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Modelling the transfer of radionuclides to fruit

Report of the Fruits Working Group of BIOMASS Theme 3

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 the activities of the Fruits Working Group under Theme 3. The IAEA wishes to acknowledge the contribution of the Working Group Leader, F. Carini of Italy, and of A. Venter of the United Kingdom, in the preparation of this report. Additional financial support was provided to this group by the Food Standards Agency (formerly Ministry of Agriculture, Fisheries and Food of the United Kingdom (MAFF)) and the Environment Agency of England and Wales. The IAEA officer responsible for this publication was Y. Inoue of the Division of Radiation and Waste Safety.

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SUMMARY

This report contains a description of the activities carried out by the Fruits Working Group and presents the main results such as conceptual advances, quantitative data and models on the transfer of radionuclides to fruit in the context of the overall objective of BIOMASS Theme 3. The aim of the study was to improve understanding of the processes affecting the migration of radionuclides in the fruit system and to identify the uncertainties associated with modelling the transfer of radionuclides to fruit. The overall objective was to improve the accuracy of risk assessment that should translate to improved health safety for the population and associated cost savings.

The significance of fruit, intended as that particular component of the human diet generally consumed as a dessert item, derives from its high economic value, the agricultural area devoted to its cultivation, and its consumption rates. These are important factors for some countries and groups of population.

Fruits may become contaminated with radioactive material from nuclear facilities during routine operation, as a consequence of nuclear accidents, or due to migration through the biosphere of radionuclides from radioactive waste disposal facilities. Relevant radionuclides when considering transfer to fruit from atmospheric deposition were identified as ^{3}H, ^{14}C, ^{35}S, ^{36}Cl, ^{90}Sr, ^{129}I, ^{134}Cs and ^{137}Cs.

The transfer of radionuclides to fruit is complex and involves many interactions between biotic and abiotic components. Edible fruit is borne by different plant species, such as herbaceous plants, shrubs and trees, that can grow under different climatic conditions and may be found in agricultural or natural ecosystems.

A review of experimental, field and modelling information on the transfer of radionuclides to fruit was carried out at the inception of the activities of the Group, taking into account results from a Questionnaire circulated to radioecologists. Results on current experimental studies have also been discussed during the biannual meetings of the Group. These findings, as well as results from those experimental studies reported directly to the Group and key interactions reported in the literature, are reported below.

Radionuclides reach fruit by three principal routes: (i) deposition to soil, vertical migration in soil, root uptake, migration to the fruit (and other plant parts); and/or (ii) deposition to exposed plant surfaces, translocation to plant interior, migration to the fruit (and other plant parts); and/or (iii) deposition to exposed fruit surfaces. The relative significance of each pathway depends upon the season during which contamination occurs, upon the stage of plant development and upon how this development is affected by climatic, edaphic and management factors.

Root uptake followed by migration to the fruit is represented in literature by the soil to plant Transfer Factor (TF), a parameter that relates radionuclide concentration in fruit to that in the soil. A collection of data on TFs for fruit crops provides ranges for caesium, strontium, plutonium and americium. The variability in TF for a given radionuclide is mainly ascribable to differences in soil properties, rather than differences between fruit species. TF values for caesium are the most variable and cover six orders of magnitude. They are markedly higher for fruit from tropical and subtropical regions than for fruit from temperate regions. The highest TF values are associated with apple, peach and grapevine in temperate regions and with papaya, breadfruit, pandanus and coconut in tropical and subtropical zones. TF values for strontium are less variable than are those for caesium. The highest TFs are associated with

blackcurrant, papaya, breadfruit and pandanus. TF values for plutonium and americium are lower for subtropical and tropical regions than for temperate regions. Aggregated transfer coefficients (T_{ag}) to wild berries also provide some evidence for a correlation between T_{ag} and the type of forest soil.

New information has been provided on soil to fruit transfer during the time of Group activities on 12 soils in Japan and concerns U, Th, Pb transfer in apple and mandarin. New data are going to be produced by current experimental studies on apple, blackcurrant, gooseberry, strawberry, blackberry and grapevine concerning strontium, caesium, plutonium, americium and iodine. Measurements in time, even if limited, will also give the opportunity of discussing and understanding key processes.

Foliar absorption is radionuclide specific. It is greater for young leaves than it is for old leaves and is time dependent. There is some evidence that absorption of strontium and caesium is similar within 24 hours after contamination, but thereafter strontium is absorbed to a much lesser extent than caesium. The rate of absorption depends both on humidity and temperature, as well as on plant species and cultivar.

Translocation from the site of contamination to other parts of the plant depends on the radionuclide, the plant species, cultivar and rootstock, and the stage of development of the plant at the time of contamination. A collection of data on the activity of fruits after foliar deposition provided values for caesium and strontium. Data are hardly comparable, given different approaches and experimental protocols. Generally speaking, caesium is more readily translocated to fruit than is strontium. Among woody trees, apple shows the highest and orange the lowest translocation of caesium to fruit. Among shrubs, gooseberry shows the highest translocation of both caesium and strontium.

The position concerning knowledge on the uptake of radioactive gases by fruit crops has been improved by recently completed experimental studies. New information has been provided on deposition, uptake, loss and translocation of $^{14}CO_2$, $CO^{35}S$ and $^{3}H_2O$ to apple, raspberry, strawberry and blackcurrant. Deposition velocities are of the same magnitude as those observed for other crops. The partitioning and allocation of ^{14}C, ^{35}S and ^{3}H (OBT) follow similar trends for all the crops studied. The relative proportions of ^{14}C, ^{35}S and ^{3}H (OBT) in leaves immediately after fumigation suggest that tritium moves rapidly throughout the plant, whilst ^{14}C moves more slowly, and ^{35}S movement is slower still.

The fruit contamination at harvest is affected to a very variable extent by the activity directly deposited on its surface. Many variables contribute to the process: the kind of deposit, wet or dry, the kind of fruit surface, the fruit’s physical exposure to the fallout and afterwards to weathering, and the time elapsed between deposition and harvest. Information to evaluate the importance of these variables is scarce. Furthermore data are mainly limited to radionuclides of Cs and Sr and to vine and apple systems.

Concentration in the fruit varies both as the fruit develops and according to the time of contamination relative to production of the fruit. For caesium, complex patterns in concentration may be observed during a growing season as a result of the combination of rate of transfer to the fruit, rate of biomass production of the fruit, and degree of water content.

Fruit storage before consumption as well as industrial or domestic processing may reduce the activity concentration in the foodstuff that is actually consumed, with implications for assessments of doses from releases of radionuclides to the environment.

The carryover of caesium in grapevines in controlled conditions and in apricot trees contaminated from Chernobyl fallout shows a decrease of one order of magnitude in three years. Similarly new information produced on ^{14}C, ^{35}S and ^{3}H (OBT) activity in apple and raspberry shows that the proportion of radionuclides carried over from one growth season to the next is very low. Information on the behaviour of strontium in the years following deposition is insufficient to define a clear trend.

