The concentration of ^{137}Cs in fish was estimated based on the “concentration factor approach” [1]. We assumed the equilibrium between the radioactive concentrations in the fish and the ambient water concerning intake and elimination of ^{137}Cs by the fish. The whole range of interest of the Iput River was considered to consist of seven sections of the stream. Each section corresponds to a local watershed and a hydrometric post defined in Table I.XI of the Scenario description. The concentration of ^{137}Cs in the fish was estimated by the following equation (Eq.1).

$$A_{s,y} = CF \times C_{s,y} \tag{1}$$

where:

$A_{s,y}$ = concentration of ^{137}Cs in the fish at the river section s in year y, (Bq kg^{-1});
$C_{s,y}$ = concentration of ^{137}Cs in river water at the river section s in year y, (Bq l^{-1}); and
CF = concentration factor (l kg^{-1}).

The subscript s denotes the section number of the river corresponding to a local watershed. The subscript y denotes the year for estimation, 1987–1996.

The concentration of ^{137}Cs in the fish ($A_{s,y}$) was averaged over the sections with a weight related to the stream length of each section as shown in Figure II-4.A.1. Finally, a selected concentration factor was employed to this averaged ^{137}Cs concentration in river water to obtain the concentration in the fish. The above methodology was applied for the years 1987–1996. Concerning the latter half of 1986, a special consideration that is described later was made. The final result is shown in Table II-4.A.1 of this report.

TABLE II-4.A.1. ESTIMATED CONCENTRATION OF ^{137}Cs IN RIVER FISH IN COMPARISON TO OBSERVED VALUES (kBq kg^{-1} f.w.)

Year	Estimated concentration	Observed concentration		
		Mean	Lower bound	Upper bound
1986	2.5	2.0	0.8	3.4
1987	1.2	2.4	1.0	4.0
1988	0.70	1.4	0.6	2.2
1989	0.31	0.6	0.24	1.0
1990	0.30	0.58	0.2	1.0
1991	0.29	0.25	0.1	0.4
1993	0.29	0.25	0.06	0.42
1993	0.28	0.20	0.06	0.34
1994	0.28	0.17	0.05	0.30
1995	0.27	0.15	0.05	0.25
1996	0.26	0.15	0.10	0.20

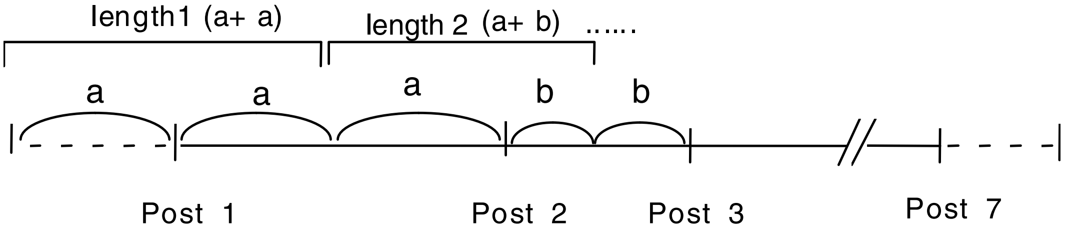

FIG. II-4.A.1. Illustration of weighting of the concentration of ^{137}Cs to produce its average through the sections.

The length of the stream of a section was determined as a sum of the half distance to neighbouring posts. At the sections at both ends, an imaginary half length was added.

II-4.A.2. DETAILED DESCRIPTION

II-4.A.2.1. Concentration of ^{137}Cs in river water

The concentration of ^{137}Cs in river water was distinguished by a section of the river, the month and the year of interest. It was assumed that the concentration of ^{137}Cs in river water follows a log linear relationship of the water flow rate:

$$C_{s,m,y} = a_s Q_m^{bs} \tag{2}$$

where:

$C_{s,m,y}$ = the concentration of ^{137}Cs in river water of the section s in the month m of the year y, Bq s^{-1};
Q_m = monthly averaged flow rate, m^3 s^{-1}; and
a_s, b_s = parameter defined for each section.

This assumption has been generally applied for the load of fluvial discharge of dissolved and suspended substances [2, 3, 4]. The determination of the parameters is described below.

(i) Parameter b_s

Following equations are deduced from Eq.2:

$$C_{s,m_1,y} / C_{s,m_2,y} = \left(Q_{m_1} / Q_{m_2}\right)^{bs} \tag{3}$$

$$b_s = \log_{10}\left[\left(C_{s,m_1,y} / C_{s,m_2,y}\right)/\left(Q_{m_1} / Q_{m_2}\right)\right] \tag{4}$$

where:

m_1, m_2 = months having distinct differences in Q and C, for example, flooding month (m_1) and dry month (m_2).

By applying the observed concentrations during a flooding period (Table I.VI of the Scenario description) and a low-water period (Table I.VII) in 1991 to this equation, the parameter b_s was calculated for each section of No.1-7. The water flow rate was from Table I.XVII. Because the data size to determine b_s was limited, its average value was used for all sections.

This means that the hydrological response of the relocation process to the precipitation event, which causes relocation and controls the river water flow rate (Q), is assumed to be uniform for all the local watersheds. The average of b_s over the sections No.1-7 was determined as 0.23, that is denoted as b, hereafter.

(ii) Parameter a_s

The annual discharge of ^{137}Cs from a section s is expressed by Eq.5

$$D_{s,y} = \sum_m Q_m \times C_{s,m,y} \times t_m \times 1.0 \times 10^{-12} \tag{5}$$

where:

D = the annual discharge of ^{137}Cs from a section s in the year y (TBq a^{-1});
Q_m = monthly averaged water flow rate of the month m (m^3 s^{-1});
t_m = seconds in the month m (s); and
1.0×10^{-12} = a conversion factor from Bq to TBq

On the other hand, the variable D must be equal to the sum of the amount of relocated ^{137}Cs from the local watershed to the river water through the sections from the first one to the section No.s (Eq.6, the summation was from the first one to the section No.s). The amount of relocated ^{137}Cs from the local watershed was connected to the stored amount of ^{137}Cs in the local watershed by Eq. 7.

$$D_{s,y} = \sum_s L_{s,y} \tag{6}$$

$$L_{s,y} = w_{s,y} \times A_{s,y} \tag{7}$$

where:

$L_{s,y}$ = the amount of relocated ^{137}Cs from the local watershed ground of the section s in the year y, Bq a^{-1};
$A_{s,y}$ = the stored amount of ^{137}Cs in the local watershed ground of the section s in the year y, Bq; and
$w_{s,y}$ = the annual wash-off rate ^{137}Cs from the local watershed ground of the section s in the year y, Bq a^{-1}.

A set of values of $A_{s,y}$ are given in Table I.XI of the Scenario. The values of $A_{s,y}$ at each year were calculated from those values taking into account radioactive disintegration. (The Table I.XI was considered to be of 1991 in our analysis, in spite of no mark in the Table.) Loss due to relocation to the river was neglected compared to the disintegration.

The value of $w_{s,y}$ was given only for 1987 (1.9×10^{-3}) and 1988 (1.1×10^{-3}) for the last section (No.7). On the other hand, it seemed reasonable that the temporal change of the value $w_{s,\,y}$ is analogous to that of the concentration of ^{137}Cs in river water judging from the closeness between the stored radioactivity and that concentration (Figure II-4.A.2). Table I.XII of the Scenario gives the temporal decrease of the annual average concentration of ^{137}Cs at the last section (No.7) from 1987 to 1991. Then, it was postulated that $w_{s,\,y}$ decreased after the same fashion as that concentration.

The result of this estimation is shown in Table II-4.A.2 of this report. Although that concentration could be extrapolated exponentially as shown in Figure II-4.A.3, we thought this extrapolation might not be correct because of a limited number of experimental data (five points, Table II-4.A.2). Therefore, the following conservative values were chosen as $w_{s,y}$ for every section s:

1987	1.9×10^{-3}
1988	1.1×10^{-3}
1989 and later	0.5×10^{-3}

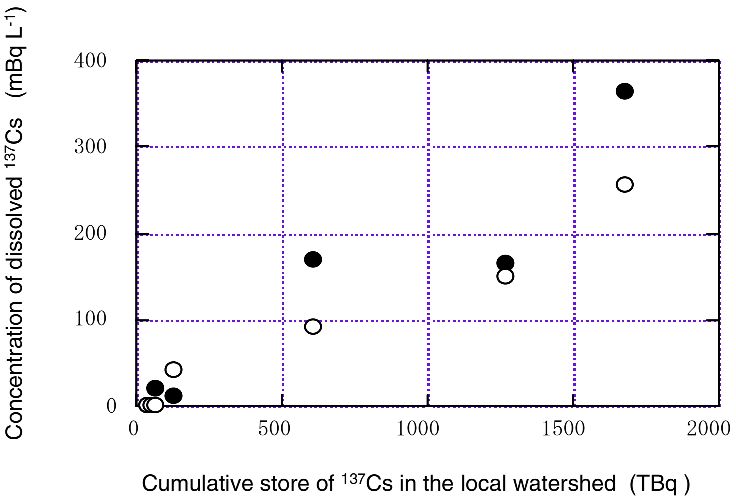

FIG. II-4.A.2. Relationship between the concentration of dissolved ^{137}Cs and the cumulative store of ^{137}Cs in the local watershed.

Both data are observed values from the Scenario. Open circles – under low-water condition; closed circles – under flooding condition.

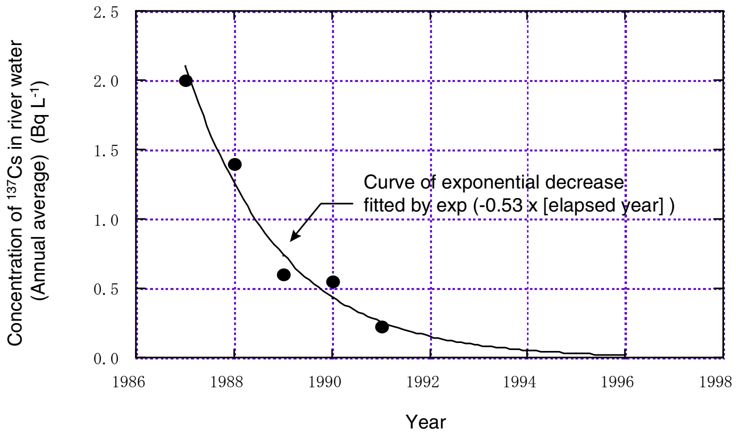

FIG. II-4.A.3. Fitting of annual decrease in the concentration of ^{137}Cs in river water.

Circles – observed concentration (annual average at the end of Section No. 7), taken from the Scenario.

TABLE II-4.A.2. WASH-OFF RATE ESTIMATED BY ANALOGY TO DECREASE IN CONCENTRATION OF ^{137}Cs IN RIVER WATER

Year	Concentration of ^{137}Cs in river water (annual average at Section No. 7)			Wash-off rate**
	observed (Bq L^{-1})	estimated* (Bq L^{-1})	decreasing ratio relative to 1987	(-)
1987	2.0	2.1	1	1.9×10^{-3}
1988	1.4	1.2	0.59	1.1×10^{-3}
1989	0.6	0.7	0.35	6.6×10^{-4}
1990	0.55	0.4	0.21	3.9×10^{-4}
1991	0.23	0.26	0.12	2.3×10^{-4}
1992	–	0.15	0.072	1.4×10^{-4}
1993	–	0.09	0.043	0.8×10^{-4}
1994	–	0.05	0.025	0.5×10^{-4}
1995	–	0.03	0.015	0.3×10^{-4}
1996	–	0.02	0.009	0.2×10^{-4}

* estimated by postulating exponential decreasing.

** calculated using the decreasing ratio with an initial value of 1.9×10^{-3} in 1987.

The value of 0.5×10^{-3} is a mean of 0.66×10^{-3} (1989) and 0.39×10^{-3} (1990) (see Table II-4.A.2). The values obtained by exponential extrapolation were also tested for the sake of comparison. This test resulted in lower concentration of ^{137}Cs in river fish than observed data by one order of magnitude in late years (after 1991).

Once the value of $w_{s,\,y}$ was determined, $D_{s,y}$ was calculated by Eq. 6 and Eq.7. Finally, one had an equation that determine a_s as follows:

$$\sum\nolimits_m Q_m \times a_s Q_m^{bs} \times t_m \times 1.0 \times 10^{-12} = \sum\nolimits_s w_{s,y} \times A_{s,y} \qquad (8)$$

After determination of a_s and b, the concentration $C_{s,m,y}$ was calculated. Then it was averaged annually to give $C_{s,y}$ in Eq.1. Figure II-4.A.4 shows the estimated concentration of ^{137}Cs in river water ($C_{s,y}$) according to the present model.

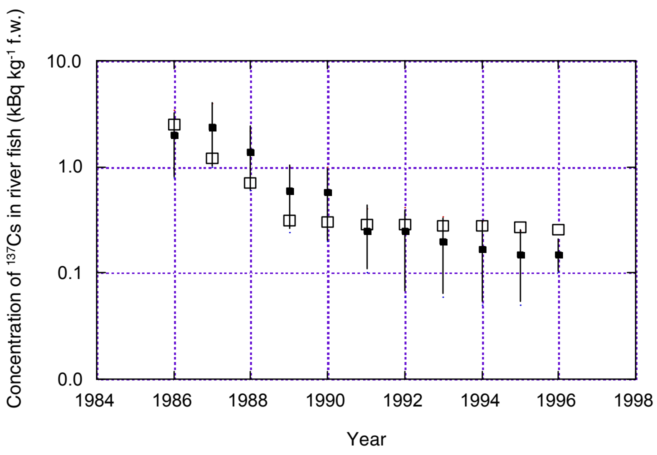

FIG. II-4.A.4. Concentration of ^{137}Cs in river fish in the test area of the Iput River.

Open square – estimation; closed square – observed mean value; range by a bar – 95% confidence interval concerning observed concentrations.

II-4.A.2.2. Concentration factor

General values of the concentration factor of ^{137}Cs in freshwater fish have been reviewed in several publications. Blaylock [5] presents a database of the factors as listed in Table II-4.A.2 of this report. According to Peterson [1], the concentration factors can be given as function of a concentration of dissolved potassium in water as follows:

For piscivorous fish,

$$CF\left(\mathrm{l\,kg^{-1}\,fresh\,mass}\right) = 1.5\times10^{4}\times[K]^{-1} \tag{3}$$

and for nonpiscivorous fish,

$$CF\left(\mathrm{l\,kg^{-1}\,fresh\,mass}\right) = 5\times10^{3}\times[K]^{-1} \tag{4}$$

where [K] is the concentration of potassium ion in mg l^{-1}. The concentration of potassium ion in the Iput River is given as 1-2 (mg l^{-1}) in the scenario. Using the mean value 1.5 (mg/l) produces 1×10^4 and 3.3×10^3 (l kg^{-1}) for piscivorous and nonpiscivorous fish, respectively. More recently, a review by IAEA [6] gives a mean of 2×10^3 (l kg^{-1} edible portion) with a range of 3×10^1–3×10^3 (l kg^{-1}). It also gives a function of dissolved potassium and calcium concentrations.

A study on the fish in rivers and impoundment (the river Pripyat, the Cooling Pond, the lake Glubokoye, the river Uzh) around the Chernobyl Nuclear Power Plant in Ukraine was conducted by the Ukrainian authority (Y. Tkachenko, *private communication)*. Using their monitoring data, concentration factors were derived in a range of 6×10^2–3.6×10^3 (l kg^{-1} fresh mass, muscle portion) with a mean of 2×10^3 (l kg^{-1}) approximately. From a viewpoint of a broad geography, the environmental condition in the Iput River area must be closer to that in Chernobyl rivers and lakes than to the environmental conditions which appear in the review literature such as in American rivers and lakes, for example (Blaylock [5]). Therefore, we decided to use the value of 2×10^3 (l kg^{-1}) which was obtained as a mean in the Chernobyl study. Although the concentration factor must be different by species of fish, one uniform value of the concentration factor was used in the present estimation.

II-4.A.2.3. Derivation of weighed average concentration of ^{137}Cs in fish

As already explained, concentrations of ^{137}Cs in fish were calculated first for each section (no.1-7) in each year (1987-1996). Secondly, these concentrations were averaged by the weight corresponding to the distance of the river sections belonging to the monitoring points. The weight G_s is given by:

$$G_s = F_s / \sum_{s'} F_{s'},$$

where:

G_s = weight to be multiplied to the ^{137}Cs concentration (fish) at the section s; and

F_s = distance covered by the section s.

$$F_s = \left[\left(P_{s+1} - P_s\right) + \left(P_s - P_{s-1}\right)\right]/2$$

where:

P_s = distance from Iput River source (km) given in Table 5 of the Scenario, provided that:

$$D_1 = 2\times[(P_2 - P_1)/2]$$
$$D_7 = 2\times[(P_7 - P_6)/2]$$

II-4.A.2.4 Estimation of the value in 1986

Because no observed value was provided in the Scenario, the value was estimated by the following consideration. The concentrations of ^{137}Cs in river water in 1986 after the accident was higher than that in 1987 by about one order of magnitude (ten times higher) in the river Pripyat at Chernobyl. On the other hand, the propagation of the increase of ^{137}Cs in river water to the fish in the river may need some time due to the accumulation of the radionuclide in the fish body and the linkage between the predatory and non-predatory species. Then, we estimated that the ^{137}Cs concentration in fish in 1986 could be higher than that in 1987 by a factor of two, not by ten times which is the case for the river water.

II-4.A.3. REFLECTION ON THE PRESENT MODEL ANALYSIS

The present result of our methodology fell into the 95% confidence level associated with the field observation, showing a reasonability of the method. Our method does not require a special, detailed type of experimental data. The following observation data were employed in the method:

(a) Stored amount of ^{137}Cs in the watershed;

(b) A multiple set of 1) the radioactive concentration in river water and 2) the river water flow rate under different hydrological conditions in terms of the river water flow rate.

(c) Monthly averaged river water flow rate through a year;

(d) Annual wash-off rate of ^{137}Cs;

(e) Temporal change in the radioactive concentration in river water for years;

(f) A mean concentration factor of ^{137}Cs for river fish.

Generally speaking, those data are fundamental ones as long as a radiological contamination of a river watershed is concerned. Therefore they will be available in an area to be studied. Then, the model must have a wide applicability. The method needs an assumption that the radioactive concentration in river water follows a log-linear relationship with the river water flow rate. The value of “the rating” in the relationship (parameter b_s or b) is determined by a response of the radioactive concentration to a difference of river water flow rate. A coefficient, which determines the magnitude of the radioactive concentration of river water, is deduced from a constraint of an amount of annual, fluvial discharge of the radionuclide. The key issue in the model is the log-linear relationship. This relationship can be applied for radionuclides of high adsorptivity to the soil in a river watershed and the suspended particles/bottom sediments in a river. They are radiocesium [3] and transuranic elements. On the contrary, strontium isotopes (e.g. ^{90}Sr) has a distinct property with regard to the river water flow rate and other hydrological conditions because of its high solubility.

Concerning the concentration factor, there remains a freedom in selecting values. An extensive study on the accumulation of Chernobyl-derived ^{137}Cs for river fish was conducted by allied European countries [7]. According to their report [7], the concentration factor lies between 1000 and 10000 (L kg^{-1}) approximately. Observed values of the concentration factor were similar within a factor of 2 for each fish species. It also changed by fish size among identical species. These findings of them suggest a validity of the concentration factor concept, and also the various elements to be considered in its use.

We consider the following issues should be solved hereafter:

- Long-term evaluation of the concentration of the radionuclides of interest in river water.
- Selection of a mean value of the concentration factor with consideration of 1) the variability with a category of the trophic level of fish, and 2) the kind and the size of fish used for consumption.

One more important issue must be the evaluation in the early stage after the occurrence of contamination. The distribution of radionuclides of interest over the non-biological component, first of all, must be far from equilibrium in the early stage. Further, the radionuclides in a lower trophic level do not necessarily reach a higher level of organisms. Some evaluation should be considered for such an "unstable" phase of radioactivity distribution other than a transfer factor or a concentration factor approach. This is because that exposure at the early stage is decisive in many cases among the whole exposure, including delayed exposure in coming years after the contamination. Thus, an approach to the first evaluation with a limited available data for the early stage exposure is keenly required, we feel.

Acknowledgement

The authors are grateful to Dr. Yuri Tkachenko of RADEK (Ukraine) for his help in providing aquatic contamination data in Chernobyl.

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II–5. CLRP MODEL — CLRP MODEL CALCULATION FOR SCENARIO IPUT

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P. Krajewski

II–5.1. MODEL DESCRIPTION

Model Name: CLRP – Concentration Levels Rapid Predictions
Model developer: Pawel Krajewski
Model user: Central Laboratory for Radiological Protection

II–5.2. IMPORTANT MODEL CHARACTERISTICS

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 co-operation with U.S. Environmental Protection Agency. The aim of this project was to examine the fate of long-lived radionuclides in the terrestrial ecosystem [1, 2]. Following the next years the model was intensively developed and extended for other radionuclides especially for iodine [3].

The aim of this code is to simulate the transport of radionuclides through the environment to human bodies and to examine the fate of some radionuclides in the ecosystem. The Input Parameters Data Base of the code has been created to permit the evaluation of the radiological impact for: I, Cs, Ru, Te, Sr. One is able to set up to 20 radionuclides of 44 elements.

All dynamic processes are described by differential formulas and are solved numerically. Radionuclide concentrations in the particular components of terrestrial ecosystem e.g. soil, vegetation, animal tissues and animal products are calculated as a function of time following calculated deposition from the atmosphere. The model considers seasonal changes in the biomass of vegetation and animal diets, also specific ploughing and crop-harvest dates. Human dietary data are included to permit calculation of time -dependent radionuclide ingestion rates as well as critical organ content of radionuclide for seven different age groups of the population.

The program enables one to calculate doses from the following pathways: external (cloud, ground exposure); internal (inhalation, ingestion) and is designed to make possible the simulation of many different radiological situations (chronic or acute releases) and dose-affecting countermeasures such as a ban on some dietary components, building shielding, as well as stable iodine prophylactics.

During the 1989–1995 period, the CLRP code performance for ^{137}Cs was checked out in the frame of the International IAEA programme “Validation of models for the transfer of Radionuclides in Terrestrial, Urban and Aquatic Environment and Acquisition of Data for that Purpose” on the basis of two “blind” scenarios, CB and S. The more detailed descriptions of the model structure and formulas one can find in references [4–6].

II–5.3. DESCRIPTION OF PROCEDURES AND PARAMETERS USED IN THE MODEL PREDICTIONS

II–5.3.1. ^{137}Cs concentration in air

Integrated air concentration 453 [Bq m^{-3} d] was assumed comparing with scenario assessment of about 200 Bq m^{-3} d.

II–5.3.2. Deposition

For deposition calculation the dry deposition velocity $6 \pm 4 \times 10^{-3}$ [m s^{-1}], and washout ratio (intensive rains) equal to $1.4 \pm 0.6 \times 10^{5}$ [m^3_{air}/ m^3_{rain}] as well as air concentration higher by a factor of two were assumed, but this assumption is not in agreement with information put in scenario. Due to lack of precise information about the ^{137}Cs concentration in ground level air, as well as weather condition, the model prediction was based on the soil contamination in the region (Table II-5.1).

TABLE II-5.1. SOIL CONTAMINATION DENSITY IN NOVOZYBKOW DISTRICT [kBq m^{-2}]

Estimation method		Average	Lower bound 95%	Upper bound 95%
Sampling survey in 1 October 1991 *(Table 3, Scenario IPUT) (1607 samples)*		**714***	**139****	**1775+**
Distribution of agricultural lands	**Total (599 km^2)**	**811++**	**579**	**1042**
(Table 35, Scenario IPUT)	Plough land (394 km^2)	764	548	981
(Time, method ???)	Hay pasture (205 km^2)	899	637	1162
	Forest (200 km^2) *(Table 17)*	?	?	?
Vertical distribution	Uncultivated soils (0–2.5 cm)	888.5	?	?
In 1 August 1990	Cultivated soils (0–15 cm)	567.7	?	?
(Table 4, Scenario IPUT)	Forest soils (0–2.5)	1114.4	?	?
Assumption about effective contamination	**Total (599 km^2)**	**501**	**350**	**652**
	Ploughed land (394 km^2)	502	351	654
	Hay pasture (205 km^2)	498	347	649
	Forest (200 km^2)	?	?	?
The predictions were made based on calculated deposition	**Total**	**490**	*259*	*925*
	Dry	182	*97*	*345*
	Wet	308	*162*	*580*

* Lognormal distribution average.

** Lower bound of 95% confidence interval of min values.

\+ Upper bound of 95% confidence interval of max values.

++ Weight average over contaminated areas percentage.

To assume effective density of ^{137}Cs contamination for Novozybkow region, the most contaminated area was excluded from the weighted average. This was performed on the basis of scenario information related to the practical implementation of protective measures (p. 19 Scenario IPUT):

- Areas from 555-1480 kBq m^{-2} – pasture land were ploughed up (1987-1988) all or part.
- Since 1987 about 40% of agricultural lands with contamination over 1.480 kBq m^{-2} have been taken out of production [p. 19, p(3), (4)].
- In 1988 all agricultural lands with contamination density over 1480 kBq m^{-2} were completely taken out of agricultural production.