Data collected by the participants have been incorporated into a database, RADFLUX, which represents a substantial collection of transfer parameters for use in models of soil–plant–animal systems. Data concern 34 types of fruit crops, from temperate, tropical and subtropical climate, deriving from studies of nuclear explosion fallout, Chernobyl accident fallout, or from controlled experimental contamination. The most represented fruits are olive, orange, apple, papaya, and strawberry. The radionuclides for which data have been collected are mainly those of caesium, strontium and Pu. New additional information from current experimental studies is being produced on apple, blackcurrant, blackberry, gooseberry, strawberry, olive, grapevine, mainly concerning caesium and strontium, but also plutonium, americium, iodine and cobalt. Data that are going to be generated consider soil or leaf contamination and give concentration in different plant components, other than fruit, at ripening. Another set of data near to completion concerns caesium in strawberry components at different times after contamination. Information is also being collected from field measurements of Chernobyl fallout on sweet cherries, apricots, pears, apples, peaches and olives.

Several models have been identified in the literature, through the review, that deal specifically with the transfer of radionuclides to fruit as well as others that are adaptations of models for an agricultural crop such as a leafy green vegetable. Each represents the soil–fruit plant system in different ways and the model parameters derived from the literature or from observations reflect the specific model structure.

A systematic approach was taken by the participants to develop a conceptual fruit model and to assess the state of the participants' knowledge for the dominant pathways. The objective was to provide guidance for future development of a model to represent the contamination of fruit following atmospheric deposition and identify gaps in participant knowledge of key processes. The Working Group comprised eighteen representatives from a broad range of interests and disciplines. They contributed to the development of a matrix for the scenario of a fruit tree subject to a deposit from atmosphere and attempted to arrive at a consensus on the key processes that determine the transfer of radionuclides to fruit.

The agreed components of the system include *Air, Leaf, Wood and Stem, Soil, Ground cover*, *Roots, Micro-organisms, Debris* and *Fruit*. *Ground cover, Micro-organisms* and *Debris* were included as part of the overall system even though limited information is available in the literature. The processes involved in the matrix interactions were identified and their definitions agreed. The relative importance of the interactions was scored and the ranked scores were used to produce a graph of cause/effect relationships and model structure diagrams. The state of knowledge of the Group about the highest-ranking interactions was also assessed qualitatively.

The *Soil* component shows that soil interacts strongly with other components but is on balance subordinate to the rest of the system. The *Air, Leaf* and *Wood and Stem* components show a weaker interaction with the system as a whole, but all of these are dominant components. The strength of interaction for both *Air* and *Leaf* with the rest of the system was thought similar by the participants. The third cluster has the weakest interactions with the system and includes

Ground cover, Roots, Micro-organisms, Debris and *Fruit.* The role of micro-organisms remains uncertain; it is known they are important within the rhizosphere and on the phylloplane, but participants do not yet have a good understanding of these interactions. Micro-organisms could probably be incorporated within the root and leaf elements without a major impact on the results obtained.

A model for fruit will need to concentrate effort on the interaction of *Air, Leaf* and *Wood and Stem* with *Soil* as a subordinate component. Although this is not an unexpected result for this scenario it has been reached through consensus and is based on a systematic analysis of the problem.

Two model intercomparison studies were undertaken by the Working Group, to identify and investigate significant areas of uncertainty and differences in approach between models. Two scenarios were developed for this intercomparison exercise, simulating an atmospheric source term, given that very few participating models were designed to simulate a terrestrial source. The first scenario was designed to simulate an acute release and the second to simulate a continuous release. Three radionuclides (^{137}Cs, ^{90}S and ^{129}I) and three fruit bearing crops (apple, blackcurrant and strawberry) were considered for each scenario. The radionuclides were chosen among those identified as relevant through the review, from the responses to the Questionnaire and taking into account those radionuclides for which most of the participating models had been calibrated. The fruits were chosen to represent three different morphological types, according to the classification of the Group: a woody tree, a shrub and an herbaceous plant.

Six models, the majority of which were identified from the Questionnaire, participated in the model-model intercomparisons: SPADE (UK), FRUTI-CROM (Spain), FRUITPATH (USA), RUVFRU (Hungary), DOSDIM (Belgium) and ASTRAL (France). The uncertainty for model parameters is in general larger for apples and blackcurrants than for strawberries. Strawberry is in fact a more common and popular fruit for many European countries than apples and blackcurrants and is represented in many models. In addition, fate and transport processes within blackcurrant bushes and apple trees are of greater complexity than those in strawberry plants and information on these is sparse and difficult to interpret.

Results for the acute deposition scenario were submitted by five models for strawberries and by four models for apples and blackcurrants, while for the continuous deposition scenario there were four models for strawberries and three models for apples and blackcurrants. The differences between models were as high as five orders of magnitude for short term predictions following the acute radionuclide deposition. For the long term consequences and for the continuous deposition scenario, the differences between models decreased to only two orders of magnitude. The large difference among model predictions seems to be much higher than parameter uncertainty for a given model and reveals the current uncertainty in predicting future concentrations of radionuclides in fruits once contamination occurs.

A validation study was undertaken to test model predictions against an independent data set. All six above mentioned models participated in the validation exercise. The scenario is based on the transfer of ^{134}Cs and ^{85}Sr via leaf to fruit and soil to fruit in strawberry plants after an acute release. Foliar contamination was carried out through wet deposition on the plant at two different growing stages, anthesis and ripening, while soil contamination was effected at anthesis only. Strawberry plants were grown in pots filled with peat substrate and placed under a ventilated tunnel in a field representative of horticultural growing conditions in Italy.

Models performed reasonably well. In the case of foliar contamination, predicted values are generally in good agreement (within one order of magnitude) with the measured values, while in the case of soil contamination models tend to underpredict. Differences for caesium are up to three orders of magnitude both for fruit and leaf, while differences are lower for strontium. One of the reasons of the underprediction may be the fact that parameter values used by most of the models refer to steady state conditions whereas the situations represented in the scenarios do not represent a state of equilibrium. The type of soil used to grow the strawberry plants may also have favoured high radiocaesium uptake. Furthermore, under experimental conditions with plants growing in pots under a tunnel, root growth and leaching might be different from field conditions for which models are calibrated. Various of these aspects are related to the scenario interpretation that is one of the causes of mispredictions of models.

1. INTRODUCTION

1.1. BACKGROUND

Fruit plays a considerable role in the global agricultural economy, with fruit representing about 8% of world agricultural production. It makes a major contribution to the human diet, particularly for some groups of the population. There is scarce qualitative or quantitative information on the behaviour of radionuclides in plants bearing fruits. For most components of the human diet such as cereals, cooked vegetables, grass, meat, milk and dairy products, a large amount of specialised literature exists. In comparison, very few resources have been invested in the study of the behaviour of radionuclides in fruit plants and those data that do exist are incomplete.

In recent years there have been two principle international programmes aimed at the improvement of methods for assessing the impact of radionuclides in the environment; they are the IAEA's VAMP programme and the BIOMOVS II study supported by organisations from Canada, Spain and Sweden.

The VAMP Programme was a Co-ordinated Research Programme on "The Validation of Models for the Transfer of Radionuclides in Terrestrial, Urban and Aquatic Environments and the Acquisition of Data for that Purpose". It was established by the International Atomic Energy Agency (IAEA) in 1988 and concluded in 1994. The VAMP programme sought to use the information on the environmental behaviour of radionuclides that became available as a result of the measurement programmes instituted in countries of the former Soviet Union and many European countries after April 1986. The information was utilised to test the reliability of models used in assessing the radiological impact of all parts of the nuclear fuel cycle.

Uncertainties associated with the transfer of radionuclides to fruit were highlighted in VAMP. For instance, the Multiple Pathways Assessment Working Group noted in scenario CB that many participants overestimated concentrations of ^{137}Cs in fruit trees, and that models for predicting the contamination of fruit were in need of further improvement, particularly with respect to time and stages of leafing and transfer within the tree and the fruit. The S scenario for Southern Finland identified the importance of the pathway for transfer to wild berries. The Terrestrial Working Group noted that the correlation of the interception fraction to biomass was strongly supported for pasture grass and other leafy crops but that for other crops such as grain, fruits and vegetables, a normalisation to leaf area appeared to be more appropriate.

The BIOMOVS (BIOspheric MOdel Validation Study) programmes were concerned with biosphere issues including those related to disposal of radioactive wastes. The BIOMOVS I programme was launched at a meeting in Paris in 1986 and was completed in Stockholm in 1990. BIOMOVS II, a follow-up programme to BIOMOVS I, was started in October 1991 and had its final meeting in Vienna in October 1996. The primary objectives of BIOMOVS II were:

(1) to test the accuracy of the predictions of environmental assessment models for selected contaminants and exposure scenarios;

(2) to explain differences in model predictions due to differences in model structure, modelling assumptions and/or differences in selected input data; and

(3) to recommend priorities for future research to improve the accuracy of model predictions.

The BIOMOVS Programmes did not specifically address the transfer of radionuclides to fruit.

The VAMP and BIOMOVS Programmes were followed by another IAEA Co-ordinated Research Programme, BIOMASS (BIOsphere Modelling and ASSessment) that started in October 1996. The overall objective of BIOMASS was to provide an international focal point in the area of biospheric assessment modelling. The Programme had three Themes. Themes 1 and 2 addressed issues of particular interest in the context of radioactive waste disposal assessment, methods for dose reconstruction, and environmental remediation assessment. The objective of Theme 3 was to identify and attempt to solve issues of potential importance in biosphere model development and application.

The significance of the transfer of radionuclides to fruit was recognised by the International Union of Radioecologists (IUR) Task Force concerned with radionuclide transfer in semi-natural ecosystems, as well as by the joint IAEA/IUR Co-ordinated Research Programme (CRP) on transfer of radionuclides from air, soil and freshwater to the foodchain to man in tropical and subtropical environments. As a consequence a formal IUR Task Force on radionuclide transfer to fruits was established in late 1996 to promote interest in this subject. On the basis of the work completed by this Task Force, a Fruits Working Group was established as a joint IAEA/IUR CRP under BIOMASS Theme 3 in September 1997.

1.2. OBJECTIVES AND SCOPE OF THE FRUITS WORKING GROUP

The objective of the Fruits Working Group was to improve understanding of the uptake and transfer of radionuclides, both anthropogenic and natural, to fruit. The aim was to reduce the uncertainties associated with modelling the transfer of radionuclides to fruit and thereby to improve the robustness of models that are used for radiological assessment and to increase the confidence with which they are applied. A combination of modelling and experimental techniques was used to obtain maximum benefits from research and modelling.

The Working Group encouraged new experimental work to provide data for independent testing and validation of existing models, as well as new models developed during the programme.

The overall objective of the Fruits Working Group was met by a programme of work with the following subsidiary objectives:

(1) To bring together modellers and experimentalists in the field of radionuclide transfer to fruits to allow for the exchange of information and peer review.

(2) To review what has been done in this and related fields with respect to research, development and application of models, and specification of data for application to radiological assessments.

(3) To develop a database of experimental observations in conjunction with existing IUR activities in this field.

(4) To undertake model intercomparisons to identify and investigate significant areas of uncertainty and differences in approach.

(5) To identify, encourage and co-ordinate additional experimental studies on the transfer of radionuclides to fruit so as to maximise the benefits of current or new experimental research in this field.

(6) Where possible and practicable, to undertake testing and validation of existing or new models against independent datasets.

1.3. SCOPE OF THIS REPORT

This TECDOC is a report on the activities of the BIOMASS Fruits WG from September 1997 to April 2000. The sections are a reflection of the various tasks undertaken by the Fruits WG.

One of the first tasks of the Fruits WG was to circulate a Questionnaire to the radioecological community. The purpose of the Questionnaire was to identify persons working in the field of radionuclide transfer to fruit, their area of expertise (experimental, modelling), radionuclides of interest, and datasets that might be suitable for model validation. The resulting responses to the Questionnaire, combined with a review of the main sources of radionuclides to the environment (Section 2), indicated that the following artificial radionuclides are generally important when considering transfer to fruit: ^{3}H, ^{14}C, ^{35}S, ^{36}Cl, ^{90}Sr, ^{129}I, ^{134}Cs and ^{137}Cs. In contrast, ^{241}Pu and ^{241}Am are considered to be of less significance.

Given that most of the models participating in intercomparison exercises had been calibrated for ^{137}Cs with some calibrated for strontium and iodine as well, it was decided to focus on these radionuclides for the initial intercomparison studies. ^{35}S was also considered, but it is of interest only in the context of releases from UK gas cooled reactors and very few models had been calibrated for ^{35}S. The choice of caesium and strontium also reflects their importance for long term radiological assessment because of their long physical half-life. Furthermore, these radionuclides are chemical analogues of potassium and calcium respectively, which are essential elements in plant systems. Iodine is of interest because of its significance in fuel reprocessing.

Apples, blackcurrants and strawberries were selected for study, as these represented three different morphological types, i.e. a fruit tree, a bush, and an herbaceous plant.

1.3.1. Review publication

One of the first tasks of the Fruits WG was to undertake a review of experimental, field and modelling information on the transfer of radionuclides to fruit in the context of the overall objective of BIOMASS Theme 3 i.e. to improve capabilities for modelling the transfer of radionuclides in those parts of the biosphere identified within BIOMASS as being of potential radiological significance. The aim was to provide a detailed review of the transfer of radionuclides to, and behaviour in, fruit bearing plants. To a certain extent, this review represents the *status quo* at the start of the activities of the Fruits Working Group (October 1997) and provided the basis for additional review, experimental and modelling studies that were undertaken by the group. The aim of these was to improve knowledge on the behaviour of radionuclides in soil–plant systems and in particular in fruit bearing species.