— This gives an effective average Cs-137 density in soil equal to 501 kBq m^{-2} (350-652 kBq m^{-2}).

The values of average Cs-137 density in soil taken for the calculation covered the range of effective Cs-137 density (Table II-5.1). The log-normal distribution was assumed.

II–5.3.3. Agricultural Plants

TABLE II-5.2. PLANTS PARAMETERS

Plant	Biomass above $[kg\ m^{-2}]$ f.w	Biomass crops $[kg\ m^{-2}]$ f.w	Crops dry matter content	Trans-location at: 29–30 Apr 1986	Soil proprieties					
					Type	Bulk density $[kg\ m^{-2}]$	TF d.w. $[Bq\ kg^{-1}]_{plant}$ $[Bq\ kg^{-1}]_{soil}$	Caesium bioavailability		
								A	T_{fast}	T_{slow}
Cereals (rye)	0.44	0.22	86%	0.012	Sand pH 5	65	0.06	60%	0.7	15
Lettuce	1.2	1.2	10%	1	Sand pH 5	50	0.4	80%	3	10
Cabbage	3	3	15%	1	Sand pH 5	65/3	0.23	60%	0.7	15
Carrot	0.6	2.3	15%	0	Sand pH 5	65/3	0.026	80%	3	10
Potatoes	0.17	1.7	20%	0	Sand pH 5	65/3	0.17	60%	0.7	15
Fruits (apple)	10	2	15%	0.35	Sand pH 5	130/1	0.02	20%	2	10
Pasture grass	0.9	0.9	15%	1	Sand pH 5	23.5/1	2	60%	0.7	15
Hay (grass)	1.3	1.3 3 cuts: (40, 35, 25%)	15%	1	Sand pH 5	65/3	2	70%	0.7	15
Maize	4	4	25%	1	Sand pH 5	65/3	0.1	60%	0.7	15
Bilberry	2.5	0.5	20%	0.05	Sand pH 5	25	0.5	10%	2	15
Cantharella t.	4.5	0.5	10%	1	Sand pH 5	25	7	10%	2	15
Boletus edulis	4.5	0.5	10%	1	Sand pH 5	25	1.5	10%	2	15

The TF factors were applied based on the Scenario soil properties description (soddy podzolic, sandy, sandy loam), Tables I.XXVII, I.XXVIII of the IPUT Scenario, 93.2% of agricultural area, which suggests higher transfer coefficients. The transfer factors for agricultural plants were selected based on [12, 13] and for seminatural products based on [18].

To simulate agrochemical measures in the Novozybkov area, the higher fast component of decreasing bioavailability of caesium was applied as follows:

Fast component contribution:	60%
Fast component half-life:	0.7 years
Slow component half-life:	15 years

II–5.3.4. Agricultural animals

II–5.3.4.1. Dairy cow

TABLE II-5.3. ASSUMED DAIRY COW DIET

DAIRY COW Component Row Products Names	DAIRY COW Component Diet Names	Restrictions date	Delay	Food processing	Period I	Period II	Period III	Period VI	Period V	Period VI
Cohorts' N#	Shift days				01 sty	01 kwi	27 kwi	31 lip	10 paž	01 gru
01					31 mar	26 kwi	30 lip	09 paž	30 lis	31 gru
grass continous	pasture grass		00	1.00	0.00	0.00	50.00	50.00	0.00	0.00
hay	hay winter		30	1.00	4.00	4.00	0.00	0.00	4.00	4.00
Maize	Green cut maize		30	0.20	15.00	15.00	0.00	0.00	15.00	15.00
rye	cereals		10	1.00	2.00	2.00	2.00	2.00	2.00	2.00
hay	cereals	01 10 87	30	4.70	4.00	4.00	0.00	0.00	4.00	4.00
hay	cereals	01 10 87	30	1.00	15.00	15.00	0.00	0.00	15.00	15.00
grass continous	pasture grass	25 04 87	00	4.70	0.00	0.00	50.00	50.00	0.00	0.00

Equilibrium factor: 5.3×10^{-3} $[d\ L^{-1}]$- for cow with yield 7 l/d.

II–5.3.4.2. Beef cow (cow meat)

TABLE II-5.4. ASSUMED BEEF COW DIET

BEEF Component Row Products Names	BEEF Component Diet Names	Restrictions date	Delay	Food processing	Period I	Period II	Period III	Period VI	Period V	Period VI
Cohorts' N#	Shift days				01 sty	01 kwi	29 kwi	31 lip	10 paž	01 gru
01					31 mar	28 kwi	30 lip	09 paž	30 lis	31 gru
Grass continuous	green fodder spring		00	1.00	0.00	0.00	7.50	7.50	0.00	0.00
Hay	hay winter		30	1.00	2.00	2.00	0.00	0.00	2.00	2.00
Maize	silage (green cut maize)		30	0.20	9.00	9.00	4.00	4.00	9.00	9.00
Rye	cereals		10	1.00	0.50	0.50	0.50	0.50	0.50	0.50
Rye	cereals		10	1.00	1.75	1.75	1.75	1.75	1.75	1.75
Grass continuous	green fodder spring	01 10 87	30	4.70	0.00	0.00	7.50	7.50	0.00	0.00
Hay	hay winter	01 10 87	30	4.70	3.00	3.00	2.00	2.00	3.00	3.00
Hay	silage alfaalfa	25 04 87	00	1.00	9.00	9.00	4.00	4.00	9.00	9.00

Equilibrium factor: 11×10^{-3} [d L^{-1}] VOIGT ET AL 1988 [10]

II–5.3.4.3. Pork

TABLE II-5.5. PORK DIET

PORK Component Row Products Names	PORK Component Diet Names	Restrictions date	Delay	Food processing	Period I	Period II	Period III	Period VI	Period V	Period VI
Cohorts' N#	Shift days				01 sty	01 mar	01 kwi	02 maj	01 lip	01 sie
01	00				29 lut	31 mar	01 maj	30 cze	31 lip	31 sie
rye	concentrates		00	1.00	2.00	2.00	2.00	2.80	2.80	2.80
grass continuous	legumes		00	1.00	0.00	0.00	0.00	5.50	5.50	5.50
root crops	beet roots		00	1.00	6.00	6.00	6.00	0.00	0.00	0.00
grass continuous	legumes	30 12 86	00	4.70	0.30	0.30	0.75	0.80	1.30	1.30

Equilibrium factor: 360×10^{-3} [d L^{-1}] VOIGT ET AL 1988 [10]

II–5.3.4.4. Hens; Eggs

TABLE II-5.6. HENS DIET

EGGS Component Row Products Names	EGGS Component Diet Names	Restrictions date	Delay	Food processing	Period I	Period II	Period III	Period VI	Period V	Period VI
Cohorts' N#	Shift days				01 sty	02 mar	16 kwi	01 lip	01 sie	02 sie
01					01 mar	15 kwi	30 cze	31 lip	01 sie	31 gru
rye	Barley (25%)		10	1.00	0.06	0.06	0.06	0.06	0.06	0.06
rye	Wheat (50%)		10	0.50	0.06	0.06	0.06	0.06	0.06	0.06
grass continous	Rye (25%)		10	1.00	0.02	0.02	0.02	0.02	0.02	0.02

Equilibrium factor: Hens: 5000×10^{-3} [d L^{-1}]
Equilibrium factor: Eggs: 300×10^{-3} [d L^{-1}] VOIGT ET AL 1988 [10]

II–5.3.5. Whole body contents

Two variants of calculation were performed:

(a) Without limits for radionuclide concentration in foodstuffs (Table I.LIII of the Scenario description);

(b) When limits had been applied so concentration levels for milk and meat (beef, pork, poultry) above limits were cut off from the data set.

Retention function for standard man [9]:

Equilibrium factor:	143.12 [Bq Bq^{-1} d]
Fast component contribution:	10%
Fast component half-life:	2 days
Slow component half-life:	110 days

TABLE II-5.7. HUMAN CONSUMPTION RATES

MAN RESTRICTION Component Row Products Names	MAN RESTRICTION Component Diet Names	Delay	Food processing	Period I	Period II	Period III	Period VI	Period V	Period VI
Cohorts' N#	Shift days			01 sty	01 maj	01 sie	01 wrz	01 paž	01 lis
01				30 kwi	31 lip	31 sie	30 wrz	31 paž	31 gru
Rye	Whole grain bread	05	0.30	0.20	0.20	0.20	0.20	0.20	0.20
Rye	Bread	05	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Salad	Leafy vegetables	01	0.30	0.00	0.00	0.00	0.00	0.00	0.00
Cabbage	Leafy vegetables	01	0.60	0.00	0.03	0.03	0.03	0.03	0.00
Cabbage	Leafy vegetables (processed)	15	0.70	0.01	0.01	0.01	0.01	0.01	0.01
CARROT	Root vegetables	01	0.90	0.09	0.09	0.09	0.09	0.09	0.09
Cucambers	Fruit vegetables	01	0.70	0.02	0.02	0.02	0.02	0.02	0.02
Been	Fruit vegetables	01	0.70	0.00	0.00	0.00	0.00	0.00	0.00
POTATOES	Potatoes early	07	0.70	0.00	0.15	0.32	0.32		
POTATOES	Potatoes early	07	0.50	0.32	0.15	0.00	0.00	0.32	0.32
Apples	Fruits		0.70	0.06	0.06	0.06	0.06	0.06	
Apples	Fruits (processed)	02	0.33	0.01	0.01	0.01	0.01	0.01	0.01
milk protective	Milk & milk drink	00	0.75	0.50	0.50	0.50	0.50	0.50	0.50
milk protective	Cottage cheese	01	0.75	0.02	0.02	0.02	0.02	0.02	0.02
milk protective	Cheese (rennet)	30	0.80	0.01	0.01	0.01	0.01	0.01	0.01
pork protective	Meat (processed)	02	0.80	0.04	0.04	0.04	0.04	0.04	0.04
pork protective	Meat (fresh)	05	0.70	0.12	0.12	0.12	0.12	0.12	0.12
beef protective	Meat (processed)	10	1.00	0.04	0.04	0.04	0.04	0.04	0.04
Hens	Poultry	01	0.58	0.03	0.03	0.03	0.03	0.03	0.03
Eggs	Eggs (without shell)	03	0.88	0.03	0.03	0.03	0.03	0.03	0.03

II–5.3.6. Dose calculation

Parameters used for external and internal dose calculation are presented below (printout from the CLRP interactive dialogue). For the test person "rural habit" was assumed with 40% (of 24 hours), about 10 hours, spent outdoors. Shielding and filtration factors for small concrete house were assumed. Ingestion doses were calculated with and without protective measures (concentration limits for milk and meat). Additionally, the dose from ingestion of semi-natural products was calculated.

TABLE II-5.8. EXTERNAL DOSE REDUCTION FACTORS

DOSE REDUCTION FACTOR FOR EXTERNAL EXPOSURE							
		CLOUD EXPOSURE			GROUND EXPOSURE		
Type of house	Residence time indoor T_{wewn} [%]	Attenuation factor for gamma irradiation		Factor	Attenuation factor for gamma irradiation		Factor
		$\Phi^{outdoor}$	Φ^{indoor}		$\Gamma^{outdoor}$	Γ^{indoor}	
Wooden house	0,6	1	0,3	0,580	1	0,1	0,460
brick house	0,8	0,6	0,05	0,160	0,3	0,01	0,068

TABLE II-5.9. DOSE FACTOR USED IN CALCULATION [14–17]

ISOTOPE	Effective dose from Immersion in Cloud [mSv d^{-1} Bq^{-1} m^{3}]						
	Man	Woman	Child 15 y	Child 10 y	Child 5 y	Child 1 y	Child 3 m
^{137}Cs	2.232E-06	2.232E-06	2.232E-06	2.400E-06	2.400E-06	2.640E-06	2.640E-06
	Effective dose from Immersion in Water [mSv d^{-1} Bq^{-1} m^{3}]						
	Man	Woman	Child 15 y	Child 10 y	Child 5 y	Child 1 y	Child 3 m
^{137}Cs	3.039E-05	3.039E-05	3.039E-05	3.273E-05	3.273E-05	4.389E-08	4.389E-08
	Effective dose from 1 m above Ground [mSv d^{-1} Bq^{-1} m^{2}]						
	Man	Woman	Child 15 y	Child 10 y	Child 5 y	Child 1 y	Child 3 m
^{137}Cs	3.170E-08	3.170E-08	3.170E-08	3.360E-08	3.414E-08	4.320E-08	4.320E-08
	Effective dose from inhalation [mSv Bq^{-1}]						
	Man	Woman	Child 15 y	Child 10 y	Child 5 y	Child 1 y	Child 3 m
^{137}Cs	8.600E-06	8.600E-06	8.600E-06	6.100E-06	5.900E-06	6.400E-06	6.400E-06
	Effective dose from Ingestion [mSv Bq^{-1}]						
	Man	Woman	Child 15 y	Child 10 y	Child 5 y	Child 1 y	Child 3 m
^{137}Cs	1.30E-05	1.30E-05	1.300E-05	1.00E-05	9.60E-06	1.20E-05	1.200E-05
	Dose rate in critical organ from 1 Bq in organ [mSv Bq^{-1} d^{-1}]						
	Man	Woman	Child 15 y	Child 10 y	Child 5 y	Child 1 y	Child 3 m
^{137}Cs	1.00E-07	1.00E-07	1.111E-07	1.89E-07	3.23E-07	5.22E-07	5.217E-07

II–5.4. COMMENTS, CONCLUSIONS

There are some notes and questions that have arisen during the preparation of the scenario IPUT parameters for model predictions.

II–5.4.1. Air concentration of ^{137}Cs

Some rough calculation shows discrepancy between air concentration assessment (Table I.1 of the Scenario description) and soil contamination data[5]. There is no rain reported near Novozybkov area (according to Table I.XIII of the scenario description) in a critical period 27 April -1 May 1986, with the exception of rain of amount 11 mm in CHECHERSK location. High precipitation was not recorded by close station in KRASNA GORA. There is no rain data from GOMEL (N. 33041).

The description of the estimation method of air concentration for Scenario IPUT should be included.

II–5.4.2. Soil contamination density data

(1) There is no indication about the soil sampling method in Table I.III of the Scenario description. Because the sampling was performed (or finished) in 1 October 1991, after ploughing countermeasures, what is the depth of soil samples (10 cm or more).

(2) With the exception of one deep Cs-137 soil profile for forest soil (Table I.IV (1 August 1990) of Scenario IPUT) that gives caesium density of 1114.4 kBq m^{-2} there is no indication in the scenario about forest soil contamination.

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[5] For 800 kBq m^{-2} and 200 Bq m^{-3} d one can obtain 15 $\times 10^{-3}$ [m s^{-1}] dry deposition velocity, order of magnitude higher than reported after Chernobyl 1$\div$2$\times 10^{-3}$ m/s [11].

(3) Uncultivated soils profile in the same table does not indicate any protective measures for pasture.

(4) There is no indication in which area AGRO** the protective measures were applied.

II–5.4.3. Agricultural animals

(1) The animal diet was taken from the scenario with the exception of beef as there is no indication in the scenario about beef cow diet seasonality (only yearly consumption rates).

(2) No information about daily ration for beef in different seasons. The mixture of maize and grass was assumed.

(3) The assumption about silage (main component is green cut maize) yields a rapid decrease of Cs-137 concentrations in milk during the winter period.

(4) There is some disagreement between the reported milk yield for Nowozybkow district: (Table I.XXXIX of scenario gives 2600/365 = 7.1 L d^{-1}) whereas in the Table I.XXXV values of (5-6) L d^{-1} are reported.

(5) Summer pig diet is characterised by a very high grass (Legumes 5.5 kg) consumption during the summer period. This yields high concentration of caesium in meat, with a peak during the summer period and decreasing during the winter period.

II–5.4.4. Whole body content of Cs-137

(1) According to scenario Table 45 pork and poultry meat was assumed as base component.

(2) The pork contamination is remarkably reflected in WBC.

(3) Two exponential fitting of WBC curve for period (1989-1992) shows different decreasing pattern as follows:

Effective half-life
Without restrictions:
Effective half-life: 7 [year]

With restrictions:

Fast component contribution: 61%
Fast component half-life: 0.96 [year]
Slow component half-life: 14 [year]

II–5.4.5. Dose estimation

(1) The average lifetime dose for the rural inhabitants (standard man) in Novozybkow district was calculated as about 65 mSv with a 95% uncertainty range of 22 - 195 mSv.

(2) External dose contributed 66% of the total life dose (42 mSv) and ingestion dose 34% (22 mSv).

(3) Without protective measures (Foodstuffs Limits) the ingestion dose rises to 78 mSv (by a factor of 3.5).

(4) Consumption of semi-natural products (wild berries, mushrooms) gives an additional lifetime dose of about 6.7 mSv (that is of 30% of ingestion dose)

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II–6. TAMDYN-UV MODEL

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II–6.1. GENERAL MODEL DESCRIPTION

II–6.1.1. Name of Model and Model users

Model Name: TAMDYN-UV
Model users: B. Kanyár, Á. Nényei and students from the University of Veszprém, Hungary.

II–6.1.2. Important characteristics

The model used contains both dynamic and steady state parts. The deposited Cs-137 transport into the soil, the weathering effect to the contamination of the vegetation surface, the root uptake, the convection inside the vegetation and metabolism in the animals as well as in man are simulated by dynamic forms, by compartments and ordinary differential equations. The atmospheric resuspension and the human dose from the different pathways were assessed by simple and explicit, algebraic forms.

Uncertainties are provided by Monte Carlo simulations.

II–6.2. COMPONENTS OF THE MODELS

II–6.2.1. Model structure of compartments, terrestrial environment

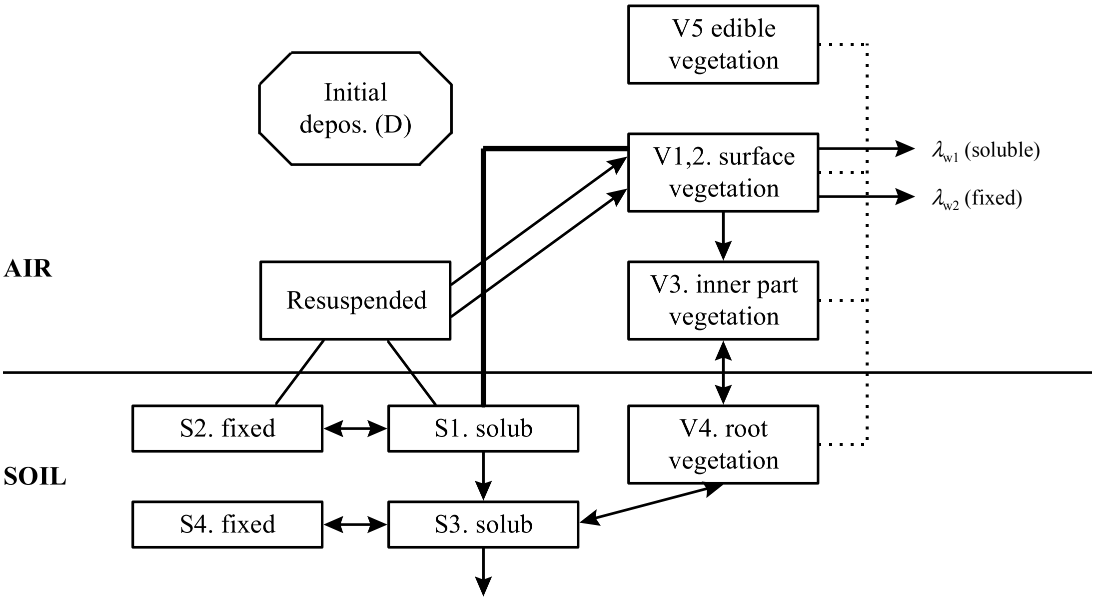

FIG. II-6.1. Compartments of the dynamic model of the terrestrial environment used for IPUT Scenario, by the software TAMDYN [9].

The sources and initial values of the contamination have been the surface deposition either to the upper soil layer (S1) or to the vegetation surface (V1). The first deposited form was taken as a soluble (ionic) one totally.

In the former versions of the simulation the deposited activity was shared by 50–50 % into soluble and special fixed forms. Among the environmental conditions the special fixed one decreased exponentially by a 6-year half-life into the soluble one (similarly as a hot particle observed near to the Chernobyl site). Due to the simulation experience of the migration in soil and to the information obtained later from the authors all the deposited form was taken as a soluble one.

The first simulations started from the air concentration measured and provided in the scenario description, but due to the long duration of sampling, there was expected to be an underestimation of the air contamination. The underestimation was confirmed by the difference between the assessed deposition and measured one by soil samples. Therefore the soil measurements were used for the source of contamination in the last version.

II–6.2.2. Cs-137 uptake and excretion in the animals and man, whole body activity

The metabolism is modelled by the linear compartmental system in Fig. II-6.2:

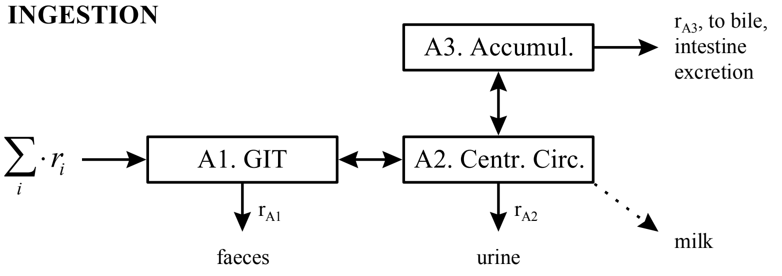

FIG II-6.2. Compartments for Cs-137 transport in the animals and man, IPUT scenario (software: TAMDYN [9], Univ. Veszprém).

All the transport coefficients used (A1-A2, A2-A3, A1-faeces, A2-urine etc.) are linear ones with dimensions of time^{-1}. The rates of ingestion (r_i) are given in Bq.d^{-1}.

II–6.3. MATHEMATICAL FORMS

In general, the activities and masses of vegetation are normalised to surface area of 1 m^2.

II–6.3.1. Soil

Upper layer (S_1, S_2):

$$dy_{s1} / dt = -(\lambda_r + SF \cdot \lambda_{roff1} + r_{sd} / d_1 + r_{sf}) \cdot y_{s1}$$
$$dy_{s2} / dt = r_{sf} \cdot y_{s1} - (\lambda_r + SF \cdot \lambda_{roff2} + r_{fs}) \cdot y_{s2}$$

Root layer (S_3, S_4):

$$dy_{s3} / dt = r_{sd} / d_1 \cdot y_{s1} + r_{v4s3} \cdot y_{v4} - (\lambda_r + SF \cdot r_{s3v4} + r_{sd} / d_2 + r_{sf}) \cdot y_{s3}$$
$$dy_{s4} / dt = r_{sf} \cdot y_{s3} - (\lambda_r + r_{fs}) \cdot y_{s4}$$

where

$y_{s1}(t)$ = activity in the upper soil layer due to the direct contamination (primary, soluble form), (Bq);
$y_{s2}(t)$ = activity in the upper soil of fixed form (Bq);
$y_{s3}(t)$ = activity in the root soil of soluble form (Bq);
$y_{s4}(t)$ = activity in the root soil of fixed form (Bq);
λ_r = the radioactive decay constant (d^{-1});
SF = seasonality function (dimensionless), value between 0 and 1, during vegetation period nearly 1, in winter 0;
λ_{roff1}, λ_{roff2} = runoff coefficient from upper soil, soluble form (1) and fixed one (2), (d^{-1});
r_{sd} = transport coefficient downward in soil (d^{-1}), only for soluble form;
r_{sf}, r_{fs} = transport coefficients from soluble form to fixed one (sf, fixation in soil), and backwards (fs), (d^{-1});
d_1, d_2 = depth of upper and root soil layers (m), varied according to the scenario description; and
r_{v4s3} = transport coefficient from vegetation root to root soil layer of soluble form (d^{-1}).

The concentrations in air, due to resuspension are defined by concentration factors, namely:

$$c_{sir,s}(t) = SF \cdot RF_s \cdot y_{s1}(t) / \rho_s / d_1$$

where

RF_s = the resuspension factor (dimensionless) for the soluble form; and
ρ_s = soil density (kg/m^3).

Similarly is assessed the concentration of the resuspended fixed form in air.

As countermeasure the ground of pasture was deep ploughed partly in 1988 and in 1989. It means the contamination in the upper 30 cm of the soil was distributed uniformly.

II–6.3.2. Vegetation

All the plants were distributed into surface part (j=1), inner part (j=2) and root part (j=3).

The activities in the vegetation surface compartments are defined by following:

$$dy_{vi} / dt = c_{sir,i} \cdot R \cdot m_{veg} / m_{v\max} \cdot (V_{di} + W_i \cdot I) - (\lambda_r + \lambda_{wi} + SF \cdot r_{i,v3}) \cdot y_{vi}, (i = 1,2)$$

where

i = refers to the two (soluble and fixed) forms on the surface of vegetation (V1, V2);
R = the interception factor for the maximal mass of vegetation (just before the harvesting, dimensionless);
m_{veg}, m_{vmax} = time dependent and maximal mass of vegetation during the seasonal growing (kg);
V_{di}, W_i = atmospheric dry deposition rate ($m.d^{-1}$) and wet deposition coefficient (-) for soluble (i=1) and fixed form;
λ_{wi} = weathering loss coefficient for soluble and fixed forms (d^{-1}); and
$r_{i,v3}$ = transport coefficients (soluble and fixed species) from surface to inner

part of vegetation (from compartment V1 or V2 to V3) (d^{-1}).

The mass of vegetation is assessed by an exponential growing curve with beginning of sowing and end of harvesting:

$$m_{vj}(t) = SF \cdot m_{v,j,\max} \cdot (1 - \exp(-SF\beta \cdot (t - t_{harv}))), \mathrm{for} t > t_{sowing} (\mathrm{or} T_{plowing})$$

where

t = the seasonal date (beginning from the 1st January);
$m_{v,j,max}$ = the maximum mass (kg) of the j-th part of vegetation (surface, inner, root), at the harvesting (in general, the surface mass of vegetation is 10-times less than the inner part and the root mass by 5 times less than the inner one, except potatoes where the root part takes the larger one);
β = the rate coefficient of growing of the proper part of plant (d^{-1});
t_{harv} = is the time (date) of harvesting (d^{-1}); and
t_{sowing} = the time of sowing.

The activities of the inner and root parts of the vegetation:

$$dy_{v3} / dt = -(\lambda_r + SF \cdot r_{v3v4}) \cdot y_{v3} + SF\left(\sum_i \cdot r_{i,v3} \cdot y_{vi} + r_{v4v3} \cdot y_{v5}\right),$$
$$dy_{v4} / dt = -(\lambda_r + DF \cdot (r_{v4s3} + r_{v4v3})) \cdot y_{v4} + SF \cdot r_{s3v4} \cdot y_{s3} + r_{v3v4} \cdot y_{v3}),$$

where

r_{v3v4} = the transport coefficient from inner to root part of the vegetation (d^{-1}). The other r–s are defined by a similar way.

The activity and mass of the edible part (V5) is calculated by a weighted sum of the vegetation parts (V1, V2, V3 and V4).

II–6.3.3. Freshwater fish

The concentrations in fish was assessed by a simple bioaccumulation factor between water and fish, namely:

$$C_{fish} = B \cdot C_{fr \cdot w \cdot}$$

where

C_{fish} = the r.nuclide concentration in fishes (Bq.kg^{-1}, wet);
$C_{fr.w.}$ = the r.nuclide conc. in the water (Bq.L^{-1}); and
B = the bioaccumulation factor (L.kg^{-1}).

The water contamination was used from the scenario description in the river Iput, Section 6. Only the contamination of fishes from river was assessed.

II–6.3.4. Tissues of animals (cow, pigs, poultry, sheep) and man

The radioactivities of Cs-137 in the tissues compartments (Figure II-6.2) are modelled by the following differential equations:

$$dy_{A1}/dt = \sum_i \cdot r_i - (\lambda_r + r_{A1} + r_{A1,A2}) \cdot y_{A1} + r_{A2,A1} \cdot y_{A2},$$
$$dy_{A2}/dt = r_{A1,A2} \cdot y_{A1} + R_{A3,A2} \cdot y_{A3} - (\lambda_r + r_{A1} + r_{A2,A3}) \cdot y_{A2},$$
$$dy_{A3}/dt = -(\lambda_r + r_{A3} + r_{A3,A2}) \cdot y_{A3} + r_{A2,A3} \cdot y_{A2}.$$

where

y_{Ai} = the activity in the i-th tissue (GIT, Central Circulation and Accumulation), (Bq);
$\Sigma_i.\ r_i$ = the total rate of intake of the radioactivity (Bq.d^{-1}) from the feed/food;
r_{Ai} = the excretion coefficient from the tissue i (d^{-1}); and
$r_{Ai,Aj}$ = the rate coefficient from Ai to Aj (d^{-1}).

The whole body activity in man has been assessed by the sum of the activities in the compartments of GIT, CC and ACC. The differences in activity concentration between man and woman come from the different intakes and the body weights.

II–6.4. DOSE ASSESSMENTS

II–6.4.1. Ingestion dose

In the first year the rate of the ingested Cs-137 activities (separately by food type and total) have been calculated monthly, later on quarterly. Food processing loss coefficients for potatoes, vegetables and mushrooms were involved by 10 %. For milk, beef and pork the loss of processing was neglected. Dose from ingestion was assessed by the time-integrated activities multiplied by the ingestion dose conversion factor given in the description (1.4 × 10^{-8} Sv/Bq).

II–6.4.2. Inhalation dose

The time integrated concentration in air from the direct plume should be reconstructed from the total deposition, namely by:

$$\text{Total dep. } (Bq \cdot m^{-2}) = v_{tot} \int_0^{\tau} c_{air}(t)dt,$$

where

v_{tot} = the the total deposition rate (dry + wet, m.d^{-1});
c_{air} = concentration in air at the surface (Bq.m^{-3}); and
τ = the time duration (d) (for the direct plume the first 8 days).

Due to the high uncertainty of the v_{tot} (depending on the aerosol diameter, rainfall etc.) the time integrated concentration in the air was assessed from the ratio of:

$$\text{ratio} = \text{total deposition } (kBq \cdot m^{-2}) / \text{ time integrated conc. in air } (Bq \cdot d \cdot m^{-3})$$

assessed in Hungary (it might be better from data near to the Iput region). According to the results ratio = 1.5 (kBq.m^{-2})/(Bq.d.m^{-3}) was used. (Due to the rainfall in Hungary the assessed ratio might be an overestimation.)

The inhaled dose (committed effective dose) comes from the product of:

$$D_{inh}(Sv) = S_{red} \cdot I_{inh}\left(m^3 \cdot d^{-1}\right) \cdot K_{inh}(Sv/Bq) \cdot \int_0^{\tau} c_{air}(t)dt.$$

where

I_{inh} = the inhalation rate; and
S_{red} = the reduction factor due to the occupancy and shielding of buildings (dimensionless).

The inhalation dose from resuspension was assessed by the time integrated concentration assessed from the resuspension by a simple concentration factor.

II–6.4.3. Cloud external exposure

The time-integrated concentration in air are used again in the following form:

$$D_{sunshine}(Sv) = S_{red,air} \cdot K_{ext,air}\left(Sv \cdot d^{-1} : Bq \cdot m^{-3}\right) \cdot \int_0^{\tau} c_{air}(t)dt.$$

The parameters used are derived from the scenario description, the time integrated air concentration as given in the description of inhalation dose.

II–6.4.4. Ground (external) exposure

In case of the ground exposure the diffusion of Cs-137 into the depth of soil is to be taken into account. The exposure from the radionuclide in depth of x, is less due to the absorption of the soil layer above the depth x. The reduction factor ($S_{abs,soil}$) is assessed by the following table (from the software MicroShield version 3.0):

x (cm)	$S_{abs,soil}$
0–2	0.8
2–20	0.3
> 20	0.0

The dose rates are assessed similarly as for the external cloud exposure, by using proper dose conversion and building reduction parameters from the scenario description an [8].

II–6.5. PARAMETERS

Most of the parameters are derived from the references given by a proper adjusting. For example, the Ref. 5 provides for the downward transfer of the total (soluble + fixed) Cs in soil, $r_{sd} = 1.9 \times 10^{-5}$ d^{-1} from a 30 cm layer. Our value of $r_{sd} = 3.0 \times 10^{-3}$ d^{-1} for the 1 m depth soil layer and only the soluble form of Cs (it is by about 1000-1500-times less than the total one) correspond to the Ref. value. Similarly, the Ref. 2 reports the K_D (partition coefficient in soil) in range of 18-60,000 L.kg^{-1} for sandy and loamy soils. From the global parameter table in our description the fixation and release rates of the Cs in soil assessed the range of K_d: 150-8000 in agricultural (cultivated) relations and nearly 2 times higher for forest (organic soil).

Most of the parameters used are derived in similar way but some of them (*marked by x*) were assessed from less validated data, from general descriptions or personal judgement. According to our calculations the last ones were less sensitive to the results.

TABLE II-6.1. GLOBAL PARAMETERS OF THE TERRESTRIAL ECOSYSTEM

Parameter	Mean	Min.	Max.	Remark/Ref.
Dry depos. rate, soluble form (m.d^{-1})	300	150	600	[3,5] for resusp. Cs-137 only
Dry depos. rate, fixed form (m.d^{-1})	200	100	500	[3,5] "
Wet depos. coeff., soluble form (-)	5×10^{5}	2×10^{5}	20×10^{5}	[3,5] "
Wet depos. coeff., fixed form (-)	5×10^{5}	2×10^{5}	20×10^{5}	[3,5] "
Soil resusp., fixed, agricult. (Bq.m^{-3}:Bq.kg^{-1})	7×10^{-5}	2×10^{-5}	20×10^{-5}	[4-6]
Soil resusp., fixed, forest (Bq.m^{-3}:Bq.kg^{-1})	3×10^{-5}	1e-5	10×10^{-5}	[4-6]
Depth of upper soil layer (m)	0.005-0.02	–	–	varied
Depth of root soil layer, agricultural (m)	0.15-0.30	–	–	varied
Depth of root soil layer, forest (m)	0.05	–	–	not varied
Density of soil (kg.m^{-3})	1500	1200	1800	[1]
Rate of fixation in soil (d^{-1})	0.3	0.1	1.0	[3]
Rate of releases from soil, agricult. (d^{-1})	3×10^{-4}	1×10^{-4}	10×10^{-4}	[3]
Rate of releases from soil, forest (d^{-1})	1.5×10^{-4}	0.5×10^{-4}	5×10^{-4}	[3]
Downward transp. in soil, sol. form (d^{-1} per 1 m soil)	0.003	0.0010	0.010	[3–5]
Weathering loss coeff., soluble (d^{-1})	0.06	0.03	0.15	[3,5]
Weathering loss coeff., fixed (d^{-1})	0.08	0.05	0.2	[3,5]
Transp. coeff. from veget. surface to inner part, fixed form (d^{-1})	0.03	0.01	0.1	[5]
Transp. coeff. from inner veg. to root (d^{-1})	0.1	0.03	0.3	[5]
Transp. coeff. from root to inner veg. (d^{-1})	0.2	0.05	1.0	[5]

TABLE II-6.2. VEGETATION DEPENDENT PARAMETERS

Parameter	Mean	Min.	Max.	Remarks/Ref.
Mass of harvested cereals (kg, dry)	0.4	0.2	0.5	[1]
Mass of harvested (cut) pasture (kg, dry)	0.2	0.1	0.5	[1]
Mass of harvested vegetables (kg, wet)	2.0	1.0	3.0	[1]
Mass of harvested potatoes (kg, wet)	2.0	0.5	3.0	[1]
Mass of harvested wild berries (kg)	0.1	0.02	0.7	x
Mass of harvested mushrooms (kg, wet)	0.02	0.01	0.05	x
Growing rate of the vegetation, β (d^{-1}) (except mushrooms)	0.02	0.01	0.05	x
Growing rate of the vegetation, β (d^{-1}) (mushrooms)	0.2	0.1	0.5	x
Interception of cereals, during the direct contamination	0.1	0.05	0.2	[2,5]
Interception of pasture, "	0.5	0.02	0.8	[2,5]
Interception of vegetables, "	0.7	0.4	0.9	[2,5]
Interception of potatoes, "	0.2	0.05	0.5	[2,5]
Interception of wild berries, "	0.1	0.03	0.5	x
Interception of mushrooms, "	0.02	0.01	0.05	x
Transp. coeff. from root to soil (d^{-1}) (except mushrooms and potatoes)	1×10^{-4}	0.2×10^{-4}	3×10^{-4}	[2,5]
Transp. coeff. from root to soil (d^{-1}) (potatoes, mushrooms)	5×10^{-3}	2×10^{-3}	20×10^{-3}	[2,4-6]
Transp. coeff. root uptake from soil (d^{-1}) (except mushrooms and potatoes)	5×10^{-4}	1×10^{-4}	20×10^{-4}	[2,4-6]
Transp. coeff. root uptake from soil (d^{-1}) (potatoes)	20×10^{-4}	5×10^{-4}	50×10^{-4}	[2,4-6]
Transp. coeff. root uptake from soil (d^{-1}) (mushrooms)	200×10^{-4}	50×10^{-4}	500×10^{-4}	[2,4-6]

TABLE II-6.3. TRANSPORT COEFFICIENTS OF ANIMALS AND MAN

Parameter	Mean	Min.	Max.	Remarks/Ref.
Bioaccumulation coeff. fish (kg.L^{-1})	3000	2000	5000	[4]
Cow, GIT excretion (d^{-1})	0.07-0.4	0.03-	0.2	varied, [3–5]
GIT to CC (d^{-1})	0.4-0.7	0.2-	1.0-	varied, [3–5]
CC to GIT (d^{-1})	0.05	0.02	0.1	[3–5]
CC (urine) excretion	0.01	0.003	0.02	[3–5]
CC to milk	0.012	0.005	0.025	[3–5]
CC to ACC (d^{-1})	0.1	0.03	0.15	[3–5]
ACC to CC (d^{-1})	0.05	0.01	0.1	[3–5]
ACC excretion (d^{-1})	0.005	0.002	0.01	[3–5]
Pig, GIT excretion (d^{-1})	0.1-0.4	0.02-	0.2-	varied, [3–5]
GIT to CC (d^{-1})	0.4-0.5	0.2-	1.0-	varied, [3–5]
CC to GIT (d^{-1})	0.05	0.02	0.1	[3–5]
CC (urine) excretion	0.01	0.003	0.02	[3–5]
CC to ACC (d^{-1})	0.1	0.03	0.15	[3–5]
ACC to CC (d^{-1})	0.1	0.02	0.2	[3–5]
ACC excretion (d^{-1})	0.005	0.002	0.01	[3–5]
Man, GIT excretion (d^{-1})	0.5	0.2	1.5	[3-5,7]
GIT to CC (d^{-1})	1.0	0.3	3.0	[3-5,7]
CC to GIT (d^{-1})	0.02	0.01	0.05	[3-5,7]
CC (urine) excretion	0.015	0.005	0.05	[3-5,7]
CC to ACC (d^{-1})	0.1	0.03	0.25	[3-5,7]
ACC to CC (d^{-1})	0.03	0.01	0.05	[3-5,7]
ACC excretion (d^{-1})	0.005	0.002	0.015	[3-5,7]

The animal feeding and human food consumption profiles - including the variation in time – were taken from the scenario description by a more or less reconstruction process.

II–6.5.1. Food processing loss factors (produced times the factor = used)

mushrooms:	0.4 (for the improved simulation, former: 0.8)
fish:	0.5
beef, pork, berries:	0.9
vegetables	0.9

II–6.5.2. Dose assessment

Inhalation rates: 22 (18-25) m^3.d^{-1} (man),20 (15-23) m^3.d^{-1} (woman).

S_{red}. = o. S_{in} + (1-o).S_{out} for inhalation: 0.45, for external ground exposure: 0.33.

II–6.6. MEASURES

The software offers the possibility to modify at any simulation date the values of any dependent variable (activity in soil compartments, in GIT etc.), any mean values of the parameters (binding coefficient in soil, root uptake, interception on vegetation, rate of inhalation, rate of mass ingestion etc.) and by special effects as ploughing of soil (it provides a homogeneous distribution of the contaminant in the given depth), sowing and cutting of vegetation.

By the modification there might be given a new value or the old one might be multiplied. In case of uncertainty analysis the limits of the parameter ranges are modified by the same factor as the mean value.

The highly contaminated (> 1480 $kBq.m^{-2}$) areas closed out from the agricultural production or reduced were taken into consideration by the decreasing of the mean contamination of the soil to 93 % in spring of 1987 and to 83 % in the spring of 1988.

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II–7. SPADE — SOIL PLANT ANIMAL DYNAMIC EVALUATION

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II–7.1. GENERAL MODEL DESCRIPTION

II–7.1.1. Introduction

SPADE (*S*oil *P*lant *A*nimal *D*ynamic *E*valuation) is the name given to a suite of codes used to assess the impact of potential radioactive discharges on man through the ingestion of contaminated food. These codes have been developed for the Radiological Safety Division of the Ministry of Agriculture, Fisheries and Food (MAFF) since 1979 during which time they have been revised and improved extensively as part of an interactive process between model development and subsequent use. Since April 2000 MAFF has become the Food Standards Agency (FSA). A probabilistic version of SPADE called PRISM (PRobabilistic Improved SPADE Model) has recently been developed for MAFF/FSA. This report describes the characteristics of SPADE version 4.5.

II–7.2. MODEL CHARACTERISTICS

II–7.2.1. Capabilities

SPADE is an interactive computer model which allows the user to predict the transfer of radionuclides from the environment to agricultural foodstuffs, for a wide range of user-specified agricultural scenarios. The soil, plant and animal models are linked by a number of transfer pathways. Six types of seasons are included in SPADE and these are:

Grow, Harvest, Fallow, Plough, Winter and Cull

The first season to be specified for any scenario must be *grow*, *winter* or *fallow*. SPADE has been primarily designed to represent agricultural systems, but there is also an option in the code suite which allows limited presentations of domestic gardens and allotments. It also includes an Upland Soil Plant Animal Model (USPAM) which deals with caesium transfer in upland pastures grazed by sheep. Two soil and two plant model structures are used within SPADE, one of each for fission/activation products and for the actinide series elements. The animal model structures are element dependent and do not fall readily into sub-groups. The numbers of compartments available in SPADE are given in the table below.

Model	Number of compartments	
	Fission/activation product elements*	Actinide elements
Soil	30	20
Plant	5 or 6	14
Animal	3 to 7 for ingestion	5 or 6 for ingestion
	15 with inhalation	15 with inhalation

* there are separate models for tritium and carbon-14.

The transfer of radionuclides between compartments in the model is controlled by empirical-derived rate coefficients, and radionuclide distribution at various times is calculated by references to the compartmental contents.

II–7.2.1.1. Transfer of radionuclides in soil

For the fission/activation products, the soil model is divided into ten layers each comprising three components (soil solution, organic matter and inorganic matter). The actinide soil model is also divided into ten layers but in each layer only two components are distinguished (soil available and soil unavailable).

The soil characteristics treated in SPADE are:

- clay, sand or loam soil type;
- neutral, acid or alkaline reaction;
- waterlogged or unwaterlogged soil; and
- disturbed or undisturbed pasture soil.

Transfers from soil to plant occur via root uptake. In SPADE transfers are between soil and plant compartments in all ten soil layers; the variation in root uptake rate with depth is taken into account by using "root shape modifiers".

Loss of radionuclides from external plant surfaces to the soil is modelled as two transfers from the external leaf compartment, one to the soil solution and one to the soil organic matter compartment in the surface layer of the soil model. The rate coefficients for the two transfers are specified by a function of the two model parameters 'washoff' and 'fractional washoff to soil solution', according to the following equations:

External leaf to soil solution: $$TC_{EL,SS} = W \times F_{SS} \quad (1)$$

where:

$TC_{EL,SS}$ = transfer coefficient, external leaf to soil solution;
W = washoff; and
F_{SS} = fraction of washoff to soil solution.

External leaf to soil organic matter:

$$TC_{EL,SOM} = W \times (1.0 - F_{SS}) \quad (2)$$

where:

$TC_{EL,SOM}$ = transfer coefficient, external leaf to soil organic matter;
W = washoff; and
F_{SS} = fraction of washoff to soil solution.

Values of W and F_{SS} are element and crop type dependent, and the default values can be modified by the user. Although these parameters are named "washoff", their values include losses arising from leaf fall.

In the fission/activation plant model, the process of root uptake is modelled by the transfer of radionuclides from the soil solution to the plant root compartment. The transfer rate is assumed to vary with soil layer depth, as a function of the root distribution throughout the soil profile. Consequently the transfer of radionuclides from the soil to root is represented by ten separate transfers, one for each of the ten layers in the soil model.

The rate coefficients applied to the soil solution to root compartment transfer in each soil layer are derived as a normalised function of the root uptake transfer rate specified in the plant model. The normalised transfer coefficient for each layer is calculated by applying seven root-shape modifiers, a_1, a_2, a_3, k_1, k_3, σ and d_m. Empirically-derived default values for these root shape modifiers, for each of the crop types, are available in SPADE. During the specification of the plant model, the pre-processor displays the calculated default values of the root uptake coefficients for amendment, if necessary.

The mathematical function used to calculate the variation in root uptake with soil depth is illustrated in equation 3:

$$\lambda_i^{SS,R} = \lambda^{SS,R}\left[a_1 exp(-k_1 d) + a_2 exp\{-(d - d_m)^2/2\sigma^2\}/(2\pi)^{1/2}\sigma + a_3 exp(-k_3 d)\right] \qquad (3)$$

where:

$\lambda_i^{SS,R}$ = the rate of absorption from soil solution to root in layer i;
d = soil layer depth ($3i$ - 1.5)cm; i=soil layer index; and
$\lambda^{SS,R}$ = normalisation function.

The three exponential functions in equation 3 correspond to three plant absorption mechanisms which are responsible for the transfer of radionuclides at the soil-root interface:

Plant-base absorption: $a_2 \exp(-k_1 d)$

Main root system absorption: $a_2 \exp\{-(d-d_m)^2/2[^2\}/(2\Xi)^{1/2}[$

Tap root absorption: $a_3 \exp(-k_3 d)$

The actual value of the soil solution to root transfer coefficient for each root layer is calculated as the product of the specified rate coefficient and the (normalised) root shape modifier (equation 4).

Root shape modifier: $$RC_i = TC_{SS,R}\ x\ \lambda_i^{SS,R} \qquad (4)$$

where:

RC_i = normalised soil solution to root rate coefficient, soil layer i;
TC = transfer coefficient, soil solution to root compartment; and
$\lambda_i^{SS,R}$ = normalised root shape modifier for soil layer i, calculated from equation 3.

II–7.2.1.2. Transfer of radionuclides in plants

The crop types that are considered in SPADE are:

- leafy green vegetables;
- leafy leguminous vegetables;
- non-leafy legumes;
- non-leguminous tubers (potatoes);

- root crops (sugar beet);
- cereals; and
- fruits (herbaceous, shrub and tree).

For the fission/activation elements, plant models are represented by up to six compartments comprising root, root store, stem, internal leaf, external leaf and grain or fruit. For the actinides there are fourteen models comprising root, root store, internal plant, external plant and grain. No fruit models are available for the actinide elements.

The quantity of radionuclides reaching the above ground compartments of the plant from external (atmospheric) sources is determined according the interception fraction which takes account of changes in plant biomass with season. Depending on the model, plants or leaves are divided into external and internal components to allow particulate deposition to be distinguished from radioactive gases and vapours. Material lost from the plant by washoff is partitioned between either soil solution and organic matter, or ‘soil available’ and ‘soil unavailable’, as appropriate.

The plant models interact with external (atmospheric) inputs, the soil, and (optionally) animal models. The rate of radionuclide deposition to the plant from external (atmospheric) sources is calculated as a function of the total ground deposition rate, according to Chamberlain’s interception fraction. The interception fraction determines the quantity of radionuclides reaching the above ground compartments of the plant. The fraction of deposit intercepted is calculated as a time-dependent function for different crop types in SOPA, according to the current dry weight herbage density, and the “absorption coefficient” of the crop. Chamberlain’s equation, which is used to calculate the interception fraction for both generic fission/activation and actinide models, takes the form:

Chamberlain’s equation:
$$r = 1 - e^{-\mu W} \tag{5}$$

where:

r = interception fraction, ie proportion of deposit retained initially;
μ = “absorption coefficient” ($m^2\ kg^{-1}$ dw); and
W = dry weight herbage density ($kg\ m^{-2}$ dw).

The deposit which is intercepted by the plant is partitioned in the models between compartments representing internal and external surfaces. In the fission/activation model the partitioning is between internal and external leaf; in the actinide models it is between internal and external plant. The code user can specify the partition ratio. The default is that all radionuclides except isotopes of iodine, sulphur and tellurium are deposited exclusively on external surfaces, and that 50% of iodine, sulphur and tellurium is deposited on external surfaces and 50% on internal.

In the actinide plant models, but not the fission/activation plant models, radionuclides are also deposited on plant surfaces as a result of resuspension of soil. The transfer is from “soil unavailable” to “external plant”. The transfer rate is crop, but not radionuclide, specific, and its value can be amended by the code user.

II–7.2.1.3. Transfer of radionuclides in animals

In SPADE, radionuclide transfer in animals can be modelled for six animal types:

beef cattle, dairy cattle, sheep, pigs, goats and chickens.