The review resulted in a substantial publication that was published in draft form as the first IAEA Working Document of the Fruits Working Group. A further version was published as a Special issue of the Journal of Environmental Radioactivity [JER, 2001]. An overview of the review is given in Section 2 of this report.

1.3.2. Derivation of a conceptual model

The participants of the Fruits Working Group perceived the importance to discuss the key processes that determine the transfer of radionuclides to fruit and to assess the state of knowledge for the dominant pathways. Eighteen participants, representatives from a broad range of interests and disciplines, contributed to the development of a conceptual model for a fruit tree subject to a deposit from atmosphere. The objective was to identify gaps in knowledge of key processes and to provide guidance for future development of a conceptual model representing the contamination of fruit following atmospheric deposition. The methodology of approach and results of the work are described in Section 3.

1.3.3. Experimental studies

The Fruits WG did not undertake experimental studies *per se*, but collected information from a wide range of studies conducted by members of the Fruits WG, as well as from non-participants. The purpose was to collect data either for further development of models or for the testing and validation of existing models. An additional purpose was to improve understanding of important processes. Data were also collected on a wider basis with the objective of identifying gaps in current activities and to provide direction for future experimental studies. Results from recent experimental studies of interest to the Fruits WG are described in Section 4, as well as ongoing experimental studies that will produce new information in this field.

1.3.4. Database

Data were collected and stored in an electronic database, which represents a substantial collection of transfer parameters for use in models of soil–plant–animal systems. Data concern 34 types of fruit crops, from temperate, tropical and subtropical climate, deriving from studies of nuclear explosion fallout, Chernobyl accident fallout, or from controlled experimental contamination. New additional information from current experimental studies is being produced. The database is described in Section 5.

1.3.5. Modelling

One of the objectives of the Fruits WG was to reduce the uncertainties associated with modelling the transfer of radionuclides to fruit and thereby to improve the robustness of the models that are used for radiological assessment and to increase the confidence with which they are applied. The Fruits Working Group therefore undertook two model intercomparison studies to identify and investigate significant areas of uncertainty and differences in approach between models. A validation study was also undertaken where the models that participated in the model intercomparison studies were tested against an independent data set. These studies are described in Section 6.

2. A CRITICAL REVIEW OF EXPERIMENTAL, FIELD AND MODELLING INFORMATION ON THE TRANSFER OF RADIONUCLIDES TO FRUIT

2.1. INTRODUCTION

This section provides a review of experimental, field and modelling information on the transfer of radionuclides to fruit in the context of the overall objective of BIOMASS Theme 3 i.e. to improve capabilities for modelling the transfer of radionuclides in those parts of the biosphere identified within BIOMASS as being of potential radiological significance. It reflects contributions provided by participants in the BIOMASS Theme 3 Fruits Working Group and includes information collected from responses to a questionnaire circulated amongst the radioecological community. The aim was to provide a detailed review of the transfer of radionuclides to, and behaviour in, fruit bearing plants. To a certain extent, this review represents the *status quo* at the start of the activities of the Fruits Working Group (October 1997) and provided the basis for additional review, experimental and modelling studies that were undertaken by the group. The aim of these was to improve knowledge on the behaviour of radionuclides in soil–plant systems and in particular in fruit bearing species. The participants of the group discussed the important role that micro-organisms may have in this field, but they were not able to address this topic as part of the review.

The review was published in draft form as the first IAEA Working Document of the Fruits Working Group [IAEA, 1999]. A further version was published as a Special issue of the Journal of Environmental Radioactivity, which should be consulted for more detail [JER, 2001].

2.2. BACKGROUND

The information reported in this section has been extracted from Carini et al., [2001].

Botanically, fruit is the structure of angiosperms that develops from the ovary wall after fertilization as the enclosed seed or seeds mature. In a strict botanical sense, fruit can be considered a very wide heterogeneous group of plant products, including cereals, vegetables, oilseeds, spices and fleshy fruits. In this review, the term “fruit” does not refer to a well defined botanical plant part, but in the horticultural sense, to a component of the human diet generally consumed as a dessert item. The common verbal usage and the way in which they are consumed allow fruits to be defined as “plant parts that have fragrant, aromatic flavours and are either naturally sweet or normally sweetened with sugar” [Desai and Salunkhe, 1991].

Edible fleshy fruits include a wide variety of plant products that have a very uneven geographical distribution. The various groups of fruits can be grouped broadly as: berries, hesperidia, pepos, drupe, pomes and nuts [Desai and Salunkhe, 1991]. Plants that bear fruits cover a vaste range of habits and morphological and physiological traits, and can be woody trees, shrubs, or herbaceous plants, evergreen or deciduous, perennial or annual.

For the purpose of this review, fruit is grouped according to whether it is produced in agricultural or semi-natural ecosystems. For the former, subdivision is made between those fruit that are produced in temperate climates and those that are produced in tropical or sub tropical climates. For those fruits produced in temperate climate regions, a further subdivision is made between woody trees and grapevines, shrubs, and herbaceous plants.

TABLE 1. CLASSIFICATION ADOPTED IN THIS REVIEW

Ecosystem	Climate	Type of plant
Agricultural	Temperate	woody trees, grape vines shrubs herbaceous plants
	Tropical and subtropical	
Natural Semi-natural		wild berries

2.3. THE INFLUENCE OF THE DEVELOPMENT OF TEMPERATE FRUIT TREE SPECIES ON THE POTENTIAL FOR THEIR UPTAKE OF RADIONUCLIDES

The information reported in this section has been extracted from the work of Atkinson and Webster [2001].

An understanding of the uptake of radionuclides by fruit plants from the atmosphere and via the soil requires an appreciation of the phenological development of above and below ground organs of different fruit bearing species and how this development is affected by climatic, edaphic and management factors. Information reported in this section concerns temperate fruit trees (top fruit), particularly with respect to apple (*Malus domestica*).

The total potential uptake of a fruit tree through its leaves will be influenced by the number of leaves on the tree at different times in the year, as well as by factors associated with leaf development such as leaf surface characteristics and the structure of cuticles. Environmental factors such as temperature and humidity will also alter the permeability of the leaf surfaces by changing the composition of the cuticular waxes [Baker et al., 1982]. Environmental/climatic factors may also influence the uptake of radionuclides by leaves, these factors including the tree moisture status, the amount of leaf shading and surface wetness, the subsequent likelihood of rainfall, and air temperature.

The total leaf area/tree will be influenced greatly by the scion species and/or cultivar, the rootstock, the level of cropping, and management practices such as pruning, irrigation and nutrition. There are often large differences among fruit species and/or cultivars in the ratio of fruit number to leaf area. Heavy fruit set usually depresses shoot growth, whilst transient drought conditions may reduce shoot growth and stimulate partial defoliation. Conversely, severe pruning, irrigation and nitrogen nutrition stimulate growth at the expense of fruit production, thereby changing the ratio of fruit to shoot.

The potential uptake of a fruit tree via soil will be influenced not only by the scale of deposition on the soil surface, but also by the stability of the breakdown metabolites from abscinding leaves or chopped shoot prunings and by the speed and efficacy of their incorporation into the soil profile. The size and competition of earthworm populations may have an influence on this incorporation. This uptake will also be influenced by the dynamics of root growth within the soil profile, by the efficiency of root distribution within the soil horizons and by the ability of these roots to take up the radionuclides.

The amounts of different types of roots produced by a tree are influenced by factors such as planting density, the type of rootstock used, orchard management, irrigation, herbicide treatment, and the presence of other plants competing for nutrients and water. Root depth and distribution, as well as root density, are also greatly influenced by the rootstock used and the scion cultivar itself [Rogers and Vyvyan, 1934; Rogers et al., 1986]. The roots of most fruit trees are usually mycorrhizal. Mycorrhizal infection can increase the uptake of mineral elements. Uptake of caesium as well as cobalt has been verified to be increased by VA mycorrhizae colonisation [Rogers et al., 1986].

2.4. THE ROLE OF FRUIT IN THE DIET

The information reported in this section has been extracted from the work of Fulker [2001].

The agricultural area in the European Union devoted to the production of fresh fruit corresponds to 11.4×10^6 ha. This represents 15.4% of arable land and comes in third place after “cereals + rice” (51.2%) and “green fodder from arable land” (16.5%) [EUROSTAT, 1996].

The average consumption rate of fruit in Europe is 347 g per day, but there are considerable variations from country to country with the highest being Belgium, Luxembourg, Netherlands and Cyprus, at around 500 g per day in 1992. The lowest fruit consumers include USA, Ireland, Japan and France (Figure 1). It should be noticed that data for different countries may be for different years and may include or exclude different fruits. In the context of this review fruit includes fruit juice, frozen and canned fruit and dried fruit, but excludes nuts [Sharp, 1997]. It has to be noticed that some consumption rate data tend to overestimate fruit consumption, because they are derived from national production, plus imports, less exports, and no allowance is made for wastage. Consumption rates based on surveys of individual habits are considered more realistic and are used, when available.

The consumption of wild growing berries may be important in assessing the dose effects of nuclear accidents, such as Chernobyl. However the consumption rate data for wild fruits are often very variable and therefore need careful interpretation.

The naturally occurring alpha emitting radioisotopes ^{210}Pb and ^{210}Po can contribute a significant dose to fruit consumers and need to be considered.

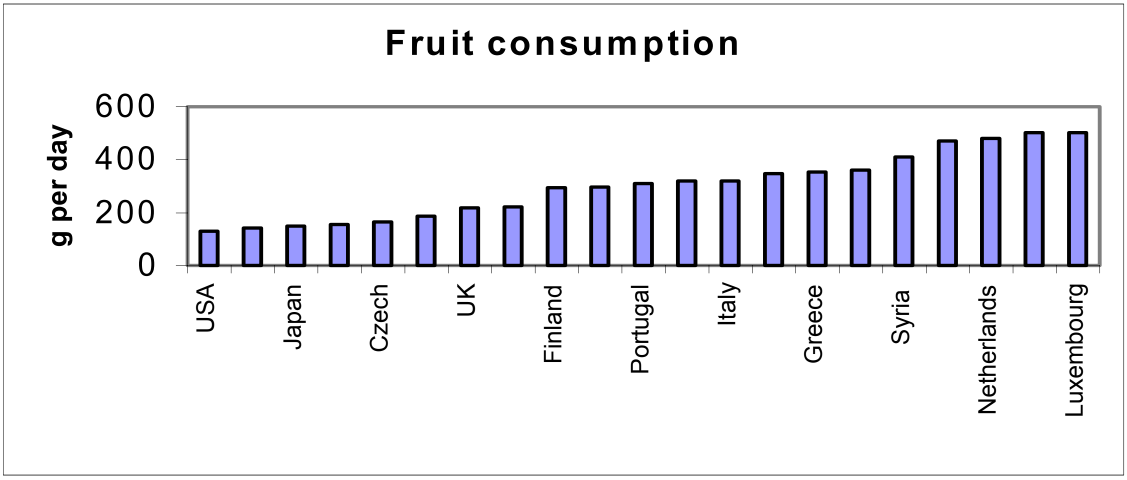

FIG. 1. Fruit consumption in various countries in g per day fresh weight [Fulker, 2001].

Consumption of fruit is rising: world production of fruit increased by 9% between 1989 and 1994. There is evidence of increasing trade in fruit between countries, with fruit juice and canned fruit being particularly important dietary components for some countries. There is also some evidence that consumption rates vary with factors such as age, socio-economic class, and climate. However, unless fruit consumption plays a major portion in the diet, it is recommended that mean consumption rates should be used when undertaking dose assessments for population groups close to nuclear establishments [Byrom et al., 1995].

2.5. TRANSFER OF RADIOACTIVITY TO FRUIT: SIGNIFICANT RADIONUCLIDES AND SPECIATION

The information reported in this section has been extracted from the work of Ould-Dada et al., [2001].

A review of the main sources of radionuclides to the environment, combined with responses to the questionnaire, indicated that the following artificial radionuclides are relevant when considering transfer to fruit: ^{3}H, ^{14}C, ^{35}S, ^{36}Cl, ^{45}Ca, ^{85}Sr, ^{90}Sr, ^{129}I, ^{131}I, ^{134}Cs and ^{137}Cs. In contrast, Pu-α, ^{241}Pu and ^{241}Am are considered to be of less significance. Naturally occurring radionuclides such as ^{210}Po and ^{210}Pb should not be ignored. ^{36}Cl was included because of its potential interest with respect to radioactive waste disposal and ^{45}Ca was included as a useful indicator of the behaviour of strontium.

A brief review of information on the chemical speciation of radionuclides indicates that there have been no published studies on the consequences of chemical speciation for foliar or root uptake of radionuclides by fruit, or on the chemical speciation of radionuclides in fruit subsequent to uptake. For ^{14}C, ^{129}I, ^{131}I, ^{3}H and ^{35}S there is some relevant information on speciation with respect to atmospheric exposure of fruit. For exposure via soil pathways there is also relevant information on speciation but this information is generally not relevant to current models.

2.6. DEPOSITION OF GASEOUS RADIONUCLIDES TO FRUIT

The information reported in this section has been extracted from the work of Stewart et al., [2001]. The authors reviewed the information available at the inception of the activities of the Fruits WG on the processes of deposition, uptake, allocation and loss of ^{14}C, ^{35}S and ^{3}H, with respect to fruit and conceptual models for gaseous radionuclides.