SPADE predicts radionuclide concentrations in the following animal products:

Cattle:	beef, offal, milk
Sheep:	mutton/lamb, offal, milk
Pigs:	pork, bacon, offal
Goats:	meat, milk, offal
Chickens:	meat, eggs

The structure of the models for cattle, sheep and goats varies considerably for different combinations of radionucide and animal type modelled. These models deal with ingestion of pasture grass, other fodder crops, fodder, and soil associated with these. Inclusion of animal intakes of radionuclides via inhalation is an option which is available in SPADE. Radionuclide excretion from cattle, sheep and goats is represented by several pathways in the models.

The approaches used in the pig and chicken models are the same as those in the models for cattle, sheep and goats. For most radionuclides the approach in the pig and chicken models tends to lead to a simple compartmental structure because of the rather sparse data for this type of animals. Isotopes of iodine are the only radionuclides for which recirculation in the body is included.

The models for cattle, sheep and goats deal with ingestion of pasture grass, other fodder crops, fodder, and soil associated with these. Ingestion of feed containing radionuclides is represented by transfers to the upper gastro-intestinal tract compartment, from either the compartments in the plant module which represent above ground vegetation or external sources, depending on the pathway specified in the scenario. The rate of radionuclide uptake is determined differently for the two scenarios. Where the plant and animal modules are linked (by specifying a scenario involving animals grazing from pasture), the rate coefficient for the transfer is calculated according to the following equation:

$$TC_{PC,UGIT} = \frac{FI}{GA \times AGB \times 86400} \qquad (6)$$

where:

$TC_{PC,UGIT}$ = transfer coefficient, above ground plant compartments (plant model) to upper gastro-intestinal tract (animal model);

FI = forage intake rate of animal (kg/day), expressed as dry mass;

GA = grazing area (m^2), expressed per animal;

AGB = above ground biomass (kg), expressed as dry mass; and

86400 = conversion factor, days to seconds.

The variables FI and GA in equation 6 are assigned default values according to the animal type being modelled; these values are available for modification by the user in the SPADE pre-processor. Above ground biomass AGB is treated similarly, although in the case of this variable a single default value is applied for all SPADE scenarios.

In the slightly simpler case of input from external sources (eg contaminated fodder), the rate of radionuclide input into the animal model is calculated according to the user-specified concentration of radionuclide in the feed. The equation uses similar variables to those described previously, but the result is expressed as a time-dependent rate of input, rather than a transfer:

$$IR_{EX,UGIT} = \frac{FC \times FI}{GA \times 86400} \tag{7}$$

where:

$IR_{EX,UGIT}$ = input rate, external to upper gastro-intestinal tract;
FC = fodder concentration of radionuclide (Bq/kg, expressed as dry mass);
FI = fodder intake rate of animal (kg/day), expressed as dry mass;
GA = grazing area (m^2), expressed per animal; and
86400 = conversion factor.

Ingestion of soil with fodder is represented by compartmental transfers to the upper gastro-intestinal tract from each of the compartments in the surface soil layer. The rate of soil intake for a scenario comprising animals grazing on pasture is calculated according to:

$$TC_{SC,UGIT} = \frac{SI}{GA \times BD_S \times 86400} \tag{8}$$

where:

$TC_{SC,UGIT}$ = transfer coefficient, surface layer soil compartments (soil model) to upper gastro-intestinal tract (animal model);
SI = soil ingestion rate (kg/day), expressed as dry mass;
GA = grazing area (m^2), expressed per animal;l
BD_S = bulk density of top soil layer (kg/m^2), expressed as dry mass; and
86400 = conversion factor.

A typical value of soil ingestion rate (SI) for the animal modelled is given as default; this value is subsequently displayed for user amendment.

The variable GA, which is used to specify the grazing area per animal in equation 8, is identical with that described previously in equation 6. The bulk density of the top 3 cm soil layer, BD_S, is hard-coded in SPADE. It is assigned a single, representative value for all soil types of 39.0 kg m^{-2} (which corresponds to 1.3 tm^{-3}).

Radionuclide uptake from the lower gastro-intestinal tract into the blood (i.e. intestinal absorption) is represented in the animal models by a single transfer between the two compartments. The basic uptake coefficient for the transfer from lower gastro-intestinal tract to blood compartments is hard-coded in SPADE, and assigned a value of 3 per day (3.4722 10^{-5} s^{-1}). An element-specific rate modifier, f_1, is then used to set the appropriate rate coefficient for the transfer, in the following manner:

$$TC_{LGIT,BLOOD} = \frac{3.4722e-05 \times f_1}{1.0 - f_1} \qquad (9)$$

where:

$TC_{LGIT,BLOOD}$ = transfer coefficient, lower gastro-intestinal tract to blood compartments; and

f_l = transfer coefficient, lower gastro-intestinal tract to blood compartments

The default value of f_l is assigned according to element and displayed for amendment by the user, if required.

This method of determining the rate of radionuclide absorption in the lower gastro-intestinal tract is not applied when an f_l value of 1.0 is specified in the model. Under these conditions, radionuclide uptake into the blood compartment occurs directly from the upper gastro-intestinal tract. The rate coefficient for the transfer is again hard-coded, and is assigned a value of 1 per day ($1.1574\ 10^{-5} s^{-1}$) for all elements except iodine, which is preferentially absorbed. For iodine $TC_{UGIT,BLOOD}$ is 3.5 per day ($4.0509\ 10^{-5} s^{-1}$).

II–7.2.1.4. Input and output

Radionuclide inputs to SPADE are results from atmospheric dispersion calculations, measured or assumed concentrations in air (Bq m^{-3}) or fodder (Bq kg^{-1} fw) and for deposition rates (Bq m^{-2} s^{-1}) to ground. Input is written to a file with extension *'.spd'*. Output is in the form of concentrations (Bq kg^{-1} fw) or areal contents (Bq m^{-2}) in selected compartments and crop or animal products. Output is written to two files (casename.*lst* and casename.*str*).

II–7.2.2. Limitations

Limitations in the use of SPADE in predicting rates of transfer of radionuclides through terrestrial foodchains and concentrations in foods as a function of time include the following:

- only one nuclide can be selected and analysed at one time;
- only one foodstuff can be selected and analysed at one time, although offals are evaluated in the same scenarios as the associated meats;
- there is no fruit crop option for actinides;
- mushrooms are not included in the model;
- some radionuclides such as ^{125}I, ^{36}Cl, and ^{226}Ra are not included;
- once a scenario is set up, the nuclide can only be changed to another one in the same group as the original nuclide (i.e. fission activation group or actinides group).

II–7.2.3. Sensitivity analysis

A comprehensive sensitivity analysis study of the SPADE models has been carried out to highlight the most sensitive parameters that will significantly affect the model results[2]. Results of this study are reported in full in Reference 2 in both tabulated and graphical forms and will provide the SPADE user with a means of distinguishing the transfers which exert the strongest influence on the results obtained by a typical model run. The vast numbers of variable interactions within a complex model such as SPADE limit the detail with which the results may be reported here.

II–7.2.4. Testing and validation

When SPADE was updated to a test version to include a MS-Windows user interface which replaced the previous MS-DOS batch file and menu driven interface. Testing of the new SPADE GUI was undertaken by AEA Technology[3] for MAFF to supplement the development testing that had been already carried out. At the same time, AEAT studied the acceptance testing scenarios against the functionality of the code and reviewed the structure of the code to make recommendations for any changes to be made to the code. The findings of this study showed that the coding methods used by the developers of SPADE conform to modern standards of flexibility and modularity, hence any maintenance or upgrading changes made to the source code can easily be managed under an adequate system of configurational control. Recommendations were also made for continuing the improvements in SPADE to meet the demands of a modern computing environment.

One of the earlier versions of SPADE (version 2) was used in an International Co-ordinated Research Programme on the Validation of Environmental Model Predictions (VAMP) to test the validations of a number of models using Chernobyl fallout data from the Central Bohemia region of the Czech Republic[4]. The validation exercise was performed against the observations of ^{137}Cs body content and the contamination of food and fodder for a three year period following the accident. In total, 14 models were used and the majority of them (including SPADE2) exhibited a predominant tendency to overestimate observed values by up to two orders of magnitude.

II–7.2.5. Model intercomparison

In the UK there are a number of mathematical models available for predicting rates of transfer of radionuclides through terrestrial foodchains and radionuclide concentrations in foods as a function of time. The first intercomparison of UK terrestrial foodchain models was initiated by MAFF in the 1980s[6]. Subsequently, databases of parameter values of UK models have been developed and improved over a number of years and the models were used in a number of international intercomparison programmes[4,5,6].

The second intercomparison study of UK foodchain models, again initiated by MAFF, was carried out in 1995[7] using a number of test cases to compare results from SPADE, FARMLAND (developed by NRPB), NECTAR2/FOODWEB (developed by Nuclear Electric, now British Nuclear) and LANDFOOD (Developed by Wastlakes Scientific Consulting). The test cases focused on a small number of radionuclides chosen from those which tend to be radiologically important in many applications of terrestrial foodchain models: ^{35}S, ^{90}Sr, ^{129}I, ^{131}I, ^{137}Cs, ^{239}Pu and ^{241}Am. The crops considered were: leafy green vegetables, root vegetables and spring cereals. The animal products were: milk from dairy cattle, meat from beef cattle and meat from sheep. Two types of input were used: one single instantaneous unit deposit and one continuous deposit at a uniform unit rate. The intercomparison showed that there are some applications where the four models would give very different results. No one model consistently predicted higher or lower radionuclide concentrations in foods than the others. The model suite giving the highest concentration varied from radionuclide to radionuclide and agricultural product to agricultural product. Most differences in predictions of the four model suites have arisen from choices of parameter values.

II–7.2.6. Supporting R&D projects

The following R&D projects have been commissioned by the Food Standards Agency to improve SPADE:

- transfer of particles from external surfaces of plant to internal compartments;
- the effect of ^{129}I speciation on deposition and transfer to food crops;
- review of data suitable for foodchain modelling of ^{3}H, ^{14}C and ^{35}S in animals;
- development of an international radionuclide flux database;
- modelling and experimental study on the transfer of deposited radioactivity (Cs+Sr) to fruit;
- deposition of gaseous ^{3}H, ^{14}C and ^{35}S to fruit;
- parameters and sub-models for dry deposition of particulate contaminants to shrubs and fruit trees.

II–7.3. APPLICATION OF SPADE TO IPUT SCENARIO

The Iput scenario deals with a real situation of ^{137}Cs contamination of a catchment basin and agricultural area in the Bryansk Region of Russia which received the highest levels of radioactive contamination in the country resulting from the Chernobyl accident. The radioactive contamination of this area was caused by the passage of the radioactive Chernobyl cloud from 28 to 30 April 1986. Because of the high contamination levels a variety of countermeasures were implemented in this area to reduce levels of exposure to the local population. The test area combines all major exposure pathways as it comprises a large number of agricultural lands as well as forest and aquatic ecosystems. The Iput scenario provided modellers with a unique opportunity to test their models over a 10-year period (1986 to 1996) and it is the most comprehensive scenario to date based on post-Chernobyl data. Participants in this modelling exercise were asked to analyse the scenario for an assessment of ^{137}Cs transfer to man via various exposure pathways (ingestion, inhalation, cloud shine and ground exposure).

SPADE calculations started with calculation of ^{137}Cs deposition from atmosphere onto the soil surface at each of the 19 sub-areas of the test area.

II–7.3.1. Calculation of initial deposition

SPADE requires the use of deposition rates to calculate radionuclide activity concentrations in food products. For the Iput scenario, ^{137}Cs concentrations in the soil were given for the year 1991. In order to calculate deposition rates of ^{137}Cs for 1986, measured ^{137}Cs concentrations in the soil in the settlements of the test area collected on 1 October 1991 were used. These 1991 data were corrected for radioactive decay to derive deposition rates for 1986 using the equation given below. No other processes (e.g. leaching, soil fixation) were considered for this correction.

$$C_{1986} = \frac{C_{1991}(1+f)}{p_t}.1000$$

where:

C_{1986} = deposition rate (Bq m^{-2} s^{-1}) for 1986;
C_{1991} = ^{137}Cs concentrations (kBq m^{-2}) in soil for 1991 (Iput scenario);
f = fraction of activity lost due to radioactive decay between 30/04/86 and 01/10/91 (i.e. during 1977 days); and
P_t = plume passage time which took place between 28/04/86 and 30/04/86 (i.e. 259200 s).

Based on information provided in the scenario, deposition was modelled to have occurred when most crops had not yet emerged from soil to intercept ^{137}Cs fallout. In SPADE deposition was therefore modelled to occur to fallow land for leafy vegetables, potatoes and cereals.

Deposition rate was calculated for each of the 19 farms (i.e. sub-areas). Average value at each farm was used to calculate activity concentration in food products (Table II-7.1). The average activity concentration in a given food product from all 19 farms was used for comparison with test values.

TABLE II-7.1. CALCULATION OF DEPOSITION RATE FROM MEASURED ^{137}Cs CONCENTRATIONS IN THE SOIL IN THE SETTLEMENTS OF THE TEST AREA ON 1ST OCTOBER 1991

Sub-area	C_{1991} (kBq m^{-2})	C_{1986} (kBq m^{-2}) *	C_{1986} (Bq m^{-2} s^{-1})
AGRO1-1	380	414	1.60
AGRO1-2	460	501	1.93
AGRO1-3	610	665	2.57
AGRO1-4	730	796	3.07
AGRO1-5	980	1068	4.12
AGRO1-6	860	937	3.62
AGRO1-7	700	763	2.94
AGRO1-8	280	305	1.18
AGRO1-9	530	578	2.23
AGRO1-10	1700	1853	7.15
AGRO1-11	900	981	3.78
AGRO1-12	600	654	2.52
AGRO1-13	310	338	1.30
AGRO1-14	700	763	2.94
AGRO1-15	470	512	1.98
AGRO1-16	1020	1112	4.29
AGRO1-17	920	1003	3.87
AGRO1-18	420	458	1.77
AGRO1-19	910	992	3.83

* C_{1991} values corrected for radioactive decay.

II–7.3.2. Calculation of ^{137}Cs concentrations in food products

Concentrations of ^{137}Cs in food products were calculated using SPADE starting from concentrations in soil for 1986 (C_{1986}, Table II-7.1) with the exception of mushrooms. In the case of wild berries contamination densities in 15 forest areas were used. SPADE results for wild berries, however, were not corrected for yield of wild berries in the test area as these data were not given in the scenario. It is therefore possible that results for wild berries reported here may have been overestimated. Activity concentrations in mushrooms were calculated using contamination densities in forest areas and average aggregated transfer factors in IAEA Technical Reports Series No. 364 (IAEA, 1994). No calculation of concentrations in fish was made.

Parameter values used in SPADE are those specified in the scenario where appropriate. SPADE default parameter values were used when no information was given in the scenario. Crop yield data provided in the scenario were different from those used in SPADE. Results were corrected to yields of crops grown in the test area except for wild berries where no suitable data on yield was provided in the scenario. Based on information given in the scenario, the soil characteristics used in SPADE are summarised in Table II-7.2.

With the exception of fruit (wild berries), it was assumed that at the time of deposition there was no above ground biomass for leafy vegetables, potatoes and cereals to intercept the Cs fallout. In SPADE, therefore, deposition was modelled to occur during the fallow season where all activity is intercepted by the soil surface. Deposition occurred during the plume passage time between 28 April 1986 and 01 May 1986.

TABLE II-7.2. SOIL CHARACTERISTICS USED IN SPADE

Parameter	Type/value
Land type	Permanent mixed pasture
Soil type	Sandy
Organic content	Poor
pH	Low
Plough depth	20 cm
Fractional deposition to soil solution	0.75
Fractional deposition to inorganic matter	0.25

In the case of fruit and cereals, agricultural scenarios were constructed in SPADE to take account of the stage of development of the crop during which no grain/fruit is yet present. To account for this, two periods were considered during the growing season (Table II-7.3). In the first period, cesium transfer to the grain/fruit compartment in SPADE was reduced to near zero. During the second period, where grain/fruit is fully developed, default transfer values were used to simulate accumulation of activity in the grain/fruit compartment. This approach allows avoiding an overestimation of transfer of radioactivity to grain/fruit.

The loss of activity through leaf fall during the autumn season was considered for contamination of fruit. In SPADE, this was simulated by considering a harvest season during which all leaves (100%) are removed (Table II-7.3).

TABLE II-7.3. SUCCESSION OF AGRICULTURAL SEASONS USED IN SPADE

Leafy vegetable	Year	Potatoes	Year	Cereals	Year	Fruit	Year
Fallow	1	Fallow	1	Fallow	1	Fallow	1
Plough	1	Plough	1	Plough	1	Plough	1
Grow	1	Grow	1	Grow	1	Grow	1
Harvest	1	Harvest	1	Grow	1	Grow	1
Fallow	2	Fallow	2	Harvest	1	Harvest	1
				Fallow	2	Grow	2

Activity concentrations in crops predicted using SPADE were scaled up to crop yield values given in scenario (Table II-7.4).

TABLE II-7.4. YIELD VALUES OF CROPS GROWN IN TEST AREA AND THOSE AVAILABLE IN SPADE

Crop	Yield value (kg m^{-2})	
	SPADE	Scenario
Leafy vegetables	3.5	2.3
Potatoes	3	2
Cereals	0.35	0.19
Pasture (summer)	1.25	0.31
Pasture (winter)	1	0.4

In the case of animals, pasture and stable periods were considered in SPADE. Parameter values used to calculate activity concentration in milk, beef and pork are summarised in Table II-7.5 below.

TABLE II-7.5. ANIMAL PARAMETER VALUES

	Mass (kg)	Grazing area (m^2/animal)	Forage intake (kg/day)	Soil intake (kg/day)
Dairy cattle	500	1321.5	21	0.3
Beef cattle	200	1321.5	21	0.3
Pork	120	520.4	5.5	0.001

It was difficult from this scenario to know the exact composition of fodder for pork. To make this simple, pork was modelled in SPADE to be grazing on pasture in summer and fed indoors in winter on grass cut straight from pasture.

II–7.3.3. Simulating countermeasures

Agricultural lands and forest areas an with average soil concentration greater than 1480 kBq m^{-2} were taken out of production and deposition values for these lands were therefore not used in the SPADE calculations.

Like all other models used in this exercise, SPADE was not built to simulate the effect of agricultural countermeasures. However, the model is flexible and some options incorporated in it allow the user to implement the effect of such measures. For example, ploughing is included in SPADE and root uptake can be modified to allow for the effect of soil treatment. To account for the effect of agricultural countermeasures in the Iput scenario, the option for root uptake was used and the default parameter value was reduced by a factor of 2 for the year 1987. This is because the effectiveness of systematic application of chemical countermeasures is about 50% reduction in root uptake (see scenario description). This effectiveness, however, has a limited duration and lasts for one vegetation season and any new application of fertilisers do not lead to additional decrease in root uptake. Ploughing, an option that is available in SPADE, was applied every year for agricultural land (i.e. for leafy green vegetables, potatoes and cereals).

Food consumption rates before and after the accident were used as specified in the scenario to calculate ^{137}Cs intake and ingestion dose.

II–7.3.4. Calculation of ^{137}Cs intake by humans

Intake of ^{137}Cs (Bq/d) through consumption of local produce was calculated for both men and women living in the test area. This was calculated from predicted ^{137}Cs concentrations in foodstuffs obtained from SPADE. Consumption rates of local produce before and after the accident were used in the calculations. Following discussion with scenario authors and from information given in the scenario, it was assumed that real consumption rates for leafy vegetables, potatoes, meat and wild mushrooms were about 25% less than those stated in the scenario. For cereals, the intake of ^{137}Cs in 1986 was assumed to be zero as cereals from previous harvest (i.e. 1985) were consumed that year. It was assumed that 100% of "milk and dairy" consumption is milk. Meat was assumed to be 56% pork, 24% beef and 20% poultry.

Predicted intakes for men and women showed similar trends but with lower values for women due to smaller amounts of food ingested. Results compared reasonably well with test data.

II–7.4. DOSE CALCULATIONS

II–7.4.1. Ingestion dose

Calculation of ingestion dose (effective dose equivalent) was one of the most important tasks in this exercise. Ingestion doses, for adult men and women, were calculated using SPADE predictions of ^{137}Cs concentrations in local food products (except for mushrooms where a transfer factor value was used) together with data on consumption rates provided in the scenario.

Results showed that the estimated ingestion dose (cumulative values) to an average adult in the test area increased with time after the accident as shown in Table II-7.6 below.

TABLE II-7.6. ESTIMATED INGESTION DOSES (mSv)

Time period	Adult man	Adult woman
27/04/86 – 30/04/86	4.1	2.7
27/04/86 – 31/12/90	5.4	3.6
27/04/86 – 31/12/95	7.2	4.7

During the post-accidental period 1986-1990, the dominant contributor to the ingestion dose for both men and women was meat consumption. After this time period the consumption of mushrooms became the dominant contributor to the ingestion dose (Table II-7.7).

TABLE II-7.7. PRINCIPAL FOODS CONTRIBUTING TO THE HIGHEST INGESTION DOSE (mSv)

Time period	Food product	Dose to man	Dose to woman
27/04/86 – 30/04/86	Meat	2.6	1.6
	Mushrooms	0.9	0.6
	Milk	0.2	0.1
27/04/86 – 31/12/90	Meat	3.7	2.2
	Mushrooms	1.7	1.1
	Milk	0.3	0.2
27/04/86 – 31/12/95	Meat	4.3	2.6
	Mushrooms	3.0	1.9
	Milk	0.4	0.2

II–7.4.2. Inhalation dose

Inhalation dose from the passing cloud was calculated using the following equation:

$$D_{inh}(t_0, t) = DF_{inh} \cdot V_{inh} \cdot F \cdot \int_{t_0}^{t} C_{air}(\tau) d\tau$$

where:

D_{inh} = the dose from inhalation of radioactive aerosols;
DF_{inh} = dose conversion factor = 8.6×10^{-9} Sv Bq^{-1} (from Iput scenario);
V_{inh} = the breathing rate of an adult = 20 m^3 d^{-1};
F = $\sum fiFi$ (*fi* is the fraction of time spent indoors or outdoors; Fi is the shielding factor for indoors = 0.2); and
$C_{air}(\tau)$ = the average air concentration at time τ (from Iput scenario).

Occupancy ratios of 0.365 outdoors and 0.635 indoors for all workers were used *(From Scenario)*.

The estimated dose from inhalation of Cs in the initial radioactive cloud was small (0.018 mSv) and very close to the test estimate (0.013 mSv). The estimated dose from inhalation is relatively small in comparison with those from other exposure pathways and is not a significant contributor to the total dose for the local population.

II–7.4.3. Cloudshine dose

Cloudshine dose was calculated using the following equation:

$$D_{cloud}(t_0, t) = DF_{cloud} \cdot SF_{cloud} \cdot \int_{t_0}^{t} C_{air}(\tau) d\tau$$

where:

DF_{cloud} = dose conversion factor = 9.30E-11 Sv m^3 h^{-1} Bq^{-1} *(Scenario p.10)*; and
SF_{cloud} = shielding factor for indoors = 0.2.

Occupancy ratios of 0.365 outdoors and 0.635 indoors for all workers were used *(From Scenario)*.

The estimated external dose from exposure to the radioactive cloud was small (2.29×10^{-4} mSv) and very close to the test estimate (2×10^{-4} mSv). The estimated dose from cloudshine is relatively small in comparison with those from other exposure pathways and is not a significant contributor to the total dose for the local population.

II–7.4.4. Ground exposure dose

Ground deposition dose was calculated using:

$$DR_{ground}(t) = DF_{ground} \times C_{dep} \times SF \times R(t) \cdot E(t)$$

where:

DR_{ground} = the dose rate from ground shine at time t after deposition on the ground (Sv y^{-1});
C_{dep} = the initial deposition on the ground;
DF_{ground} = 1.3×10^{-12} Sv m^2 h^{-1} Bq^{-1} is dose conversion factor;
SF = 0.1 is shielding factor for indoors; SF = $\sum fiSFi$ (fi is the fraction of time spent indoors or outdoors; SF_i is the shielding factor for indoors = 0.2)
$R(t)$ = a factor taking into account radioactive decay of caesium deposited on the ground; and
$E(t)$ = a factor taking into account the decrease of groundshine due to environmental processes such as radionuclide migration deeper into the soil, weathering, leaching.

External doses from exposure to groundshine were calculated for three time intervals after the Chernobyl accident (Table II-7.8). This exposure pathway was an important contributor to the total dose received by members of the local population.

TABLE II-7.8. ESTIMATED GROUNDSHINE DOSE

Time period	Groundshine dose (mSv)
27/04/86 – 30/04/86	3.74
27/04/86 – 31/12/90	16.3
27/04/86 – 31/12/95	30.6

II–7.5. CHANGES TO EARLIER RESULTS

The first predictions made did not include the effect of countermeasures. When further discussions with participants took place and more information on the scenario was made available an attempt was made to simulate the effect of countermeasures in SPADE. Initially, this was done by reducing the root uptake by a factor of two and this was assumed to last during the whole assessment period (i.e. from 1987 to 1995). When more information on the ‘real’ implementation of countermeasures became available, and mainly because of economical and social reasons, the effect of agricultural countermeasures was simulated to last for a year after application in 1987. This is also because the effectiveness of application of chemical countermeasures is about 50% reduction in root uptake (see scenario description). This effectiveness, however, has a limited duration and lasts for one vegetation season and any new application of fertilisers does not lead to additional decrease in root uptake. Ploughing, applied as a countermeasure in the test area, was used in SPADE and applied every year for agricultural land (i.e. for leafy green vegetables, potatoes and cereals).