The mechanisms for the uptake of $^{14}CO_2$ ([^{14}C]-carbon dioxide), $CO^{35}S$ ([^{35}S]-carbonyl sulphide) and HTO ([^{3}H]-water) by vegetable crops have been studied fairly extensively and their deposition velocities have been quantified. There is also a reasonable body of work on the translocation of ^{14}C once in the crop, but much less for ^{35}S and ^{3}H, which are considered to follow source-sink relationships. The uptake of $^{14}CO_2$ during fruit growth is of potential significance in terms of the ingestion dose to man, because fruits are irreversible storage sinks of assimilates [Ho, 1988]. The loss rates of the three radionuclides show large differences, with tritium lost rapidly in the form of HTO but retained longer when converted to OBT (Organically Bound Tritium). The losses of ^{14}C are less and those of ^{35}S are minimal post fixation.

Information collected at the inception of the Fruits WG activities shows that there had been relatively little investigation of uptake by fruit crops. Results from experiments completed during the years of activity of the Fruits WG on ^{14}C, ^{35}S and ^{3}H fill some of these gaps. A summary of these is reported in Section 4.

2.7. AERIAL CONTAMINATION OF FRUIT THROUGH WET DEPOSITION AND PARTICULATE DRY DEPOSITION

The information reported in this section has been extracted from the work of Kinnersley and Scott [2001]. The authors reviewed the knowledge at the inception of the activities of the Fruits WG on processes and pathways which lead to the contamination of fruit crops by non-gaseous airborne contaminants.

Given the wide range of fruit canopies, the authors consider it necessary to look for generic factors which affect the contribution of each process and pathway to distribution through the canopy, losses from the canopy back to the atmosphere, and the fate of particle-bound substances once attached to the canopy. This latter stage represents the greatest source of uncertainty in determining levels of contamination. For wet deposition the controlling factors appear to be the ability of the canopy surface to store precipitated water, and the interaction of the contaminant species with the leaf cuticle, which appears to act as an ion exchange medium, selectively accumulating certain ionic species.

No data were identified on deposition and interception fractions specific to fruit canopies. The authors suggest that in general a figure of 75% of the total deposition to ground, derived from other sources of data, would not result in a serious over or under estimate of interception by canopies of fruit bearing species. There is a similar marked lack of data on the distribution of radionuclides within fruit canopies following deposition.

Most work on the interception and initial retention of wet deposited radionuclides has been done with pasture grass with few data available for validation on other crop types. For bean, wheat and grass canopies in typical UK conditions it has been shown that it is total rainfall, regardless of intensity, which dominates the amount of radiocaesium that is intercepted. The type of plant, including its stage of development, will have an important influence on retention of wet deposited radionuclides.

2.8. POST DEPOSITION TRANSPORT OF RADIONUCLIDES IN FRUIT

The information reported in this section has been extracted from the work of Carini and Bengtsson [2001]. The authors collected the information for fruits from temperate regions, available at the inception of the Fruits WG, on the processes of (i) absorption after deposition directly to exposed fruit surfaces, and (ii) absorption after deposition to other exposed plant surfaces followed by translocation to fruit. The majority of information available concerns ^{134}Cs and ^{85}Sr in soluble form in apple, strawberry and grapevine.

Radionuclides can be directly deposited onto fruit surfaces and absorbed by the skin of fruits. Information on direct deposition, very scarce at the inception of the activities of the Group, was extended by few additional results reported in Section 4. The factors affecting fruit absorption are differences in wettability and roughness of the fruit surface, different cultivars, the age of fruits and the kind of radionuclide. Absorption of radionuclides by the surfaces of fruit occurs in favourable humidity conditions and, in such cases, is higher for caesium than for strontium.

Foliar absorption is radionuclide specific. It is greater for young than old leaves and is time dependent. The rate of absorption depends both on humidity and temperature, as well as on plant species and cultivar. For strontium and caesium there is some evidence to indicate that absorption occurs to the same extent shortly after contamination i.e. within 24 hours, but that at subsequent times strontium is absorbed to a much lesser extent than is caesium.

TABLE 2. ACTIVITY OF FRUITS AFTER FOLIAR DEPOSITION, EXPRESSED AS PERCENTAGE OF THE APPLIED OR INTERCEPTED ACTIVITY

Fruit	Phenological stage at time of contamination	Time between contamination and harvest	% of the applied or intercepted activity			Reference
			Cs	Sr	Ca	
Apple	green fruit	84 d	29	0	–	Bengtsson, 1992
Apple	–	41 d	16	0	–	Bengtsson, 1992
Apple	mature fruit	1 d	1	0	–	Bengtsson, 1992
Pear	green fruit	50 d	12.8	0.98	–	Carini et al., 1999
Orange	–	–	0.1	0.004	–	Delmas et al., 1971
Grapevine	–	–	1.8–9.6	0.09–0.73	–	various (to be completed)
Redcurrant	–	–	2	0.003	0.2	Kopp et al., 1990
Blueberry	–	–	0.7	0.02	0.02	Kopp et al., 1990
Gooseberry	–	–	3.4	2.1	2.7	Kopp et al., 1990
Strawberry	anthesis	22–48 d	11.2	1.6	–	Carini, 1997
Strawberry	ripening	24 h–27 d	6.5	2.2	–	Carini, 1997

The largest portion of the radionuclide inventory in a contaminated plant remains in the vicinity of the site of contamination. Translocation from the site of contamination to other parts of the plant depends on the radionuclide, the plant species, cultivar and rootstock, and the stage of development of the plant at the time of contamination. A collection of data is reported in Table 2. In general, caesium is more readily translocated to fruit than is strontium. Among woody trees, apple shows the highest and orange the lowest translocation of caesium to fruit. Among shrubs, gooseberry shows the highest translocation of both caesium and strontium.

Data on leaf to fruit translocation of caesium and ruthenium from the Chernobyl accident demonstrated large differences among species and varieties, ascribable to metabolic processes of the plants. Peach and grapevine showed a higher fruit:leaf activity ratio than apples and pears.

Ultimate concentration in the fruit varies as the fruit develops and according to the time of contamination relative to production of the fruit. For caesium, complex patterns in concentration may be observed during a growing season as a result of the combination of rate of transfer to the fruit, rate of biomass production of the fruit, and water content.

Additional information on post deposition transport processes has been collected during the activities of the Fruits WG and is summarised in Section 4.

2.9. SOIL TO FRUIT TRANSFER

The information reported in this section has been extracted from the work of Carini [2001]. The author collected the information on the transfer of radionuclides from soil to fruit, available at the inception of the Fruits WG activities.

The processes that affect the transfer of radionuclides from soil to fruit are usually synthesised into a single parameter – the soil to plant transfer factor (TF). This factor relates radionuclide concentration in edible products to that in the soil and may be expressed either as a ratio of concentration in plant to that in soil (i.e. Bq kg^{-1} fresh or dry weight in plant per Bq kg^{-1} dry weight in soil) or as a ratio of concentration in plant to content in soil (i.e. Bq kg^{-1} fresh or dry weight in plant per Bq m^{-2}), denoted T_{ag} [IAEA, 1994]. Soil to fruit TFs reported in Table 3 are related to fresh weight of fruit to dry weight of soil and are derived from agricultural ecosystems.

TABLE 3. RANGES OF SOIL TO FRUIT TRANSFER FACTORS FOR Cs, Sr, Pu AND Am

Product	Transfer Factor $Bq\ kg^{-1}$ f.w. fruit per $Bq\ kg^{-1}$ d.w. soil			
	Cs	Sr	Pu	Am
Woody trees (grape vine included)	$8.6\ 10^{-4} - 8.0\ 10^{-2}$	$1.2\ 10^{-3} - 7.0\ 10^{-2}$	$1.3\ 10^{-6}$ – $(9.2\ 10^{-4})\ 3.0\ 10^{-2}$	$1.3\ 10^{-6} - 6.2\ 10^{-4}$
Citrus (and olives for Cs)	$7.6\ 10^{-4} - 3.5\ 10^{-2}$	$2.4\ 10^{-2} - 2.7\ 10^{-2}$	–	–
Shrubs	$6.9\ 10^{-4} - 5.7\ 10^{-3}$	$1.4\ 10^{-2} - 1.1\ 10^{-1}$	$6.4\ 10^{-5} - 2.7\ 10^{-4}$	$6.5\ 10^{-5} - 2.3\ 10^{-4}$
Herbaceous plants	$4.1\ 10^{-4} - 8.9\ 10^{-3}$	$5.4\ 10^{-3} - 2.1\ 10^{-1}$	$2.7\ 10^{-5} - 8.3\ 10^{-4}$	$4.1\ 10^{-5} - 7.2\ 10^{-4}$
Subtropical and tropical fruits	$1.8\ 10^{-3} - 3.8\ 10^{0}$	$1.5\ 10^{-3} - 1.6\ 10^{-1}$	$7.2\ 10^{-7} - 2.0\ 10^{-4}$	$6.8\ 10^{-7} - 5.9\ 10^{-6}$

The variability in TF for a given radionuclide is ascribable to differences in soil properties, rather than differences in climate. For caesium the highest values are reported for peat or light textured soils in temperate regions, and for calcareous soils with low exchangeable potassium contents in subtropical and tropical regions. For strontium, the lowest TFs are reported for organic soils and for soils with high calcium content.

TF values for caesium are the most numerous and the most variable, covering many orders of magnitude. The highest TF values are associated with apple, peach and grapevine in temperate regions and with papaya, breadfruit, pandanus and coconut in tropical and subtropical zones. The highest TF values for strontium are associated with blackcurrant, papaya, breadfruit and pandanus.

The transfer of radionuclides in natural and semi-natural ecosystems is often expressed using empirical transfer coefficients, termed aggregated transfer coefficients (T_{ag}). They are calculated using the expression [Howard et al., 1996]:

$$T_{ag} = [\text{activity concentration in the food product } (Bq\ kg^{-1})] \,/\, [\text{activity of deposit per unit area } (Bq\ m^{-2})]$$

Aggregated transfer coefficients, T_{ag} ($m^2\ kg^{-1}$ dw), to wild berries also provide some evidence for a correlation between T_{ag} and the type of forest soil. The highest levels for radiocaesium are often found on peaty, nutrient poor bogs [Johanson et al., 1991].

Studies on the distribution of radionuclides within different components of fruit bearing species provide, for fruit trees, some evidence that leaves and growing shoots act as a accumulation organs for strontium. Similarly, some fruits (grapes and oranges) have been shown to act as a sink for caesium while others (olives and apricots) do not act as sinks. In deciduous fruit plants the total annual loss of caesium through removal of leaves and fruits is a very small fraction of the total inventory in the plant. This reflects re-allocation of caesium at fall to woody parts to the extent that little is subsequently available for new growth. Information about the magnitude of re-translocation is rare and difficult to interpret.

The half-life for radiocaesium in agricultural ecosystems of four years following deposition appears to be almost independent of the fruit tree species. Leaves have the same time dependence of radiocaesium concentration as fruits. Radiocaesium from the Chernobyl accident was reduced by a factor of three between 1987 and 1988 in all new products of apricot trees, and strontium was reduced to a half or less in apples, pears, and blackcurrants. In contrast, radiocaesium increased in natural and semi-natural ecosystems, particularly in fruits such as cloudberries that prefer peaty soils.

Long term remobilization has been studied mainly for ^{137}Cs deposited after the Chernobyl accident and by fallout from testing of nuclear weapons. Little or no information is available for most of the other long lived radionuclides. Both experimental observations and those following the Chernobyl accident proved that for fruit trees like apple, peach, cherry, and apricot, the contribution of the soil is negligible in comparison with the contribution of the trunk reservoir in the first few years after deposition.

Results from recently completed studies provide new information on the time dependence of gaseous and dry deposited radionuclide activity in fruits. These are reported in chapter 4.

2.10. THE EFFECT OF STORAGE AND PROCESSING ON RADIONUCLIDE CONTENT OF FRUIT

The information reported in this section has been extracted from the work of Green [2001]. Storage or processing may reduce the activity concentration in the foodstuff that is actually consumed, with implications for assessments of doses from releases of radionuclides to the environment.

The delay between harvest and consumption (Table 4) can be important for short lived radionuclides such as ^{131}I. However, for cautious general assessments, it should be assumed that there is no delay, especially if the fruits can be eaten raw. Individual cases may require specific data if available.

Activity concentrations may also be affected by the processing of fruits, whether industrially before sale, or domestically, after sale. There are several ways of expressing processing factors [Green, 2001]; the most commonly accepted, F_r does not use activity concentrations but rather total activity. F_r is the fraction of activity retained in the processed food, and is given by the equation:

$$F_r = \frac{\text{total activity in processed food}}{\text{total activity in raw food}}$$

Values of F_r for fruit are summarised in Table 5. For fruits that are consumed raw, washing is an important process, being especially effective for removing both fresh deposition and soil contamination in the case of, for example, strawberries, where the fruit is close to the soil surface. In the case of processing, it may not be possible to specify exactly what processing or preparation takes place. For cautious general assessments, it should be assumed that no activity is lost on processing. Individual cases may require specific data if available.