To calculate activity concentrations in mushrooms and wild berries, contamination densities in the 15 forest areas were used accounting for protective measures that were applied in these areas. Changes were also made to earlier results to account for differences in yield of crops between SPADE default values and scenario values. Differences in food consumption rates before and after the accident were also considered to make changes to earlier results.

II–7.6. LESSONS LEARNED

Experiences and lessons learned from this exercise are as follows:

(1) A model is generally built for a particular purpose but it is important that the model is flexible so that it can simulate a wide range of scenarios. Modellers need to bear this in mind when developing models.

(2) When data are incomplete and/or information is missing subjective judgement by the modeller is inevitable and this will lead to uncertainties in the assessment.

(3) Both the model and modellers play an important part in the assessment. The modeller needs to be very familiar with the model and aware of its capabilities and limitations. The model on the other hand needs to be transparent, robust and flexible.

(4) SPADE is a complex model and performed well in this scenario but this does not necessarily mean that performance of a model is related to its complexity. Simple models can perform as well as complex ones or even better.

(5) Although SPADE performed well for this scenario it may not automatically perform well for other scenarios with different radionuclides and environmental conditions.

(6) Not all data or information provided in scenario is necessarily useful to the modeller. The latter needs to assess the suitability of data for the model or methodology used. For example, the modeller may chose to use deposition data to run the model and ignore data on air concentration, rainfall, meteorological conditions etc. Different models often have different starting points. Some data supplied in the scenario may be of no use to the modeller because the model being used does not include the relevant processes (e.g. ploughing). In some cases, the modeller may need to convert some data to a suitable format for use in the model (e.g. averaging of data).

(7) Radiological assessments such as dose reconstruction are better performed by more than one modeller because of the benefit of discussions on interpretation of data and the sharing of knowledge and expertise.

(8) Current models are not designed to simulate the implementation of countermeasures and the modeller needs to be aware of the implications that this has on the final results. In this case the modeller can make subjective judgement to take account of countermeasures. This will lead to uncertainties in the final results. Sources of uncertainties also include the model, the scenario and the modeller.

II–7.7. CONCLUSIONS

Using independent real data provided a valuable means for testing SPADE. In comparison with the test data, SPADE has performed well in calculating ^{137}Cs concentrations in foodstuffs and this gives more confidence in its fitness for use in radiological assessments. Using agricultural characteristics of the Iput scenario, SPADE proved to be flexible for use in modelling agricultural conditions other than those in the UK.

This exercise has provided a unique opportunity for participants to exchange knowledge and expertise in radiological assessment methods. The Iput scenario in particular has provided modellers with a unique opportunity to gain experience in interpreting the implementation of agricultural countermeasures and modelling their effectiveness. This exercise has revealed the uncertainties due to subjective judgement made by modellers in considering the effect of countermeasures and the difficulties in simulating them in current models. It has also revealed uncertainties concerning the ‘real’ implementation of countermeasures which may vary depending on economical and social reasons.

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II–8. ECOMOD MODEL

Evaluation of ECOMOD Model performance for the Scenario “Iput”, SPA “Typhoon”, Obninsk, Kaluga Region, Russian Federation

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II–8.1. GENERAL MODEL DESCRIPTION

II–8.1.1. Name of model and model users

Model name: ECOMOD
Model users: SPA “Typhoon”, Obninsk, Kaluga region, Russia

II–8.1.2. Important model characteristics

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.

Two versions of the ECOMOD model have been developed:

(a) radionuclide transfer in terrestrial food chains – submodel ECOMOD-T;

(b) radionuclide transfer in aquatic food chains –submodel ECOMOD-W.

II–8.1.3. Past experiences using ECOMOD model

The first version of ECOMOD-W model was developed in 1985 to simulate the impact of the Leningrad NPP on the cooling coastal waters of the Kopora bay of the Gulf of Finland.

The modified ECOMOD-W model was used to assess the radioecological situation in the cooling pond of the Chernobyl NPP in 1986–1997 (under BIOMOVS II programme).

The “terrestrial” version of the model ECOMOD-T in a simplified form was used for the radiation assessment in the area of the Leningrad NPP in the early period after the Chernobyl accident.

The ECOMOD model (both terrestrial and aquatic submodels) has been used for calculations on Scenario S under the VAMP programme (1994–1996).

II–8.1.4. Modifications made for this scenario

For scenario I the ECOMOD model was modified and adapted with consideration for local agricultural and climatic characteristics, as well as for the countermeasures taken and their effectiveness.

II–8.2. CALCULATIONS OF CONTAMINATION OF TERRESTRIAL VEGETATION AND AGRICULTURAL PRODUCE, USING ECOMOD-T MODEL

The starting point for the calculations was the density of fallout which was estimated in accordance with Table I.III of the Scenario description. The distribution of agricultural subareas by contamination density was taken from Table I.XLI of the Scenario description.

Grass contamination consisted of three components: direct contamination in the course of fallout, secondary surface contamination due to resuspension of nuclides from the soil surface, and root intake.

Part of the radioactivity intercepted by grass at the instant of fallout, R, was estimated depending on the biomass of grass with the following formula:

$$R = \frac{Y}{K + Y}$$

where:

Y = the biomass of grass, g/m^2;
K = the half-saturation factor equal to the biomass of grass, at which $R = 0.5$.

This factor is calculated on the assumption that at the value of the biomass of grass at the time of its harvesting $R = 1$.

A seasonal dynamics of the grass biomass growth was calculated with the following formula:

$$\frac{dY}{dt} = a \cdot SOL(t) \cdot \exp(0.065 \cdot T) - \varepsilon \cdot Y$$

where:

$SOL(t)$ = the diurnal energy of photosynthetically active solar radiation at a given latitude, kcal/cm^{2}day;
t = the time since the beginning of the year, days;
T = is the air temperature, °C;
α = the growth factor; and
ε = the metabolic loss factor.

The exponent accounts for the growth acceleration with increasing temperature (in accordance with the Arrhenius law). The factors α and ε can be determined from the initial and finite values of the biomass of grass and the time of the beginning of its vegetation and harvesting (Table I.XXXI of the Scenario Description).

Direct contamination of grass due to fallout was calculated with the following formula:

$$T_s = R \cdot A \cdot \exp(-(\lambda_r + \lambda_w)t)$$

where:

A = the density of fallout, Bq/m^2;
λ_r = the radioactive decay constant; and
λ_w = the radionuclide loss constant due to external factors, such as washout and blowout.

The value of λ_w was taken to be equal to 0.05, which corresponds to a half-period of two weeks.

To take into account resuspension and root intake of radionuclides, we used soil-to- plant transfer coefficients (SPTC):

$$C_{in} = SPTC \cdot A$$

Table II-8.1 presents the values of transfer coefficients for different plants, which were used in the model.

To calculate specific activities of ^{137}Cs in beef and milk, we used the following set of equations:

$$\frac{dC_b}{dt} = \frac{F_b \alpha \cdot I_c(t)}{m_c} - \lambda_b C_b$$

$$\frac{dC_m}{dt} = \frac{F_m \alpha \cdot I_c(t)}{m_m} - \lambda_m C_m$$

where:

C_b = the activity of ^{137}Cs in beef, Bq/kg;
C_m = the activity in milk, Bq/L;
$\alpha = 0.2$ = the coefficient of food bioassimilation by a cow, $F_b + F_m = 1$;
m_c = the mass of a cow;
m_m = the daily milk yield; and
λ_m and λ_b = the coefficients of self-purification of milk and beef, respectively.

The coefficients of self-purification were determined on condition that at equilibrium the activity in beef accounted for 5.5 % of the intake and the activity in milk accounted for 1 % of the intake. The numerical values of the coefficients are given in Table II-82.

TABLE II-8.1. SOIL-TO-PLANT TRANSFER COEFFICIENTS OF ^{137}CS, USED FOR CALCULATIONS ON THE SCENARIO I. TYPE OF SOIL- SODDY-PODZOLIC

Type of plant	Transfer coefficient (Bq/kg)/(kBq/m^2)
Grass	7.5
Leafy vegetables	1.0
Potato	0.2
Cereals	1.4
Maize	0.7

TABLE II-8.2. PARAMETERS AND VALUES FOR ^{137}CS TRANSFER TO MILK AND BEEF

Parameter of the model		Value
α	The coefficient of food bioassimilation by a cow	0.2
F_b,F_m	Beef and milk partition coefficients of ^{137}Cs:	
	bull	F_b=1, F_m=0
	dairy cow	F_b=0.65, F_m=0.35
m_b	the mass of a bull calve	200 kg
m_c	the mass of a dairy cow	500 kg
m_m	daily milk yield	6 L/day
λ_b	the coefficient of self-purification of beef	0.018 day^{-1}
m_p	the mass of a pig	10 – 100 kg
λ_p	the coefficient of self-purification of pork	1.7/m_p day^{-1}
λ_m	the coefficient of self-purification of milk	1 day^{-1}

To calculate specific activities of ^{137}Cs in pork, we used the equation:

$$\frac{dC_p}{dt} = \frac{F_p \alpha \cdot I_c(t)}{m_p} - \lambda_p C_p$$

where:

C_p = the activity of ^{137}Cs in pork, Bq/kg;
$\alpha = 0.2$ = the coefficient of food bioassimilation by a pig, F_p =1;
m_p = the mass of a pig (varied from 10 to 100 kg, from March to December); and
λ_p = the coefficient of self-purification of pork.

The intake of a radionuclide to the organism of an animal with food, $I_c(t)$, was determined with the following formula:

$$I_c(t) = \sum_{i=1}^{n} C_i m_i + C_s m_s$$

where:

C_i = the activity of ^{137}Cs in beef, Bq/kg;
m_i = the consumption of the *i*th component of food by a cow, kg/day;
C_s = the activity in the uppermost soil layer, Bq/kg; and
m_s = is the soil mass swallowed by a cow, while grazing on pasture (0.3 kg/day for pasture period).

Daily rations of cows in the summer and winter periods were taken from Table I.XXXV of the Scenario description.

To take into account countermeasures, we used the information given in par. I.1.3.5 of the Scenario description, its Tables I.LIV,- I.LV, I.LVIII, and Table I.LIX where the distribution of agricultural subareas by contamination density is given. No countermeasures were taken for areas contaminated below 185 kBq/m^2, whereas for areas with a contamination density from 185 to 555 kBq/m^2 simplified improvement and amelioration of meadows were performed. The effectiveness of countermeasures according to Table I.LV of the scenario description was estimated to 1.3±0.2.

For areas with contamination density from 555 to 1480 kBq/m^2 ploughing, liming, and application of mineral fertilizers were conducted. In this case, the effectiveness of the countermeasures was estimated to 2±0.5.

In 1987, 40 % of lands contaminated over 1480 kBq/m^2 were taken out of agricultural production and in 1988, 100 % of lands with this contamination density were taken out of agricultural production.

References describing detailed documentation of model

KRYSHEV, I.I., SAZYKINA, T.G., Simulation models of ecosystem's dynamics under unthropogenic impact of thermal and nuclear power plants, Moscow: Energoatomizdat.; 184 PP.(Monograph, in Russian) (1990).

ALEKSEEV, V.V., KRYSHEV, I.I., SAZYKINA T.G., Physical and Mathematical Modelling of Ecosystems, St.-Petersburg: Hydrometeoizdat; 367 PP.(Monograph, in Russian) (1992).

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SAZYKINA, T.G., ECOMOD – An Ecological Approach to Radioecological Modeling, Journal of Environmental Radioactivity, **50** (2000) 207–220.

II–9. LINDOZ MODEL

Description of LINDOZ model for “IPUT” scenario

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II–9.1. GENERAL MODEL DESCRIPTION

LINDOZ model was developed after the Chernobyl accident as a dynamic compartmental radiological assessment model. It was initially calibrated with local data from Romania, then compared with Chernobyl data in BIOMOVS I (Scenario A4) and further upgraded and used in VAMP and BIOMOVS II. In 1994, the VAMP version of LINDOZ was used for the initial IPUT scenario. This version is presented here, as it was used in 1994. The reader should understand that much more information on the IPUT site and Chernobyl characteristics became available in the mean time, but it was not included in a new calculation.

LINDOZ model consists of a number of modules that compute contamination of crops, pasture grasses, animal products, fish, mushrooms, and estimate the body burden. The model explicitly includes the physical-chemical form of deposition, the foliar absorption, the translocation in plant and the growth dilution.

For the model version used for IPUT scenario (1994), the deposition in the area was estimated from an assessed air concentration, precipitation, Activity Aerodynamic Median Diameter (AMAD) of particulate, wind velocity at 10 m (U_{10}) and washout fraction, together with Leaf Area Index (LAI) of plants. For the average deposition in IPUT area, we considered the ground to be covered by grass.

Dry deposition is modeled semi-empirically. The dry deposition velocity is:

$$V_d = \left(7.77 * \left(1.24 * \text{AMAD}^2\right) * \left(U_{10} / 4\right)^{1.07} * \text{LAI}^{0.33}\right) / 24 \text{ [in m/h]} \tag{1}$$

For IPUT conditions AMAD was taken to be 5.5 micron and U_{10}=4 m/s. The dry deposition [Bq/m^2] is calculated as

$$C_a[\text{Bq/m}^3] * V_d[\text{m/h}] * \text{time[h]} \tag{2a}$$

Wet deposition [Bq/m^2] is modeled using a washout factor (*wash*) and the rain intensity *R* [mm or m] as

$$C_a[\text{Bq/m}^3] * R[\text{m}] * wash[\text{unitless}] \tag{2b}$$

The dry interception fraction R_{DRY} on pasture is given by:

$$R_{DRY} = 0.9 * \left(1 - \exp(-2.3 * Y)\right) \tag{3}$$

where *Y* is the pasture yield at time of deposition.

For crops, the dry interception fraction is LAI*RM, where RM is a crop dependent parameter (0.09 for cereals, 0.19 for maize, 0.12 for potatoes, and 0.5 for apple trees.) The dry interception is increased by a fruit (or crop) interception fraction increasing from zero at fruit start to a maximum value RETFM at harvest. For IPUT scenario, RETFM is 0.15 for winter wheat, 0.2 for barley and rye, 0.01 for maize, 0.0 for potatoes and 0.05 for apple.

Wet interception is modeled as in ECOSYS model (Müller and Pröhl, 1993).

$$R_{wet} = \frac{LAI \cdot R_{RAIN}}{R} \cdot \left[1 - \exp\left(\frac{-\ln 2}{3 \cdot R_{RAIN}} R \right) \right] \qquad (4)$$

The interception parameter R_{RAIN} is 0.2 mm, and R is rain intensity (in mm).

The dry and wet deposition on crops and soil is divided into a soluble and an insoluble fraction. For the IPUT scenario, the soluble fraction of fallout is SOLUB=0.5.

II–9.2. LINDOZ SUBMODEL FOR CROPS

For crops, LINDOZ model has the following compartments (Figure II-9.1):

(1) Soluble deposition on surface soil;

(2) Soluble deposition in root soil;

(3) Soluble deposition on external plant;

(4) Soluble deposition on internal plant;

(5) Soluble deposition on external fruit (grain);

(6) Soluble deposition on internal fruit;

(7) Soluble internal compartment (potato tuber or trunk for fruit-tree);

(8) Insoluble contamination of soil;

(9) Insoluble deposition on external plant;

(10) Insoluble deposition on external fruit.

The soluble component on external plant or external fruit is subject to weathering rate (C31, C51) and to foliar absorption rate (C34, C56). From the internal plant we have the translocation rate to fruit (C46) or to tuber (trunk; C47). C47 is zero for cereals and maize.

From the soluble soil compartments 1 and 2, we have the root absorption to internal plant (C14 and C24) and migration down (C12 and C2D). A fixation rate CFIX removes the soluble deposition from the soil compartment 1 and 2 to the insoluble soil (compartment 8 and a sink for root soil). A resuspension and rain splash rate C13 moves the soluble surface deposition from soil to external plant. The resuspension rate to the edible plant part is less by a fraction FRAC (as generally the ear is higher in position)

For potato, compartment 7 is tuber and we have a transfer from soil to tuber (C17 and C27). For apple-tree, compartment 7 is the trunk, and we have a translocation rate from internal leaf (comp 4) to trunk C47, a translocation from trunk to leaf C74 and from trunk to fruit C76 as well as a fixation rate in trunk C77.

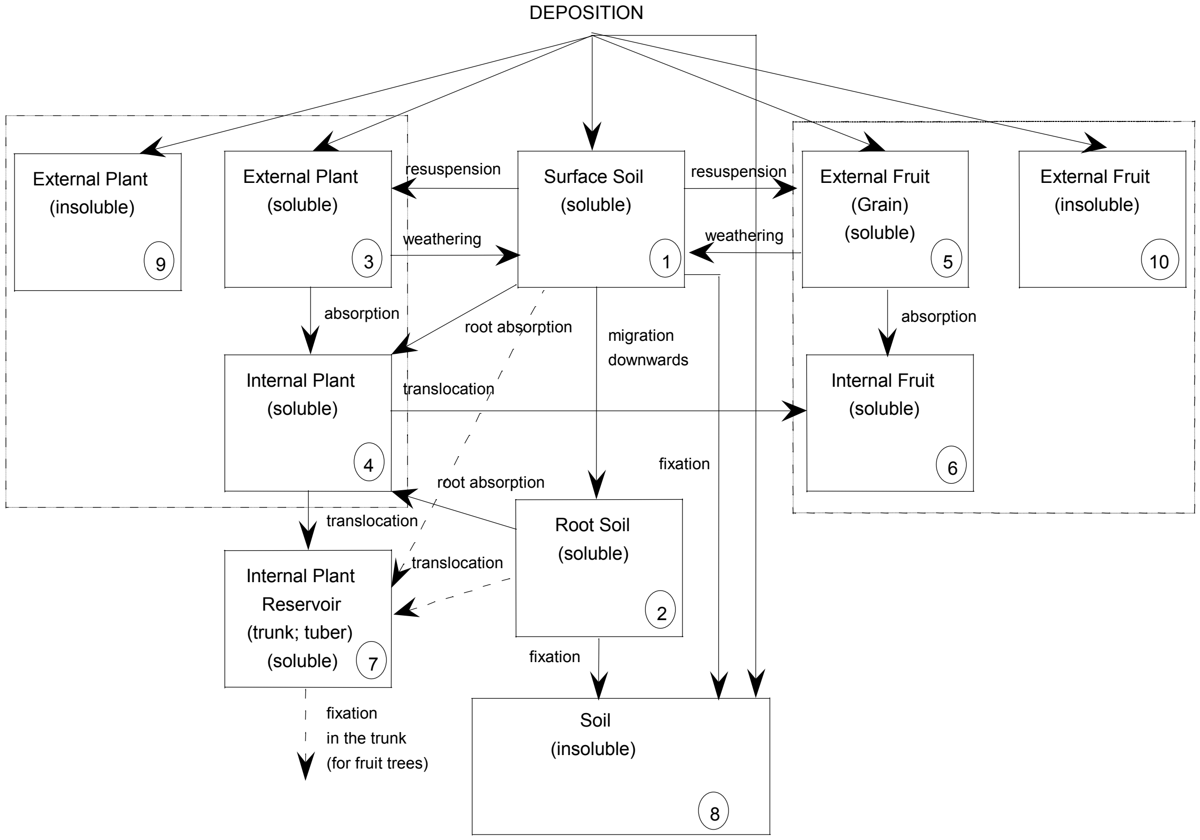

FIG. II-9.1. A schematic of the LINDOZ compartmental model for crops.

The crop model needs the time dependence of LAI and yield (dry and fresh), given in the input file, as well as the harvest index FRCOM. Also, the Julian day of emergence (TCI), harvest (TCH), start fruit (ear, tuber) formation (TCF), and maturity (TCM) are given, depending on location condition.

Winter rye is typical example for cereals, in general. The parameters for other crops are not very different from the parameters for winter rye, which are presented in Tables II-9.1 through II-9.4 for Cs-137.

TABLE II-9.1. LINDOZ CROP SUBMODEL PARAMETERS FOR WINTER RYE (FOR CS-137)

Parameter	Value	Units
RM	0.09	unitless
R_{RAIN}	0.2	m
RETFM	0.2	unitless
FRAC	0.05	unitless
FRCOM	0.3	unitless
TCI	265	Julian days
TCH	225	Julian days
TCF	165	Julian days
TCM	200	Julian days

TABLE II-9.2. WINTER RYE CROP YIELD USED IN LINDOZ MODEL

Julian Day	$Y_{\text{dry mass}}$ [kg/m^2]	$Y_{\text{fresh mass}}$ [kg/m^2]
0	0.00	0.00
40	0.20	0.80
230	0.10	0.80
260	0.80	3.00
295	1.00	2.30
325	1.00	1.50

TABLE II-9.3. LEAF AREA INDEX (LAI) FOR WINTER RYE

Days after emergence	Leaf Area Index (LAI) (unitless)
0	0.0
40	1.0
230	0.5
260	5.0
295	3.0
325	1.5

TABLE II-9.4. TRANSFER RATES [1/day] FOR THE LINDOZ CROP SUBMODEL. VALUES ARE FOR TRANSFER OF CESIUM IN WINTER RYE

Rate	Value	Rate	Value	Rate	Value	Rate	Value
C12	6.6×10^{-5}	C2D	3.3×10^{-6}	C13	3.0×10^{-4}	C31	7.5×10^{-2}
C14	2.0×10^{-5}	C24	4.0×10^{-4}	C17	$0.0 \times 10^{+0}$	C27	$0.0 \times 10^{+0}$
C34	2.0×10^{-2}	C46	6.0×10^{-3}	C47	$0.0 \times 10^{+0}$	Cfix	2.8×10^{-4}
Clos	1.4×10^{-1}	C74	$0.0 \times 10^{+0}$	C76	$0.0 \times 10^{+0}$	C77	$0.0 \times 10^{+0}$

II–9.3. LINDOZ PASTURE-FEED-ANIMAL SUBMODEL

In the pasture-feed-animal submodel we distinguish again between soluble and insoluble fallout on surface soil and external plant and we model the foliar absorption (at a rate of 0.005 d^{-1}).

PASTURE-FEED-ANIMAL submodel compartments:

(1) surface soil, soluble fallout (0-1 cm depth);

(2) root soil I, soluble (1-5 cm);

(3) root soil I, soluble (5-15 cm);

(4) external pasture, soluble deposition;

(5) internal pasture (always soluble);

(6) cow milk I, fast transfer;

(7) beef I, fast transfer;

(8) beef II, slow transfer

(9) sheep milk;

(10) sheep meat;

(11) chicken meat;

(12) pork meat;

(13) external pasture insoluble deposition;

(14) surface soil, insoluble deposition;

(15) cow milk II, slow transfer.

TRANSFER RATES (1/day):

C12	surface soil → root soil I
C14	resuspension
C15	surface soil →internal plant
C25	root soil I→internal plant
C23	root soil I→root soil II (migration)
C3D	root soil II→ deep soil (migration)
C35	root soil II→ internal plant
C41	weathering (from soluble and insoluble external plant)
C45	foliar absorption (from external to internal plant)
CRD	radioactive decay
C44	grazing loss
C46	transfer rate feed→cow milk I (per L)
C415	transfer rate feed→cow milk II (per L)
C49	transfer rate feed→sheep milk
C47	transfer rate feed→beef meat I (per kg)
C48	transfer rate feed→beef meat II (per kg)
C410	transfer rate feed→sheep meat (per kg)
C411	transfer rate feed→chicken meat (per kg)
C412	transfer rate feed→pork meat (per kg)
C66	cow milk loss rate I
C1515	cow milk loss rate II
C99	sheep milk loss rate
C77	beef meat loss rate I
C88	beef meat loss rate II
C1010	sheep meat loss rate
C1111	chicken meat loss rate
C1212	pork meat loss rate
CFIX	soil fixation rate
CFE	recycling rate (grass-cow-soil)

Other model parameters:

TPI	start grass growing
TPAST	start grazing season
TSTAB	start stabulation season
YD	dry yield grass (kg/m^2)
FW	dry/wet ratio of masses for grass
RM	retention parameter

QV	dry matter intake for cows (kg/d)
QO	dry matter intake for sheep (kg/d)
QSOL	percent soil intake
DENS	soil density
FP	intake fraction from pasture
FG, FB, FS	intake fraction from other feed (relative to 1-FP), in pasture season
FFS, FGS, FSS, FBS	intake fraction of hay and other feed in stabulation
FPAP, FPAS, FPAB	hen feed intake parameters
FPOP, FPOS, FPOB	pork feed intake parameters

FEED concentration other than pasture and hay is given externally as a time array (i.e. HF, HS, HB).

The yield of grass or hay during the vegetation period is described by a logistic model:

$$Y=YD/(1+(YD/YMI-1)*EXP(-RINT)) \tag{5}$$

where:

YMI = the minimum yield (0.05 $kg_{dry\ mass}/m^2$);
YD = the maximum (potential) yield (0.25 $kg_{dry\ mass}/m^2$); and
RINT = a growth rate, which depends on the day in the vegetation period (Table II-9.5).

Multiple harvests are allowed for pasture grass (NHVP=2 in this example). They take place at specified Julian days (THVP=165 and 205). The amount harvested is given for each harvest (YPHVP = 0.15 $kg_{dry\ mass}/m^2$ and 0.10 $kg_{dry\ mass}/m^2$, respectively).

TABLE II-9.5. THE TIME-DEPENDENT GROWTH RATE FOR THE LOGISTIC MODEL DESCRIBING THE YIELD OF GRASS AND HAY

Julian day	20	36	60	120	190
RINT	0.04	0.08	0.05	0.02	0.06

The following main characteristics of Iput River area were used to choose the parameter values. The soil is turf podzolic sandy loam with a reduced acidity (pH = 5.8), low potassium, and moderate amounts of Ca. The area is a low land field located in a Central-Northern climate (52° N latitude). The site-specific parameters of the LINDOZ pasture-feed-model submodel are presented in Tables II-9.6 and II-9.7.

TABLE II-9.6. PARAMETERS USED IN THE PASTURE-FEED-ANIMAL MODEL. THE PARAMETERS ARE SPECIFIC FOR CESIUM AND FOR IPUT RIVER REGION

Name	Value	Name	Value	Name	Value	Name	Value
TPI	100	TPAST	125	TSTAB	288	YD	0.25
YMI	0.05	FW	0.20	RM	2.30		
QSOL	0.04	QV	12.0	QO	2.50	DENS	1300
FP	0.75	FG	0.00	FB	0.99	FS	0.00
FFS	0.33	FGS	0.16	FSS	0.33	FBS	0.17
FPAP	0.00	FPAS	0.00	FPAB	0.096		
FPOP	0.00	FPOS	0.00	FPOB	2.00		
NHVP	2.00	THVP	165	YDHVP	0.15		
		THVP	205	YDHVP	0.10		

TABLE II-9.7. TRANSFER RATES (1/DAY) USED IN THE LINDOZ PASTURE-FEED-ANIMAL SUBMODEL FOR THE IPUT RIVER SCENARIO

Rate	Value	Rate	Value	Rate	Value	Rate	Value
C12	0.330×10^{-3}	C14	3.000×10^{-5}	C15	0.750×10^{-3}		
C23	0.100×10^{-3}	C25	1.200×10^{-4}	C3D	0.500×10^{-4}	C35	0.500×10^{-4}
C41	$0.050 \times 10^{+0}$	C44	$0.007 \times 10^{+0}$	C46	2.400×10^{-3}	C66	$0.480 \times 10^{+0}$
C47	2.508×10^{-4}	C77	$0.152 \times 10^{+0}$	C48	0.280×10^{-3}	C88	$0.019 \times 10^{+0}$
C49	1.800×10^{-2}	C99	$0.310 \times 10^{+0}$	C410	6.000×10^{-3}	C1010	$0.020 \times 10^{+0}$
CRD1	9.216×10^{-4}	CRD2	0.533×10^{-1}	CRD3	6.328×10^{-5}	CFIX	0.028×10^{-2}
C45	0.500×10^{-2}	CFE	0.200×10^{-1}	CINH	$0.480 \times 10^{+0}$	CEG	$0.430 \times 10^{+0}$
C411	$0.205 \times 10^{+0}$	C111	$0.046 \times 10^{+0}$	C412	$0.007 \times 10^{+0}$	C1212	$0.023 \times 10^{+0}$
C415	0.800×10^{-4}	C1515	0.040×10^{-0}				

The pasture-feed-animal submodel is more elaborate than the crop model and most of the parameters have been carefully chosen for the IPUT region. Feed intake was taken from the scenario and the consumption of straw was included. The vegetation period was determined from the monthly temperature.

The assessed deposition is lower than the estimated, due to underestimation of rain, or due to transport after May 6. We used a rain intensity of 1 mm, while, from the most recent scenario description, it seems that there was more rain in adjacent regions.

The transfer from soil to grass was determined considering the A-bomb fallout data (Marei A.N.; Health Physics 22(9) 1972) and other more recent sources of information (Prister B.; The Science of the Total Environment 112(79) 1992.) Transfer coefficients, defined for each soil type, have been averaged (based on fraction of each soil type in each area, and the fraction of each area in the entire region). For a uniform and fully soluble contamination of 0–10 cm of pasture soil, the transfer factor for grass is 0.63. The effective transfer to grass depends also on the initial soluble fraction and migration rates. The potential transfer factor for cereals is 0.3 and for potato is 0.1.

The soluble fraction in the fallout was chosen to be 0.5, intermediate between values from close and far regions, as reported in literature. Fixation rate in soil was kept the same as for the S scenario in VAMP, and is not adapted to IPUT area. Our value of 0.1 y^{-1} applies for the soluble fraction. The insoluble fraction of fallout deposited on plant is not bioavailable. As a consequence, it is not transferred to milk or meat. Our transfer rates (and implicitly the transfer factors) refer to the fully soluble contaminant and are assessed consequently. The transfer factor to cow's milk is 0.007, beef 0.016 and to pork is 0.32.

The results for IPUT scenario, included in this document, are those obtained in May 1994, and the description presented above is for the 1994 version of the LINDOZ model. No new calculations were done in the mean time. When time and budget will permit, new calculations will be done, starting with the most recent scenario description and using all submodules of the LINDOZ model (vegetables, mushrooms, fish, human intake and body burden, internal and external dose).

ANNEX III

SUMMARY OF MODEL PREDICTIONS

The tables in this Annex contain the final predictions submitted for each endpoint by the participants in the exercise. The observations or authors' estimates are included as appropriate. The columns in the tables labelled "lower" and "upper" refer to the 95% confidence intervals on observations or authors' estimates or to the 95% subjective confidence intervals on model predictions.

TABLE III-I. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN LEAFY VEGETABLES (Bq kg^{-1} FRESH WEIGHT)

	Observed	lower	upper	LIETDOS	lower	upper	RADCON	lower	upper	TAMDYN-UV	lower	upper
June 1986										343	42	1910
July 1986	607	466	748	483	170	1020	593	61	5740	249	31	1190
August 1986										369	36	2030
1987	270	194	346	261	91	552	97	10	948	158	23	640
1988	170	113	227	207	72	437	76	8	708	97	14	337
1989	179	140	217	169	59	358	77	9	686	70	13	229
1990	117	87	148	143	50	304	67	7	597	95	17	585
1991	70	56	84	125	44	265	59	6	557	119	17	737
1992	58	48	68	113	39	238	54	6	516	73	18	255
1993	45	35	54	103	36	219	49	5	441	99	17	411
1994	31	24	38	97	34	205	42	5	388	60	14	195
1995	66	45	88	92	32	194	38	4	362	97	17	496
1996	55	46	64	88	31	186	34	3	347			

	CLRP	lower	upper	SPADE	lower	upper	OSCAAR	lower	upper	ECOMOD	lower	upper
June 1986	3410	1420	8180	87.9	73.2	102.7	222	159	285			
July 1986	347	145	832									
August 1986	295	123	707							15000	6800	23200
1987	81	34	194	27.2	22.7	31.8	179	134	223	410	160	660
1988	65	27	157	32.2	26.8	37.6	134	97	171	310	120	500
1989	53	22	127	18.8	15.7	22.0	163	117	209	230	90	370
1990	43	18	104	10.9	9.1	12.7	148	107	189	180	100	260
1991	35	15	85	6.3	5.2	7.3	199	138	260	130	50	210
1992	29	12	70	3.7	3.1	4.3	178	124	232	100	45	165
1993	24	10	58	2.2	1.8	2.6	160	111	208	85	30	140
1994	20	8	49	1.4	1.2	1.7	143	99	186	85	30	140
1995	17	7	41	1.0	0.8	1.1	128	89	167	85	30	140
1996				0.7	0.6	0.8	114	80	149			

TABLE III-II. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN POTATOES (Bq kg^{-1} FRESH WEIGHT)

	Observed	lower	upper	LIETDOS	lower	upper	RADCON	lower	upper	TAMDYN-UV	lower	upper
1986	256	187	326	54	26	96	581	132	2554	1600	280	4820
1987	156	127	185	37	14	76	82	19	360	101	33	305
1988	119	99	140	29	11	60	76	18	330	92	32	239
1989	98	69	126	24	9	49	69	14	333	86	19	236
1990	93	73	114	20	8	42	61	14	269	76	17	191
1991	75	66	84	18	7	37	54	11	256	82	18	263
1992	73	48	97	16	6	33	46	10	213	71	16	182
1993	34	28	39	15	5	30	43	9	195	74	17	201
1994	29	26	32	14	5	29	39	8	186	61	16	179
1995	51	39	63	13	5	27	34	8	152	60	15	175
1996	40	32	47	13	5	26	31	7	144			

	CLRP	lower	upper	SPADE	lower	upper	SENES	lower	upper	ECOMOD	lower	upper
1986	259	108	622	290.2	241.6	338.8	375	32	3423	150	30	270
1987	47	20	113	86.7	72.2	101.2	225	19	1926	90	20	160
1988	35	15	84	101.1	84.2	118.1	190	18	1730	70	10	130
1989	29	12	70	59.0	49.2	68.9	155	14	1429	45	9	80
1990	26	11	63	34.0	28.3	39.7	130	13	1273	35	7	60
1991	24	10	58	19.6	16.4	22.9	107	10	984	32	6	60
1992	22	9	53	11.6	9.6	13.5	70	6.8	636	26	5	45
1993	21	9	50	7.0	5.8	8.1	57	5.5	482	17	5	29
1994	19	8	46	4.5	3.7	5.2	53	4.5	428	17	5	29
1995	18	8	43	3.0	2.5	3.5	42	3.8	344	17	5	29
1996				2.2	1.8	2.6						

	LINDOZ	OSCAAR	lower	upper
1986	364.0	154	110	198
1987	223.4	123	93	154
1988	195.5	92	68	117
1989	171.0	113	81	144
1990	149.6	102	73	130
1991	130.9	140	97	182
1992	114.6	125	87	163
1993		112	78	146
1994		101	70	131
1995		90	63	118
1996		81	56	105

TABLE III-III. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN CEREALS (Bq kg^{-1})

	Observed			LIETDOS			RADCON		
		lower	upper	rye	lower	upper	winter wheat	lower	upper
1986	670	568	772	949	364	1917	1136	96	13390
1987	468	331	605	378	130	807	118	7	2019
1988	434	208	660	297	102	634	111	7	1797
1989	195	131	260	242	83	516	98	6	1611
1990	82	50	115	203	70	434	92	6	1467
1991	39	32	45	176	61	376	80	5	1194
1992	33	30	37	157	54	336	71	4	1168
1993	25	20	31	144	50	307	64	4	1041
1994	38	33	42	134	46	286	57	3	993
1995	63	57	68	127	44	271	46	3	743
1996	56	47	64	121	42	259	44	2	770

	TAMDYN-UV	lower	upper	CLRP	lower	upper	SPADE	lower	upper
1986	7800	2770	19300	843	430	1650	1825.1	1519.5	2130.6
1987	126	34.1	350	71	36	140	476.5	396.8	556.3
1988	105	30.6	247	53	27	104	507.0	422.1	591.8
1989	111	36	287	45	23	87	257.5	214.4	300.7
1990	102	36	221	40	20	78	131.8	109.7	153.9
1991	97	27	231	37	19	72	67.9	56.6	79.3
1992	95	29	203	34	17	66	36.5	30.4	42.6
1993	89	28	214	31	16	62	20.5	17.1	23.9
1994	86	25	189	29	15	58	12.7	10.6	14.8
1995	87	26	215	27	14	54	9.0	7.5	10.5
1996							7.1	5.9	8.3

	SENES - wheat	lower	upper	OSCAAR	lower	upper	LINDOZ	ECOMOD	lower	upper
1986	354	39	3320	3882	2170	5593	2000	1550	700	2400
1987	294	32	2758	104.6	77.2	131.9	360	570	230	910
1988	204	22	1909	78.2	56.8	99.6	320	430	170	690
1989	156	17	1463	95.4	67.2	123.7	260	340	140	540
1990	120	13	1129	86.0	60.7	111.4	230	250	100	400
1991	93	10	875	117.4	79.6	155.2	200	190	80	300
1992	78	9	727	105.4	71.4	139.3	180	140	50	230
1993	64	7.1	604	94.6	64.1	125.0		120	40	200
1994	53	5.9	501	84.9	57.5	112.2		120	40	200
1995	44	4.9	416	76.2	51.6	100.7		120	40	200
1996				68.3	46.3	90.4				

TABLE III-IV. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN HAY (Bq kg^{-1})

	Observed	lower	upper	LIETDOS*	lower	upper	RADCON	lower	upper
1986	34627	27002	42252	15906	6029	32337	31304	9610	101973
1987	16238	14002	18473	12859	4844	26225	3801	859	16831
1988	16715	9838	23592	7907	2979	16127	3262	730	14572
1989	8761	7279	10243	5206	1961	10617	2909	663	12764
1990	10140	6367	13120	3716	1400	7578	2561	530	12371
1991	3130	2714	3547	2887	1088	5889	2235	494	10113
1992	2290	1892	2689	2420	912	4936	2133	468	9717
1993	1110	979	1241	2150	810	4386	1805	399	8167
1994	2991	2364	3618	1988	749	4055	1623	354	7439
1995	3375	2822	3927	1885	710	3845	1475	320	6803
1996	2260	1996	2524	1815	684	3702	1330	283	6249

	CLRP	lower	upper	ECOMOD	lower	upper
1986	11900	5710	24700	53200	23900	82500
1987	6390	3080	13300	30800	12300	49300
1988	4350	2090	9040	23200	9300	37100
1989	3470	1670	7220	18000	7200	28800
1990	3020	1450	6290	14200	5700	22700
1991	2750	1320	5710	14000	5600	22400
1992	2530	1220	5270	11000	3850	18150
1993	2350	1130	4890	9200	3220	15180
1994	2190	1050	4560	9200	3220	15180
1995	2040	983	4250	9200	3220	15180
1996						

	TAMDYN-UV	lower	upper
Jun-86	208000	58000	468000
Jul-86	133000	45000	306000
Aug-86	126000	21000	480000
Sep-86	132000	32000	473000
May-87	103000	15000	460000
Aug-87	85100	14500	302000
May-88	3870	728	14700
Aug-88	4960	794	19900
May-89	4450	1020	14400
Aug-89	4300	859	12800
May-90	3590	707	10400
Aug-90	3590	573	12900
May-91	2730	530	7890
Aug-91	2720	545	10000
May-92	2560	384	8710
Aug-92	2420	465	7940
May-93	2180	323	7420
Aug-93	1980	296	9820
May-94	1780	259	6510
Aug-94	1670	319	6140
May-95	1490	254	4890
Aug-95	1380	223	5240

	LINDOZ
1986-06-04	158000
1986-07-14	78600
1987-06-04	61600
1987-07-14	55500
1988-06-04	42800
1988-07-14	38600
1989-06-04	29900
1989-07-14	27100
1990-06-04	21100
1990-07-14	19100
1991-06-04	14900
1991-07-14	13500
1992-06-04	10700
1992-07-14	9700

* LIETDOS reported values for pasture grass; these were converted to values for hay based on a wet-to-dry weight conversion factor of 5.

TABLE III-V. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN MILK (Bq L^{-1})

	Observed	lower	upper	LIETDOS	lower	upper	RADCON	lower	upper
May 1986	9609	7377	11841	3000	1157	6200	3164	703	14238
June 1986	4438	3577	5298	1804	694	3720	1958	370	10368
July 1986	2968	2093	3844	1492	574	3079	1412	226	8823
August 1986	2544	1835	3252	1482	571	3059	1226	171	8796
September 1986	1961	1530	2391	1584	609	3265	1097	154	7820
IV 1986	1063	830	1296	1120	425	2277	1098	136	8849
I 1987	1183	903	1464	1120	425	2277	988	110	8879
II 1987	1854	1563	2145	486	183	991	155	29	843
III 1987	1935	1539	2332	399	150	813	146	27	784
IV 1987	615	412	818	230	87	469	133	25	719
I 1988	623	541	706	230	87	469	133	23	757
II 1988	1762	1339	2185	296	111	603	126	23	685
III 1988	2016	1458	2575	243	92	495	128	23	706
IV 1988	730	557	903	149	56	305	125	21	726
I 1989	636	550	721	149	56	305	121	22	676
II 1989	1089	888	1290	195	74	398	116	20	663
III 1989	1610	1265	1955	161	60	327	114	20	633
IV 1989	403	360	446	105	40	214	113	20	653
I 1990	330	284	377	105	40	214	108	19	623
II 1990	428	362	494	140	53	285	102	17	611
III 1990	351	309	393	115	43	235	103	17	631
IV 1990	115	103	128	79	30	162	95	18	506
I 1991	125	109	141	79	30	162	95	17	535
II 1991	406	334	478	109	41	222	90	16	515
III 1991	449	348	550	90	34	183	92	17	504
IV 1991	122	107	137	64	24	131	88	17	471
I 1992	156	136	176	64	24	131	85	14	512
II 1992	215	174	256	91	34	186	85	14	515
III 1992	285	235	335	75	28	153	78	13	461
IV 1992	118	101	135	55	21	113	76	13	449
I 1993	136	117	155	55	21	113	77	14	430
II 1993	176	153	198	81	31	166	76	14	402
III 1993	159	141	177	67	25	136	70	12	410
IV 1993	122	98	146	50	19	101	71	11	438
I 1994	116	95	137	50	19	101	71	12	414
II 1994	311	265	357	75	28	153	67	11	406
III 1994	388	326	451	62	23	126	63	11	377
IV 1994	181	156	206	46	17	93	61	11	344
I 1995	156	129	182	46	17	93	61	11	344
II 1995	237	207	268	71	27	145	59	9	372
III 1995	489	367	610	59	22	119	58	10	328
IV 1995	140	123	157	43	16	88	52	9	310
I 1996	161	136	186	43	16	88	54	9	327
II 1996	228	192	264	68	26	140	53	9	323
III 1996	450	275	625	56	21	115	50	8	318
IV 1996	146	107	185	41	16	84	49	9	276

TABLE III-V. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN MILK (Bq L^{-1}) (CONTINUED)

	TAMDYN-UV	lower	upper	CLRP	lower	upper	SPADE	lower	upper
May 1986	3990	1580	8500	2180	1240	3850	126	105	147
June 1986	8970	3430	17300	1120	637	1980	218	182	255
July 1986	9680	3200	19200	1050	593	1850	269	224	314
August 1986	8400	3410	17600	1040	588	1830	312	260	365
September 1986	7870	2950	15700				341	284	398
IV 1986	7160	2930	12600	606	300	1230	167	139	195
I 1987	6230	2930	11600	463	221	969	179	149	210
II 1987	7770	4010	13300	1560	871	2790	367	305	428
III 1987	9600	4160	17400	3730	2120	6580	338	281	394
IV 1987	6620	2950	12000	2070	1200	3590	141	117	164
I 1988	4240	1850	7640	1470	851	2520	146	122	171
II 1988	3840	1490	7420	1600	914	2810	332	277	388
III 1988	1090	438	2230	2760	1570	4880	369	307	431
IV 1988	520	244	1020	1480	854	2560	186	155	217
I 1989	323	139	668	1010	589	1750	197	164	230
II 1989	337	140	617	1240	709	2180	395	329	462
III 1989	428	185	744	2300	1300	4050	324	270	379
IV 1989	334	117	614	1210	699	2100	120	100	140
I 1990	221	97	418	817	474	1410	121	101	141
II 1990	247	108	490	1070	609	1870	278	231	325
III 1990	346	132	672	2040	1150	3590	253	210	295
IV 1990	277	125	493	1070	615	1850	102	85	119
I 1991	180	71	309	715	415	1230	111	92	129
II 1991	198	79	332	964	549	1690	261	218	305
III 1991	267	101	493	1860	1060	3290	218	182	255
IV 1991	213	78	395	975	563	1690	73	61	86
I 1992	137	54	253	651	378	1120	71	59	83
II 1992	175	78	294	887	506	1560	169	141	198
III 1992	263	116	435	1720	978	3040	155	129	181
IV 1992	215	100	370	899	520	1560	60	50	70
I 1993	127	53	221	601	349	1030	63	52	73
II 1993	154	75	252	824	469	1450	152	126	177
III 1993	215	93	383	1600	910	2830	133	111	155
IV 1993	135	60	236	837	483	1450	48	40	57
I 1994	102	43	183	558	324	961	48	40	56
II 1994	148	64	267	767	437	1350	116	97	136
III 1994	181	78	302	1490	846	2630	108	90	127
IV 1994	121	49	204	778	449	1350	43	36	51
I 1995	88	39	153	520	302	896	44	37	51
II 1995	130	56	251	715	407	1250	108	90	126
III 1995	155	68	274	1390	790	2460	99	83	116
IV 1995	84	37	168	726	419	1260	39	32	45

TABLE III-V. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN MILK (Bq L^{-1}) (CONTINUED)

	ECOMOD	lower	upper
May 1986	18000	8700	29300
June 1986	5000	1600	8400
July 1986	2800	900	4700
August 1986	2700	900	4600
September 1986	2700	900	4600
IV 1986	1500	300	2700
I 1987	1400	250	2650
II 1987	1900	630	3170
III 1987	2000	700	3300
IV 1987	900	300	1500
I 1988	800	260	1340
II 1988	1100	360	1840
III 1988	1200	400	2000
IV 1988	700	230	1170
I 1989	600	200	1000
II 1989	800	260	1340
III 1989	900	300	1500
IV 1989	500	160	840
I 1990	460	150	770
II 1990	480	160	800
III 1990	480	160	800
IV 1990	240	80	400
I 1991	230	70	380
II 1991	420	120	720
III 1991	420	120	720
IV 1991	150	50	250
I 1992	140	45	135
II 1992	340	100	580
III 1992	340	100	580
IV 1992	120	40	200
I 1993	110	40	180
II 1993	280	80	480
III 1993	280	80	480
IV 1993	90	30	150
I 1994	85	30	150
II 1994	280	80	480
III 1994	280	80	480
IV 1994	90	30	150
I 1995	85	30	150
II 1995	280	80	480
III 1995	280	80	480
IV 1995	90	30	150

	OSCAAR	lower	upper
1986	21090	11880	30290
1987	308	180	435
1988	168	97	240
1989	184	105	263
1990	141	83	198
1991	279	145	412
1992	248	129	367
1993	221	115	326
1994	197	103	290
1995	175	91	258
1996	156	81	230

	LINDOZ
1986-04-27	0.001
1986-04-28	7.1
1986-04-29	33
1986-04-30	29
1986-05-01	18
1986-05-02	12
1986-05-03	8
1986-05-04	5.5
1986-05-06	572
1986-05-08	2260
1986-05-10	3880
1986-05-12	5170
1986-05-14	6100
1986-05-16	6750
1986-05-18	7260
1986-05-21	7660
1986-05-24	7190
1986-05-27	6570
1986-05-30	6000
1986-06-02	5550
1986-06-05	5160
1986-06-08	4850
1986-06-15	4420
1986-06-22	4190
1986-06-29	4060
1986-07-06	3980
1986-07-13	3950
1986-07-20	3950
1986-07-27	3960
1986-08-26	4060
1986-09-26	4240
1986-10-14	4350
1986-10-25	3450
1986-11-25	2890
1986-12-24	2800
1987-01-24	2770
1987-02-23	2760
1987-03-24	2750
1987-04-23	2750
1987-05-23	2550
1987-06-22	2600
1987-07-22	2810
1987-08-21	2950
1987-09-21	3050
1987-10-14	3150
1987-10-20	3170
1987-11-20	1800
1987-12-19	1700
1988-01-19	1660
1988-02-18	1650
1988-03-19	1650
1988-04-18	1640
1988-05-18	1480
1988-06-17	1750
1988-07-17	1910
1988-08-16	2030
1988-09-16	2090
1988-10-14	2170
1988-10-15	2170
1988-12-14	1190
1989-02-13	1160
1989-04-13	1150
1989-06-12	1200
1989-08-11	1410
1989-10-10	1510
1989-10-14	1510
1989-12-09	834
1990-02-08	811
1990-04-08	806
1990-06-07	837
1990-08-06	967
1990-10-05	1040
1990-10-14	1050
1990-12-04	595
1991-02-03	569
1991-04-03	565
1991-06-02	594
1991-08-01	678
1991-10-01	730
1991-10-14	744
1991-11-30	422
1992-01-29	403
1992-03-29	400
1992-05-28	423
1992-07-27	478
1992-09-26	518
1992-10-14	532
1992-11-25	315

TABLE III-VI. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN BEEF (Bq kg^{-1})

	Observed	lower	upper	LIETDOS	lower	upper	RADCON	lower	upper
May 1986	6073	2449	9697	8572	3249	17399	9782	2614	36609
June 1986	7615	5673	9556	5155	1957	10480	16511	4280	63703
July 1986	8224	5065	11382	4262	1619	8669	15026	3730	60532
August 1986	4626	3076	6176	4235	1611	8628	14214	3311	61032
September 1986	5960	2524	9395	4526	1717	9198	11863	2774	50739
IV 1986	2908	2035	3781	3200	1213	6506	11781	2387	58144
I 1987	3334	2078	4591	3200	1213	6506	10456	1998	54717
II 1987	3653	2439	4867	1389	523	2832	1683	346	8176
III 1987	3654	2270	5038	1139	429	2323	1520	311	7424
IV 1987	1906	1254	2558	657	248	1340	1514	304	7528
I 1988	1183	903	1464	657	248	1340	1525	323	7204
II 1988	3079	2217	3941	845	318	1724	1351	251	7270
III 1988	5256	3408	7105	694	261	1416	1392	247	7844
IV 1988	1994	1605	2383	427	161	871	1381	263	7259
I 1989	1831	1338	2323	427	161	871	1328	256	6896
II 1989	3066	2165	3966	558	210	1139	1253	241	6509
III 1989	3303	2399	4208	459	173	935	1167	228	5984
IV 1989	896	753	1038	300	113	612	1254	241	6541
I 1990	908	758	1058	300	113	612	1217	227	6516
II 1990	1328	984	1672	400	151	815	1160	222	6065
III 1990	2128	1732	2524	329	124	670	1051	197	5618
IV 1990	565	432	699	227	85	463	1059	200	5619
I 1991	464	356	572	227	85	463	1028	200	5275
II 1991	1001	649	1354	311	117	635	956	179	5102
III 1991	957	723	1191	256	96	522	984	185	5237
IV 1991	348	281	414	184	69	375	893	170	4688
I 1992	393	307	479	184	69	375	886	170	4628
II 1992	876	515	1238	261	98	532	960	185	4981
III 1992	869	634	1104	215	81	438	879	168	4612
IV 1992	509	310	708	158	59	322	892	178	4464
I 1993	540	336	743	158	59	322	839	156	4514
II 1993	606	322	890	232	87	473	843	158	4514
III 1993	858	527	1188	191	72	389	794	158	3977
IV 1993	437	328	546	142	53	289	804	143	4514
I 1994	450	318	582	142	53	289	755	143	3984
II 1994	600	427	774	214	81	437	736	137	3942
III 1994	555	423	687	176	66	360	684	130	3599
IV 1994	521	275	767	131	49	267	695	128	3757
I 1995	526	325	727	131	49	267	666	128	3478
II 1995	532	356	708	203	77	415	646	119	3523
III 1995	518	399	637	167	63	341	641	128	3205
IV 1995	477	244	710	124	47	252	616	112	3397
I 1996	497	379	615	124	47	252	576	108	3063
II 1996	351	309	393	196	74	399	584	111	3060
III 1996	462	376	547	161	61	328	553	105	2921
IV 1996	471	448	493	118	45	241	543	97	3035

TABLE III-VI. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN BEEF (Bq kg^{-1}) (CONTINUED)

	TAMDYN-UV	lower	upper	CLRP	lower	upper	SPADE	lower	upper
May 1986	6840	3550	10800	215	122	379	2868	2388	3349
June 1986	43200	18500	68600	333	190	585	3247	2711	3782
July 1986	61400	21100	111000	373	213	653	3778	3156	4400
August 1986	62900	24200	123000	395	226	692	4166	3476	4856
September 1986	58800	19200	115000				4473	3728	5218
IV 1986	50400	21100	113000	456	264	1230	3307	2713	3901
I 1987	49700	22400	111000	495	287	969	4859	3947	5770
II 1987	49900	18000	108000	606	350	2790	6036	4993	7080
III 1987	70200	31900	130000	612	352	6580	4074	3401	4748
IV 1987	57800	22600	117000	1280	740	3590	2504	2070	2937
I 1988	34600	11100	88600	1770	1030	2520	1195	995	1394
II 1988	30200	11000	72000	1740	1000	2810	11769	9563	13976
III 1988	10300	2360	34300	1590	912	4880	5863	4853	6872
IV 1988	5410	1340	15900	1470	853	2560	2939	2419	3459
I 1989	3410	696	17700	1320	768	1750	3867	3159	4575
II 1989	2160	728	5880	1230	712	2180	5709	4730	6689
III 1989	3100	1350	7030	1240	713	4050	3890	3249	4532
IV 1989	3210	1140	8110	1190	688	2100	2119	1760	2478
I 1990	1860	662	4650	1060	618	1410	1011	835	1187
II 1990	1610	635	3730	1000	577	1870	9777	7979	11574
III 1990	2370	910	4620	1070	613	3590	4401	3669	5134
IV 1990	2400	820	5090	1040	602	1850	1994	1658	2329
I 1991	1470	443	3440	931	540	1230	2726	2248	3203
II 1991	1370	498	2950	880	507	1690	3614	3020	4209
III 1991	1760	890	3320	968	554	3290	2337	1922	2752
IV 1991	1760	810	3200	947	549	1690	1508	1260	1757
I 1992	1130	330	2870	847	492	1120	676	526	826
II 1992	1060	419	2320	802	463	1560	6261	5174	7349
III 1992	1850	846	3480	891	510	3040	2582	2139	3025
IV 1992	1870	721	3980	873	506	1560	1421	1187	1654
I 1993	1020	332	2080	782	454	1030	2069	1719	2418
II 1993	948	387	2170	741	427	1450	2470	2040	2900
III 1993	1400	684	2840	827	474	2830	1550	1187	1913
IV 1993	1190	449	2610	811	470	1450	1212	1010	1413
I 1994	889	254	1930	726	422	961	626	478	774
II 1994	1030	401	2000	689	397	1350	4626	3853	5400
III 1994	1210	548	2190	770	441	2630	2092	1699	2484
IV 1994	1040	380	2120	755	438	1350	1178	981	1375
I 1995	743	255	1720	676	393	896	1776	1481	2071
II 1995	849	372	1940	642	370	1250	2010	1624	2396
III 1995	1120	505	2410	718	411	2460	1264	903	1625
IV 1995	700	206	1740	704	408	1260	1074	890	1257

TABLE III-VI. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN BEEF (Bq kg^{-1}) (CONTINUED)

	LINDOZ	ECOMOD	lower	upper
May 1986	3200	18600	7400	29800
June 1986	8100	21800	8700	34900
July 1986	8650	16000	6400	25600
August 1986	9540	12200	4900	19500
September 1986	10200	10100	4000	16200
IV 1986	11000	7700	2300	13100
I 1987	12500	6500	1900	11100
II 1987	10050	6300	2500	9100
III 1987	9000	4500	1800	7200
IV 1987	9700	3800	1500	6100
I 1988	7200	3600	1400	5800
II 1988	6400	3600	1400	5800
III 1988	7200	3200	1200	5200
IV 1988	7000	2900	1200	4600
I 1989	5800	2700	1100	4300
II 1989	5400	2700	1100	4300
III 1989	6100	2400	1000	3800
IV 1989	5400	2200	900	3500
I 1990	4000	2000	800	3200
II 1990	3800	2000	800	3200
III 1990	4300	1500	530	2470
IV 1990	5100	1170	410	1930
I 1991	3300	1060	370	1750
II 1991	2800	1110	390	1830
III 1991	3800	1200	400	2000
IV 1991	3000	1000	370	1670
I 1992	2200	700	250	1150
II 1992	2400	900	315	1485
III 1992	3000	1050	370	1730
IV 1992	4000	720	250	1190
I 1993		360	130	590
II 1993		420	150	690
III 1993		510	180	840
IV 1993		480	170	790
I 1994		360	130	590
II 1994		420	150	690
III 1994		510	180	840
IV 1994		480	170	790
I 1995		360	130	590
II 1995		420	150	690
III 1995		510	180	840
IV 1995		480	170	790

	OSCAAR	lower	upper
1986	11360	4134	18580
1987	2638	1713	3563
1988	1594	998	2189
1989	1544	989	2100
1990	1209	764	1655
1991	2273	1395	3152
1992	2024	1242	2806
1993	1802	1107	2498
1994	1605	986	2224
1995	1429	878	1980
1996	1272	782	1762

TABLE III-VII. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN PORK (Bq kg^{-1})

	Observed	lower	upper	LIETDOS	lower	upper	RADCON	lower	upper
May 1986	1325	815	1836	6261	2373	12729	2541	576	11219
June 1986	4088	2556	5620	5439	2061	11057	4650	1092	19800
July 1986	3385	2151	4618	4438	1682	9023	5044	1224	20784
August 1986	3140	2407	3873	4411	1672	8967	4313	856	21718
September 1986	1995	1518	2472	4714	1787	9583	4285	810	22670
IV 1986	1508	927	2089	6532	2476	13279	3302	623	17497
I 1987	1223	696	1750	6532	2476	13279	3041	504	18349
II 1987	2340	1954	2726	2096	790	4275	477	78	2920
III 1987	2879	1916	3841	1767	666	3604	465	75	2868
IV 1987	1041	656	1425	563	212	1148	414	69	2484
I 1988	1002	786	1217	563	212	1148	439	62	3107
II 1988	1820	1417	2224	1321	498	2694	407	61	2696
III 1988	3145	1707	4583	1121	422	2287	377	60	2350
IV 1988	981	810	1152	387	146	790	392	63	2445
I 1989	966	807	1124	387	146	790	365	55	2421
II 1989	1787	1027	2547	902	340	1840	342	53	2187
III 1989	1308	1096	1519	771	290	1572	343	53	2216
IV 1989	521	402	640	286	108	583	328	49	2204
I 1990	675	441	909	286	108	583	333	51	2171
II 1990	922	743	1101	665	251	1356	309	46	2070
III 1990	1452	1077	1827	571	215	1165	320	47	2190
IV 1990	503	274	731	224	84	457	314	43	2271
I 1991	311	243	379	224	84	457	291	48	1773
II 1991	765	505	1025	529	199	1078	279	46	1683
III 1991	1284	862	1705	456	172	930	284	43	1874
IV 1991	253	199	307	186	70	379	257	39	1683
I 1992	410	277	543	186	70	379	250	39	1602
II 1992	323	211	434	449	169	916	273	43	1736
III 1992	352	322	383	388	146	791	242	34	1731
IV 1992	124	94	155	162	61	329	250	39	1585
I 1993	125	95	154	162	61	329	238	35	1623
II 1993	133	81	186	401	151	817	225	37	1346
III 1993	252	111	394	346	130	706	224	35	1437
IV 1993	110	74	145	145	55	297	222	34	1435
I 1994	173	114	233	145	55	297	213	32	1420
II 1994	164	101	227	370	139	755	205	31	1350
III 1994	224	160	288	320	121	652	194	29	1294
IV 1994	151	124	177	134	51	274	204	30	1390
I 1995	133	99	167	134	51	274	186	28	1236
II 1995	166	110	223	350	132	713	184	31	1097
III 1995	201	152	250	302	114	616	175	29	1046
IV 1995	229	137	321	126	48	258	165	25	1096
I 1996	216	134	297	126	48	258	163	25	1066
II 1996	179	146	211	335	126	683	163	22	1195
III 1996	192	154	230	289	109	590	152	23	989
IV 1996	150	100	199	120	45	245	150	22	1005

TABLE III-VII. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN PORK (Bq kg^{-1}) (CONTINUED)

	TAMDYN-UV	lower	upper	CLRP	lower	upper	SPADE	lower	upper
May 1986	1000	550	2300	3070	1740	5410	63873	50086	77659
June 1986	26300	9700	53000	6310	3580	11100	61351	48109	74593
July 1986	27400	8800	56000	6940	3940	12200	50666	39730	61601
August 1986	24700	7900	57000	7310	4160	12900	44663	35023	54303
September 1986	14600	3500	42000				41541	32575	50507
IV 1986	9600	2100	29000	8280	4710	14500	169	133	206
I 1987	6000	1800	21000	5760	3280	10100	10417	8168	12665
II 1987	5900	1700	19000	2190	1280	3760	30015	23537	36494
III 1987	14000	3100	32000	1260	732	2170	387	303	470
IV 1987	11000	2300	26000	2260	1280	3980	8697	6820	10574
I 1988	4600	1500	12000	1910	1080	3370	11743	9209	14278
II 1988	2700	1000	9500	3520	2010	6160	387	303	470
III 1988	2800	1060	9400	2730	1610	4610	16688	13086	20290
IV 1988	1800	570	5800	628	371	1060	7616	5972	9260
I 1989	990	310	2900	218	121	394	144	113	175
II 1989	750	270	2800	953	541	1680	12606	9885	15327
III 1989	900	310	3400	5260	2980	9270	17049	13369	20728
IV 1989	800	290	2900	7520	4270	13300	161	126	195
I 1990	670	270	2600	4700	2640	8380	3951	3098	4803
II 1990	610	270	2400	1190	680	2090	12486	9791	15181
III 1990	680	280	2700	456	264	788	331	260	403
IV 1990	720	310	3000	1420	805	2500	2889	2266	3513
I 1991	630	270	2500	1240	700	2200	3150	2470	3829
II 1991	620	250	2600	2130	1220	3720	315	247	382
III 1991	620	240	2400	1600	945	2700	5127	4020	6233
IV 1991	640	260	2700	371	220	627	2747	2154	3340
I 1992	580	210	2000	143	79	258	135	106	164
II 1992	530	200	1900	737	418	1300	3770	2956	4584
III 1992	660	240	2100	3860	2190	6810	4766	3738	5795
IV 1992	610	230	2000	5450	3090	9620	125	98	152
I 1993	540	210	1900	3390	1900	6050	1012	794	1231
II 1993	550	210	2000	858	490	1510	3038	2382	3693
III 1993	600	230	2100	381	220	661	299	234	363
IV 1993	670	240	2300	1340	760	2360	786	616	956
I 1994	530	190	1800	1140	641	2010	1002	786	1219
II 1994	470	180	1800	1710	980	2980	306	240	372
III 1994	610	210	2100	1190	703	2010	1405	1102	1708
IV 1994	640	220	2100	278	164	470	703	551	854
I 1995	520	190	1800	111	61	200	121	95	148
II 1995	450	160	1600	620	352	1090	821	644	998
III 1995	470	170	1700	3210	1820	5660	3	3	4
IV 1995	470	160	1500	4530	2570	7970	0	0	1

TABLE III-VII. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN PORK (Bq kg^{-1}) (CONTINUED)

	LINDOZ	ECOMOD	lower	upper
May 1986	340	3600	1200	6000
June 1986	900	8000	2600	13400
July 1986	1150	5200	1700	8700
August 1986	1260	4000	1300	6700
September 1986	1330	3200	1100	5300
IV 1986	1735	2800	900	4700
I 1987	2400	2650	970	4430
II 1987	2300	2600	860	4340
III 1987	2050	2500	825	4175
IV 1987	2000	1700	560	2840
I 1988	1200	1550	510	2590
II 1988	1100	1500	500	2500
III 1988	1150	1500	500	2500
IV 1988	1200	1140	370	1910
I 1989	650	1120	340	1900
II 1989	900	1120	340	1900
III 1989	900	1000	330	1670
IV 1989	900	860	260	1460
I 1990	700	850	250	1450
II 1990	660	860	260	1460
III 1990	720	890	270	1510
IV 1990	900	710	210	1210
I 1991	600	750	230	1270
II 1991	520	770	230	1310
III 1991	600	810	270	1350
IV 1991	800	740	245	1235
I 1992	400	730	260	1200
II 1992	420	720	250	1190
III 1992	570	580	200	960
IV 1992	660	480	170	790
I 1993		290	100	480
II 1993		360	130	590
III 1993		380	130	630
IV 1993		310	110	510
I 1994		290	100	480
II 1994		360	130	590
III 1994		380	130	630
IV 1994		310	110	510
I 1995		290	100	480
II 1995		360	130	590
III 1995		380	130	630
IV 1995		310	110	510

	OSCAAR	lower	upper
1986	4551	1272	7831
1987	1184	702	1666
1988	678	385	971
1989	716	417	1015
1990	566	326	805
1991	1051	570	1532
1992	936	508	1363
1993	833	453	1213
1994	742	404	1080
1995	660	360	961
1996	588	321	855

TABLE III-VIII. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs in mushrooms (Bq kg^{-1} FRESH WEIGHT)

	Observed	lower	upper	LIETDOS	lower	upper	RADCON	lower	upper	TAMDYN-UV	lower	upper
1986	11200	7600	14800	16410	5673	34968	71412	10489	486195	51300	10000	197000
1987	17900	5400	30400	16086	5561	34277	59656	7984	445749	32100	8390	90700
1988	12000	5700	18300	15769	5452	33602	52138	7500	362439	25900	7860	73100
1989	10100		29700	15465	5347	32955	46755	6194	352941	27600	6810	82000
1990	13400	5800	21000	15172	5245	32331	40035	5476	292693	22000	4920	48600
1991	5900		14300	14888	5147	31725	36709	4788	281467	21500	5200	66800
1992	7000	4200	9700	14611	5051	31135	33896	4729	242965	20100	6850	61600
1993				14341	4958	30559	31687	4479	224172	23000	10800	83100
1994	15600	5200	26000	14077	4867	29996	25925	3592	187112	26800	16400	97300
1995	15300	2300	28300	13818	4777	29445	23145	3101	172747	19300	6330	51000
1996	14500	1600	27400	13565	4690	28905	22465	2955	170788			

	Cantharellus	lower	upper	*Boletus*	lower	upper	SPADE	lower	upper	OSCAAR	lower	upper
1986	6610	2960	14800	1420	635	3160	60000	60000	60000	61760	39810	83710
1987	6030	2700	13500	1290	579	2880	60000	60000	60000	60360	38900	81810
1988	5520	2480	12400	1190	530	2640	60000	60000	60000	58980	38020	79950
1989	5080	2280	11400	1090	488	2430	60000	60000	60000	57640	37150	78130
1990	4700	2110	10500	1010	451	2240	60000	60000	60000	56330	36310	76360
1991	4350	1950	9700	931	418	2080	106377	106377	106377	55050	35480	74620
1992	4040	1810	9000	863	387	1930	106377	106377	106377	53800	34680	72920
1993	3750	1680	8360	802	360	1790	106377	106377	106377	52580	33890	71270
1994	3490	1570	7770	746	335	1670	106377	106377	106377	51380	33120	69640
1995	3240	1460	7240	695	311	1550	106377	106377	106377	50210	32360	68060
1996										49070	31630	66510

TABLE III-IX. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN WILD BERRIES (Bq kg^{-1} FRESH WEIGHT)

	Observed	lower	upper	LIETDOS	lower	upper	RADCON	lower	upper
1986	8000	3000	14000	8205	2837	17484	26862	13734	52539
1987	4000	1200	7000	8043	2781	17139	1435	77	26591
1988	3500	1000	5000	7885	2726	16801	1152	67	19761
1989	2600	900	4300	7733	2673	16478	1040	68	16025
1990	2400	900	4000	7586	2623	16165	960	69	13429
1991	2300	800	4000	7444	2574	15862	923	56	15237
1992				7306	2526	15567	716	43	11874
1993	6800		14000	7170	2479	15279	653	41	10346
1994				7038	2433	14998	625	36	10978
1995	2100		7100	6909	2389	14722	532	34	8218
1996	5500		21400	6782	2345	14452	494	32	7628

	TAMDYN-UV	lower	upper	CLRP	lower	upper	SPADE	lower	upper
1986	5916	539	25100	2210	990	4930	67625	45434	89815
1987	1601	296	6730	1760	787	3920	655	440	871
1988	966	167	3710	1610	720	3590	68	45	90
1989	1100	219	4960	1480	662	3300	57	38	76
1990	705	178	2370	1360	611	3040	47	31	62
1991	803	121	3310	1260	566	2820	63	50	77
1992	986	160	4810	1170	525	2610	45	35	54
1993	622	125	2223	1090	487	2430	32	25	38
1994	469	82	1430	1010	453	2260	24	19	29
1995	604	113	2700	941	422	2100	17	13	21

	OSCAAR	lower	upper
1986	4240	3179	5302
1987	4144	3106	5181
1988	4050	3036	5064
1989	3958	2967	4948
1990	3868	2899	4836
1991	3780	2833	4726
1992	3694	2769	4619
1993	3610	2706	4514
1994	3528	2644	4411
1995	3447	2584	4311
1996	3369	2526	4213

TABLE III-X. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN FISH (Bq kg^{-1} FRESH WEIGHT)

	Observed river	lower	upper	Observed lake	lower	upper	LIETDOS	TAMDYN-UV	lower	upper
1986	2000	800	3400	36000	7000	65000	1180	2500	1000	6000
1987	2400	1000	4000	42000	9000	75000	700	3600	2000	6500
1988	1400	600	2200	28000	5000	50000	416	3000	1800	5500
1989	600	240	1000	16000	3000	30000	247	1200	750	2200
1990	580	200	1000	10000	6000	14000	147	1150	750	2100
1991	250	100	400	12000	7000	18000	87	950	600	1700
1992	250	60	420	11000	7000	15000	51.7	550	350	1000
1993	200	60	340	10000	7000	13000	30.7	400	240	850
1994	170	50	300	6700	4700	8700	18.2	230	120	500
1995	150	50	250	4000	1000	7000	10.8	190	90	370
1996	150	100	200	3000	500	5500				

	SENES	lower	upper	OSCAAR
1986	1581	254	11008	2500
1987	897	215	4108	1228
1988	641	152	2904	691
1989	261	62	1124	308
1990	249	59	1137	300
1991	107	24	486	294
1992	120	17	771	288
1993	72	11	432	282
1994	43	6	262	274
1995	25	4	173	267
1996				261

TABLE III-XI. ESTIMATED AND PREDICTED INTAKE OF ^{137}Cs BY MEN (Bq d^{-1})

	Authors' estimates controlled area	lower	upper	Authors' estimates non-controlled area	lower	upper	LIETDOS controlled area	lower	upper	LIETDOS non-controlled area	lower	upper
June 1986	2546	1875	3216	2603	2011	3194	1295	901	2138	1564	972	2651
IV 1986	292	159	425	944	677	1212	719	500	1186	1078	744	1804
II 1987	312	179	446	1324	1020	1629	538	390	909	623	468	1108
IV 1987	276	143	409	736	488	984	279	206	584	523	394	982
II 1988	224	149	299	1035	774	1296	277	204	582	460	317	829
IV 1988	190	117	264	536	380	691	255	168	497	424	287	786
II 1989	175	0	356	649	283	1015	254	168	496	410	274	735
IV 1989	154	0	335	370	29	712	240	151	468	388	255	710
II 1990	176	92	261	396	241	551	240	151	468	482	282	892
IV 1990	172	88	257	315	166	464	302	174	585	469	271	880
II 1991	132	52	212	314	160	469	302	173	585	473	277	867
IV 1991	112	33	192	199	52	347	300	172	571	460	267	854
II 1992	138	98	177	262	196	328	298	170	568	467	268	856
IV 1992	123	86	161	220	158	283	298	171	566	454	257	843
II 1993	170	62	278	296	101	491	294	168	562	461	264	850
IV 1993	160	53	266	273	80	467	297	172	567	447	252	837
II 1994	265	151	379	454	251	656	292	168	562	458	269	832
IV 1994	232	121	343	393	195	591	293	163	529	443	256	816
II 1995	263	131	396	461	220	702	286	157	522	455	267	834
IV 1995	250	118	382	416	177	655	304	181	554	438	253	816
II 1996							292	171	542	445	263	809
IV 1996							297	174	542	428	248	792

	RADCON	lower	upper	TAMDYN-UV	lower	upper	CLRP controlled area	lower	upper	CLRP non-controlled area	lower	upper	SPADE*
June 1986	3377	1633	6982	1800	870	5300	1190	730	1940	1178	546	2538	784
August 1986				5050	2100	9700							
IV 1986	2002	684	5860	2700	1300	5100	552	241	1270	1424	647	3135	502
II 1987	729	149	3561	1780	770	3200	564	272	1180	1124	511	2470	302
IV 1987	663	139	3168	950	480	1700	338	140	820	1096	511	2355	106
II 1988	368	86	1587	510	260	890	335	140	810	1053	489	2268	256
IV 1988	357	82	1559	360	190	740	195	78	488	671	313	1438	224
II 1989	335	72	1561	400	220	760	219	93	516	615	285	1326	176
IV 1989	306	72	1306	480	250	800	331	126	868	1345	626	2895	212
II 1990	486	89	2648	440	230	820	253	119	546	570	265	1229	154
IV 1990	457	87	2400	480	240	700	280	134	592	594	276	1276	97
II 1991	410	74	2278	370	180	640	203	86	486	634	294	1365	236
IV 1991	411	76	2206	420	210	630	161	70	371	438	204	939	229
II 1992	372	69	1994	380	190	640	169	74	386	445	206	959	228
IV 1992	350	63	1946	400	190	630	202	72	562	985	458	2118	226
II 1993	375	93	1508	370	170	590	191	89	415	433	201	932	244
IV 1993	365	87	1533	440	180	820	201	91	447	492	229	1057	225
II 1994	363	87	1506	320	170	610	199	90	444	506	235	1090	255
IV 1994	313	78	1254	410	190	690	147	67	325	348	162	745	232
II 1995	543	112	2626	310	150	630	160	74	348	361	167	779	234
IV 1995	515	99	2683	360	160	680	198	76	521	809	376	1741	234
II 1996	467	89	2440							350	163	755	
IV 1996	458	90	2330							285	134	607	

	OSCAAR controlled area	lower	upper	OSCAAR non-controlled area	lower	upper	SENES** with counter-measures	lower	upper	SENES** without counter-measures	lower	upper
1986	212	152	273	2470	1131	3808	28	3.7	279	28	3.7	279
1987	90	68	111	477	237	717	91	11	447	93	12	465
1988	50	36	64	421	196	647	67	8.9	341	69	9.1	348
1989	53	39	67	405	186	625	42	4.6	205	53	6.5	262
1990	48	35	61	394	180	608	32	3.4	168	41	4.4	212
1991	56	41	72	383	174	591	25	3.0	135	32	3.9	158
1992	55	40	70	371	168	574	19	2.3	117	27	3.0	129
1993	232	155	310	399	193	605	15	1.8	73	20	2.3	96
1994	219	145	293	384	184	584	12	1.5	64	16	1.8	81
1995	197	131	263	378	182	574	11	1.3	61	13	1.6	70

* Predictions for SPADE were made outside the main computer code.

** Predictions for SENES include only the contributions from grains, potatoes, and fish.

TABLE III-XII. ESTIMATED AND PREDICTED INTAKE OF ^{137}Cs BY WOMEN (Bq d^{-1})

	Authors' estimates controlled area	lower	upper	Authors' estimates non-controlled area	lower	upper	LIETDOS controlled area	lower	upper	LIETDOS non-controlled area	lower	upper
June 1986	2181	1681	2681	2010	1559	2461	1030	737	1726	1257	848	2060
IV 1986	217	144	291	710	516	904	575	412	964	869	625	1435
II 1987	251	176	327	940	720	1161	433	326	750	501	377	928
IV 1987	198	126	270	552	373	732	226	169	492	421	318	827
II 1988	186	140	232	789	625	952	224	167	490	367	256	679
IV 1988	137	95	178	420	321	520	205	136	405	339	233	647
II 1989	139	46	232	510	254	766	204	135	404	331	224	627
IV 1989	106	14	198	291	42	540	194	122	383	314	210	608
II 1990	111	67	156	328	220	436	193	122	382	372	235	685
IV 1990	105	60	149	257	151	363	228	139	440	361	226	673
II 1991	94	52	136	257	147	368	228	138	439	368	234	677
IV 1991	74	33	115	160	52	267	228	140	439	356	223	665
II 1992	93	70	116	205	160	250	226	138	437	364	229	685
IV 1992	80	59	101	166	122	209	227	140	432	351	218	672
II 1993	103	47	159	244	103	385	223	137	429	361	233	658
IV 1993	95	40	149	220	80	361	224	140	423	347	222	644
II 1994	199	129	268	371	227	516	220	137	420	352	212	640
IV 1994	159	95	224	300	159	441	225	130	400	338	201	625
II 1995	191	115	268	362	189	536	218	124	392	345	209	609
IV 1995	170	90	250	319	146	491	230	138	410	330	196	594
II 1996							220	129	400	337	203	599
IV 1996							225	137	398	323	191	582

	RADCON	lower	upper	TAMDYN-UV	lower	upper	CLRP controlled area	lower	upper	CLRP non-controlled area	lower	upper	SPADE*
June 1986	3376.84	1633.31	6981.57	1310	760	2900	952	584	1550	942	437	2030	432
August 1986				4050	2050	8200							
IV 1986	2001.68	683.72	5860.18	2830	1500	6400	442	193	1010	1139	518	2508	382
II 1987	725.43	155.9	3375.67	1500	680	3100	451	218	942	899	409	1976	231
IV 1987	676.29	141.54	3231.28	690	290	1200	270	112	656	877	408	1884	75
II 1988	380.98	87.85	1652.21	295	160	640	268	112	648	843	391	1814	166
IV 1988	359.52	80.87	1598.31	275	160	530	156	62	390	537	250	1151	147
II 1989	336.01	75.7	1491.52	255	140	500	175	75	413	492	228	1060	113
IV 1989	314.57	67.34	1469.47	360	170	680	265	101	695	1076	500	2316	139
II 1990	291.97	67.84	1256.56	280	135	620	203	95	437	456	212	983	115
IV 1990	277.87	62.12	1242.99	250	130	480	224	107	474	475	221	1020	64
II 1991	267.67	58.01	1235.04	220	120	430	163	69	389	507	236	1092	160
IV 1991	249.26	59.39	1046.07	230	120	420	129	56	297	350	163	751	155
II 1992	229.05	52.9	991.72	220	110	430	135	60	309	356	165	767	150
IV 1992	230.80	50.16	1062.05	210	120	410	161	58	450	788	366	1695	150
II 1993	303.14	77.21	1190.12	210	110	410	153	71	332	346	161	746	159
IV 1993	288.13	70.03	1185.46	310	140	530	161	73	358	394	183	846	144
II 1994	268.33	65.87	1093.16	220	110	430	159	72	355	405	188	872	164
IV 1994	256.77	61.93	1064.57	220	120	410	118	54	260	278	130	596	147
II 1995	428.87	86.7	2121.43	210	110	410	128	59	278	289	134	623	149
IV 1995	396.4	81.16	1936	200	100	410	159	61	416	647	301	1393	154
II 1996	371.19	72.3	1905.8							280	130	604	
IV 1996	366	74	1797							228	107	486	

	OSCAAR controlled area	lower	upper	OSCAAR non-controlled area	lower	upper	SENES** with counter-measures	lower	upper	SENES** without counter-measures	lower	upper
1986	208	148	268	2381	1065	3696	28	3.7	279	28	3.7	279
1987	85	65	106	390	202	577	81	9	382	82	9	386
1988	50	36	64	336	163	510	63	6.4	309	64	6.5	316
1989	53	39	67	322	154	491	37	4.2	194	48	4.8	226
1990	40	30	51	315	150	481	28	2.8	157	38	3.3	181
1991	46	34	58	306	145	467	23	2.4	129	29	3.0	143
1992	45	33	57	296	139	452	17	1.8	111	24	2.1	123
1993	165	112	218	314	155	472	13	1.4	73	18	1.7	89
1994	167	114	221	301	148	455	11	1.1	60	14	1.4	77
1995	151	103	199	290	141	440	10	1.0	53	12	1.1	62

* Predictions for SPADE were made outside the main computer code.

** Predictions for SENES include only the contributions from grains, potatoes, and fish.

TABLE III-XIII. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN THE WHOLE BODY OF MEN (Bq kg^{-1})

	Observed controlled area	lower	upper	Observed non-controlled area	lower	upper		Measurements controlled area	lower	upper	Measurements non-controlled area	lower	upper
1986-09-30	2239	1448	3029	2307	1600	3015	1986-09-01	1792.2	1720.86	1863.54	740	716.4	763.6
1987-09-30	544	319	768	2389	1848	2930	1987-03-15	456.75	400.2	513.3	388.8	370.4	407.2
1988-09-30	377	252	502	1731	1235	2227	1987-09-15	334.95	293.19	376.71	562.8	469.2	656.4
1989-09-30	277	0	578	1252	615	1889	1990-10-15	256.65	198.36	314.94			
1990-09-30	301	160	443	670	414	926	1991-09-15	172.26	155.73	188.79			
1991-09-30	253	119	387	610	350	871	1992-03-15	152.25	125.28	179.22			
1992-09-30	239	171	307	469	354	583	1992-06-01	88.74	80.04	97.44			
1993-09-30	308	129	487	511	187	834	1992-09-15	267.09	146.16	388.02			
1994-09-30	488	294	681	826	483	1169	1993-09-15	504.6	249.69	759.51			
1995-09-30	547	314	779	1013	590	1436	1994-09-15	273.18	228.81	317.55			
							1995-09-15	254.04	166.17	341.91			
							1996-09-15	156.6	127.02	186.18			
							1997-09-15	274.05	236.64	311.46	176.8	128.8	224.8
							1998-09-15	503.73	421.95	585.51			
							1998-09-18				460	326	594

	LIETDOS controlled area	lower	upper	LIETDOS non-controlled area	lower	upper	TAMDYN-UV	lower	upper	CLRP	lower	upper
1986-09-30	813	565	1342	1769	1113	2958	2800	1250	7300	80700	34900	187000
1987-09-30	496	362	991	1101	790	1967	1820	730	4050	69800	24100	202000
1988-04-30	424	293	844	839	589	1511	970	420	2300	53900	25300	115000
1988-09-30	406	272	798	755	518	1359	740	300	1700	50500	17900	142000
1989-09-30	380	241	740	654	426	1177	590	230	1600	40200	14100	115000
1990-09-30	464	269	899	745	435	1363	540	230	1200	34800	13000	93100
1991-09-30	471	270	897	743	428	1379	480	240	1050	31800	11800	85800
1992-09-30	468	269	889	734	426	1360	440	220	920	27200	8910	82800
1993-09-30	466	270	889	724	419	1326	470	230	1000	26500	10200	68700
1994-09-30	460	257	836	719	421	1309	480	240	980	28900	11100	75400
1995-09-30	474	280	866	715	417	1309	430	210	900	26000	9080	74600

TABLE III-XIV. OBSERVED AND PREDICTED CONCENTRATIONS OF ^{137}Cs IN THE WHOLE BODY OF WOMEN (Bq kg^{-1})

	Observed controlled area	lower	upper	Observed non-controlled area	lower	upper		Measurements controlled area	lower	upper	Measurements non-controlled area	lower	upper
1986-09-30	1906	1268	2544	1782	1229	2336	1986-09-01	1644.3	1587.75	1700.85	680	658.8	701.2
1987-09-30	454	320	588	1699	1309	2089	1987-03-15	387.15	354.09	420.21	276.4	262.4	290.4
1988-09-30	320	236	404	1355	1091	1619	1987-09-15	260.13	226.2	294.06	524	482	566
1989-09-30	210	56	364	956	522	1389	1990-10-15	174.87	128.76	220.98	133.2	112.8	153.6
1990-09-30	199	124	274	576	395	758	1991-03-15	103.53	77.43	129.63			
1991-09-30	190	118	262	494	308	681	1991-09-15	96.57	88.74	104.4			
1992-09-30	164	124	204	373	296	449	1992-03-15	83.52	74.82	92.22			
1993-09-30	187	93	280	417	182	652	1992-06-01	62.64	58.29	66.99			
1994-09-30	378	249	506	685	441	928	1993-09-15	301.02	174	428.04			
1995-09-30	445	301	590	825	526	1125	1994-09-15	173.13	127.02	219.24			
							1995-09-15	137.46	93.96	180.96			
							1997-09-15	117.45	92.22	142.68	83.6	68.8	98.4
							1998-09-15	304.5	177.48	431.52			
							1998-09-18				340.4	281.6	399.2

	LIETDOS controlled area	lower	upper	LIETDOS non-controlled area	lower	upper	TAMDYN-UV	lower	upper	CLRP	lower	upper
1986-09-30	650	466	1090	1421	959	2330	2560	1100	6700	64600	27900	150000
1987-09-30	400	296	829	885	652	1601	1660	740	3600	55800	19300	162000
1988-04-30	342	238	696	672	483	1237	890	410	2100	43100	20200	92000
1988-09-30	327	220	652	603	424	1114	540	250	1200	40400	14300	114000
1989-09-30	306	194	605	527	358	995	390	200	790	32200	11300	92000
1990-09-30	352	215	681	577	368	1065	370	190	770	27800	10400	74500
1991-09-30	357	219	688	577	367	1063	330	170	650	25400	9440	68600
1992-09-30	355	220	679	571	360	1073	330	180	660	21800	7130	66200
1993-09-30	352	220	665	567	365	1037	320	160	600	21200	8160	55000
1994-09-30	352	206	631	553	337	1008	320	160	610	23100	8880	60300
1995-09-30	360	215	641	543	328	961	290	150	600	20800	7260	59700

TABLE III-XV. OBSERVED AND PREDICTED DISTRIBUTIONS OF WHOLE BODY CONCENTRATIONS OF ^{137}Cs IN MEN (Bq kg^{-1})

September 1987

percentile	Observed controlled area	non-controlled area	TAMDYN-UV	lower	upper	LIETDOS controlled area	lower	upper	LIETDOS non-controlled area	lower	upper
0.975	60.9	19.6	420	340	500	329	189	522	747	463	1120
0.95	78.3	25.6				363	209	576	814	504	1220
0.9						407	234	645	899	557	1350
0.68			1030	700	1250	523	300	829	1120	692	1680
0.5	258.39	90	1310	900	1600	604	347	958	1270	785	1900
0.32			1650	1200	2500	699	401	1110	1440	891	2160
0.1						898	514	1430	1790	1110	2690
0.05	847.38	313.2				1000	575	1590	1970	1220	2960
0.025	1087.5	408	3710	3200	4400	1090	626	1730	2130	1320	3190

September 1991

percentile	Observed controlled area	TAMDYN-UV	LIETDOS controlled area	lower	upper	LIETDOS non-controlled area	lower	upper
0.975	28.71	125	244	126	413	399	196	641
0.95	37.41		274	141	463	445	220	718
0.9			312	161	528	505	250	818
0.68		270	419	216	709	669	335	1100
0.5	128.76	336	496	256	839	786	397	1300
0.32		411	588	303	994	924	470	1540
0.1			790	406	1330	1220	630	2060
0.05	450.66		901	463	1520	1390	718	2350
0.025	587.25	820	1010	519	1700	1550	804	2630

TABLE III-XVI. ESTIMATED AND PREDICTED EXTERNAL DOSE (mSv)

Cloud Exposure	Mean	lower	upper
Authors' estimates	2.00E-04	7.00E-05	3.40E-04
LIETDOS	3.99E-04	2.21E-04	5.76E-04
RADCON	2.54E-04	8.86E-05	7.32E-04
TAMDYN-UV	4.40E-04	2.00E-04	7.00E-04
CLRP	7.27E-04	3.64E-04	1.45E-03
SPADE	2.29E-04	7.94E-05	3.79E-04
OSCAAR	2.74E-04	2.42E-04	3.06E-04

Ground Exposure	27 April 1986- 30 April 1987			27 April 1986 - 31 December 1990		
	Mean	lower	upper	Mean	lower	upper
Authors' estimates	3.53	2.84	4.22	11.1	8.9	13.3
LIETDOS	4.34	1.50	9.25	16.09	5.56	34.30
RADCON	2.43	1.59	3.70	9.08	5.85	14.08
TAMDYN-UV	1.7	0.9	3.4	5.2	3	9.5
CLRP	3.28	1.64	6.56	12.80	6.40	25.60
SPADE	3.74	0.92	7.47	16.3	4.02	32.5
SENES	4.2	3.4	5.7	12.6	10.2	16.1
OSCAAR	2.68	2.284	3.076	8.82	7.48	10.16

Ground Exposure	27 April 1986 - 31 December 1995			27 April 1986 - Lifetime		
	Mean	lower	upper	Mean	lower	upper
Authors' estimates	18.4	14.8	22	39.6	31.8	47.4
LIETDOS	27.76	9.60	59.16	68.62	23.72	146.20
RADCON	15.89	10.07	25.03	41.35	25.47	67.14
TAMDYN-UV	8.9	4.8	13	11.3		
CLRP	20.10	10.10	40.20	42.80	21.40	85.60
SPADE	30.6	7.56	61.2			
SENES	20.7	16.9	25.4	43.3	35.4	53.9
OSCAAR	15.1	12.77	17.43	45	38	52

TABLE III-XVII. ESTIMATED AND PREDICTED INHALATION DOSE (mSv)

Cloud			
	Mean	lower	upper
Authors' estimates	0.013	0	0.03
LIETDOS	0.0369	0.0205	0.0534
RADCON	0.0152	0.00552	0.042
TAMDYN-UV	0.037	0.015	0.07
CLRP	0.0934	0.0311	0.28
SPADE	0.018	0.006	0.029
SENES-men	0.031	0.0066	0.12
SENES-women	0.023	0.0056	0.094
OSCAAR	0.0229	0.0202	0.0256

Resuspension	27 April 1986- 30 April 1987			27 April 1986 - 31 December 1990		
	Mean	lower	upper	Mean	lower	upper
Authors' estimates	0.026	0.022	0.029	0.027	0.023	0.031
LIETDOS	0.0117	0.00404	0.0249	0.0121	0.00419	0.0258
TAMDYN-UV	0.033	0.01	0.075	0.17	0.05	0.32
OSCAAR	0.000588	0.00049	0.000686	0.00128	0.00107	0.00149

Resuspension	27 April 1986 - 31 December 1995			27 April 1986 - Lifetime		
	Mean	lower	upper	Mean	lower	upper
Authors' estimates	0.027	0.023	0.031	0.029	0.025	0.033
LIETDOS	0.01224	0.00423	0.0261	0.0124	0.00427	0.0263
TAMDYN-UV	0.28	0.08	0.63	0.4	0.11	0.9
OSCAAR	0.0015	0.00126	0.00174	0.00203	0.00173	0.00233

TABLE III-XVIII. ESTIMATED AND PREDICTED INGESTION DOSE FOR MEN (mSv)

		27 April 86 - 30 April 87			27 April 86 - 31 December 90			27 April 86 - 31 December 95			27 April 86 - Lifetime		
		Mean	lower	upper	Mean	lower	upper	Mean	lower	upper	Mean	lower	upper
Authors' estimates													
Controlled area	milk	3.89	2.63	5.15	3.89	2.63	5.15	4.61	2.96	6.25	8.51	5.72	11.3
	meat	0.49	0.28	0.69	0.98	0.59	1.36	1.53	0.95	2.12	1.87	1.47	2.27
	mushrooms	0.64	0.18	1.09	2.63	0.21	5.06	4.94	0.38	9.51	13.71	0	58.09
	Total	5.31	3.95	6.67	7.88	5.09	10.68	11.57	6.64	16.5	26.48	16.68	36.28
Authors' estimates													
Non-controlled area	milk	4.75	3.26	6.23	9.67	6.42	12.91	11.69	7.69	15.68	20.96	8.04	33.87
	meat	1.26	0.79	1.73	3.3	1.96	4.64	4.03	2.41	5.66	4.46	2.78	6.14
	mushrooms	1.2	0.4	2.01	4.98	0.58	9.37	9.34	1.06	17.62	25.89	0	173.22
	Total	7.56	5.8	9.33	18.73	13.09	24.37	25.99	16.63	35.35	54.09	36.07	72.12
LIETDOS													
Controlled area		4.14	2.90	7.04	9.17	6.13	16.97	16.79	10.52	31.21	37.03	22.56	68.17
Noncontrolled area		9.03	5.91	15.30	18.09	11.96	31.79	29.92	18.93	53.35	60.27	36.89	108.00
RADCON	mushrooms	2.80	0.49	17.13	8.00	1.13	59.06	14.30	1.90	111.30	29.23	3.52	248.17
	beef	1.67	0.31	8.91	1.93	0.36	10.53	2.60	0.46	14.65	4.03	0.66	25.09
	grain	1.08	0.14	9.32	1.36	0.15	14.62	1.62	0.17	19.47	2.07	0.19	27.74
	Total	12.12	4.54	32.77	20.43	6.34	71.26	30.80	8.60	119.37	53.73	12.69	248.10
TAMDYN-UV	pork	3.8			6.3			7.8			12		
	potatoes	3.5			5.6			6.7			9		
	beef	2.5											
	mushrooms				5.5			10.6			15		
	Total	14	8	30	24	13	45	34	17	55	46	22	85
CLRP													
Controlled area		2.64	1.32	7.92	9.62	4.81	28.90	13.70	6.85	41.10	22.00	11.00	66.00
Noncontrolled area		4.34			29.00			38.60			78.00		
SPADE	meat	2.59			3.05			3.15					
	mushrooms	0.92			1.71			3.26					
	milk	0.17			0.28			0.32					
	Total	4.1			5.4			7.2					

TABLE III-XIX. ESTIMATED AND PREDICTED INGESTION DOSE FOR WOMEN (mSv)

		27 April 86 - 30 April 87			27 April 86 - 31 December 90			27 April 86 - 31 December 95			27 April 86 - Lifetime		
		Mean	lower	upper	Mean	lower	upper	Mean	lower	upper	Mean	lower	upper
Authors' estimates													
Controlled area	milk	3.23	2.22	4.24	3.23	2.22	4.24	4.04	2.74	5.35	8.76	6.89	10.63
	meat	0.59	0.35	0.83	1.32	0.83	1.81	1.75	0.85	2.64	2.81	0.15	5.47
	mushrooms	0.32	0.08	0.55	1.32	0.07	2.56	2.47	0.13	4.81	6.85	0	18.44
	Total	4.44	3.37	5.51	6.29	4.57	8.02	8.89	6.01	11.77	20.32	14.58	26.06
Authors' estimates													
Non-controlled area	milk	3.55	2.42	4.69	6.93	4.82	9.03	8.86	6.3	11.41	17.31	12.19	22.44
	meat	0.91	0.55	1.26	2.68	1.81	3.55	3.24	2.18	4.29	3.45	2.8	4.1
	mushrooms	0.88	0.31	1.46	3.66	0.5	6.82	6.87	0.9	12.83	19.04	0	95.97
	Total	5.67	4.34	7	13.84	9.92	17.77	19.64	13.03	26.24	41.72	28.83	54.61
LIETDOS													
Controlled area		3.32	2.39	5.74	7.30	4.99	13.71	13.08	8.51	24.46	28.42	17.68	51.77
Noncontrolled area		7.26	4.91	12.14	14.45	9.85	25.45	23.59	15.53	42.14	46.60	29.12	82.84
RADCON	mushrooms	2.80	0.49	17.13	7.07	1.00	52.72	11.32	1.53	86.76	22.73	2.79	190.01
	beef	1.67	0.31	8.91	1.95	0.36	10.67	2.46	0.44	13.84	3.42	0.58	20.29
	grain	1.08	0.14	9.32	1.34	0.15	14.56	1.57	0.16	18.78	1.98	0.19	26.72
	Total	12.12	4.54	32.77	19.49	6.22	65.26	27.11	8.05	97.38	45.22	11.54	191.47
TAMDYN-UV	pork	3.8			6.3			7.8			12		
	potatoes	3.5			5.6			6.7			9		
	beef	2.5											
	mushrooms				5.5			10.6			15		
	Total	14	8	30	24	13	45	34	17	55	46	22	85
SPADE	meat	1.55			1.88			1.97					
	mushrooms	0.57			1.07			2.04					
	milk	0.09			0.16			0.20					
	Total	2.7			3.6			4.7					

TABLE III-XX. ESTIMATED AND PREDICTED TOTAL DOSE FOR MEN AND WOMEN (mSv)

	27 April 86 - 30 April 87			27 April 86 - 31 December 90			27 April 86 - 31 December 95			27 April 86 - Lifetime		
	Mean	lower	upper	Mean	lower	upper	Mean	lower	upper	Mean	lower	upper
Authors' estimates men controlled area	9.2	7.6	10.8	20.2	16.5	23.9	32	25.9	38.3	70.5	57.5	83.5
Authors' estimates men non-controlled area	9.4	7.6	11.2	24.4	18.7	30.2	35.4	25.9	44.9	74.3	55.8	92.8
Authors' estimates women controlled area	8.3	7	9.7	18.6	15.6	21.6	29.3	24.7	34.2	64.3	53.9	74.7
Authors' estimates women non-controlled area	7.5	6.1	8.9	19.5	15.5	23.6	29	22.1	35.9	61.9	48.4	75.4
LIETDOS - men	9.74	5.18	18.40	27.29	13.10	54.53	46.97	21.93	94.15	108.64	48.41	218.53
RADCON - men	14.55	6.13	36.47	29.51	12.19	85.34	46.69	18.67	144.40	95.08	38.16	315.24
TAMDYN-UV - men	16	5	30	29.8	10	60	43.9	15	110	58	27	150
CLRP - men	6.01	2.00	18.00	22.50	7.50	67.50	33.90	11.30	102.00	64.90	21.60	195.00
SPADE-men	7.9			21.7			37.8					
SPADE-women	6.5			19.9			35.3					

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Meetings

BIOMASS Theme 2 Planning Meeting, Vienna, Austria: 24–28 June 1996
BIOMASS Dose Reconstruction WG Planning Meeting, Mol, Belgium: 11–13 June 1997
BIOMASS Plenary and Working Group Meetings, Vienna, Austria: 20–24 October 1997
BIOMASS Dose Reconstruction WG Meeting, Veszprém, Hungary: 8–12 June 1998
BIOMASS Research Co-ordination, Plenary and Working Group Meetings,
Vienna, Austria: 5–9 October 1998
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Vienna, Austria: 4–8 October 1999
BIOMASS Dose Reconstruction WG Meeting, Kjeller, Norway: 25–26 May 2000
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