TABLE 4. DELAY TIMES BETWEEN HARVESTING AND CONSUMPTION

Fruit	Minimum	Typical value (range)
fresh apples	0 day	3.5 months (0 day – 8 months)
fresh pears	0 day	3.5 months (0 day – 8 months)
fresh drupe fruits	0 day	4 days (0 – 14 days)
fresh soft fruit	0 day	4 days (0 – 8 days)
rhubarb	0 day	4 days (0 – 10 days)
canned fruit	14 days	1 year (14 days – 2 years)
frozen fruit	7 days	6 months (7 days – 1 year)
jams and jellies	1 day	1 year (7 days – 2 years)

from Green [2001]

TABLE 5. EFFECT OF PROCESSING ON ACTIVITY CONCENTRATIONS IN FRUIT

Fruit	Nuclide	Preparation	F_r
blackberry	^{3}H, ^{35}S	stew (reject juice)	0.23 – 0.55
blackcurrant	^{137}Cs, ^{103}Ru	wash	0.70 – 0.90
	^{137}Cs	puree	0.57 – 0.71
	^{137}Cs	juice from steamed	0.20 – 0.25
blueberry	^{137}Cs	puree – manual press	0.72 – 0.85
cherry	^{137}Cs, ^{134}Cs, ^{131}I, ^{103}Ru	remove unpalatable	0.35 – 0.78
	^{90}Sr, ^{60}Co	can in syrup	0.44 – 0.54
currant	^{137}Cs, ^{134}Cs	stew (reject juice)	0.7
grape	^{137}Cs, ^{90}Sr	red wine	0.60
	^{137}Cs, ^{90}Sr	rosé wine	0.15 – 0.70
	^{134}Cs	white wine	0.33
lingonberry	^{137}Cs	wash	0.80
	^{137}Cs	puree – manual press	0.75
	^{137}Cs	juice	0.46 – 0.88
olive	^{137}Cs	press – oil; cake	0.13; 0.43
peach	^{137}Cs, ^{90}Sr	lye peel (chemical)	0.03 – 0.70
	^{90}Sr	mechanical peel	0.5
	^{90}Sr	can	0.5
pear	^{137}Cs, ^{90}Sr, ^{60}Co	can in syrup	0.63 – 0.73
redcurrant	^{137}Cs	wash	0.79
rhubarb	^{137}Cs, ^{134}Cs, ^{131}I, ^{103}Ru	remove unpalatable	0.03 – 0.18
	^{131}I	wash	0.78
strawberry	^{137}Cs; ^{90}Sr	wash	0.6 – 0.88

from Green [2001]

2.11. MODELS FOR RADIONUCLIDE TRANSFER TO FRUITS

The information reported in this section has been extracted from the work of Mitchell [2001], who reviewed models for radionuclide transfer to fruit available at the inception of the Fruits Working Group activities.

As with all major agricultural and horticultural crop plants, radionuclides reach fruit by three principal routes following a release to atmosphere:

(a) deposition to soil, vertical migration in soil profile, root uptake, migration to the fruit (and other plant parts); and/or

(b) deposition to exposed plant surfaces (directly from the atmosphere or as a result of resuspension), followed by entry into the plant and transfer to the fruit (and other plant parts); and/or

(c) deposition to exposed fruit surfaces.

The main processes involved in the transfer of radionuclides to fruits are shown in Figure 2. The relative significance of each pathway is dependent both on the stage of plant development, the crop and the season during which the contamination event occurs.

At the inception of the work programme of the Fruits Working Group, several models were identified that deal specifically with the transfer of radionuclides to fruit as well as others that are adaptations of models for an agricultural crop such as a leafy green vegetable. When models for annual crops are modified there is a need to take into account the biennial or perennial nature of some fruit crops.

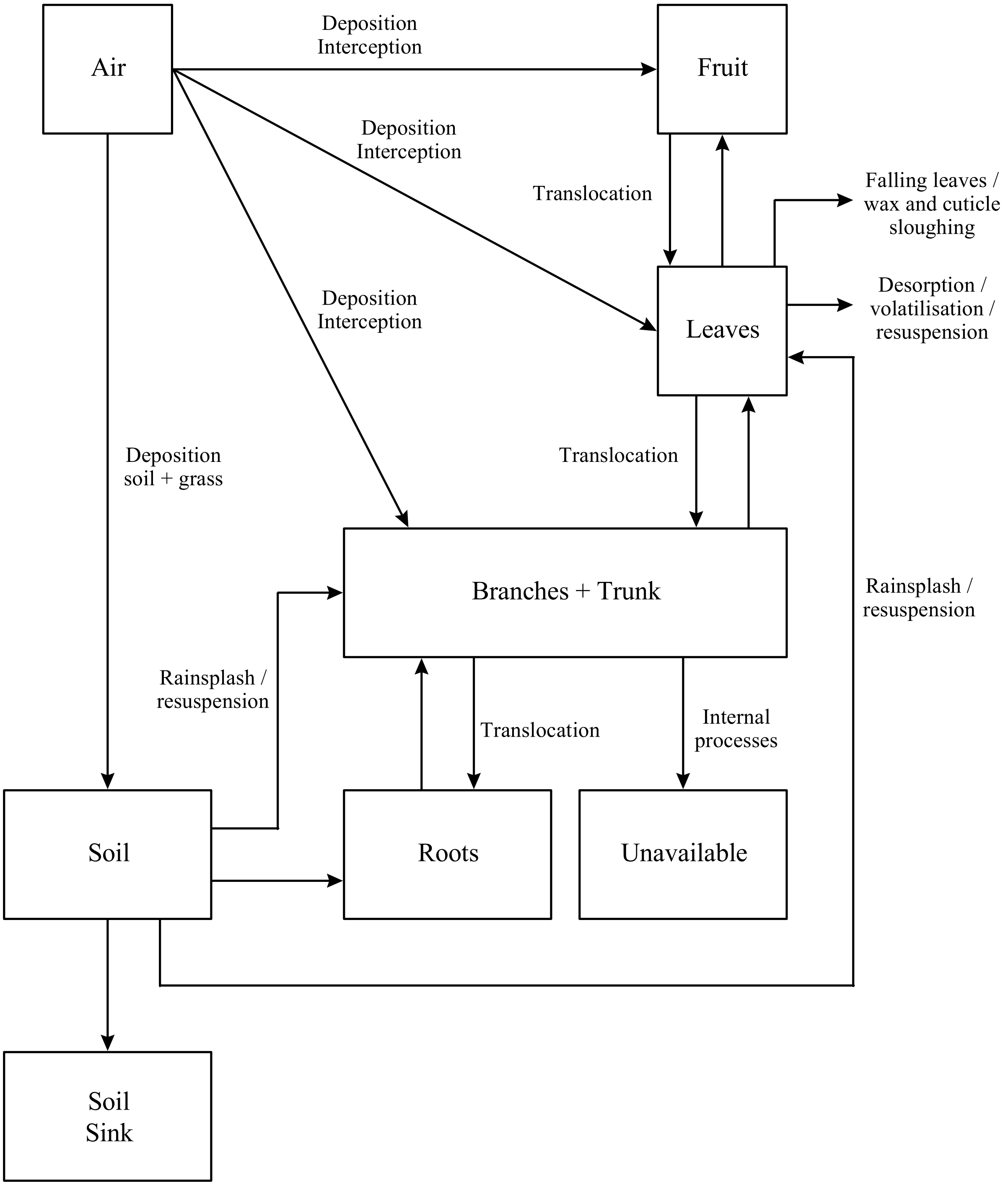

FIG. 2. Processes involved in the transfer of radionuclides to fruit (Adapted from Apostoaei, I.A. pers comm. [1998]. From Mitchell [2001].

TABLE 6. MODEL ENDPOINTS

Model	Developer	Model endpoint
Fruit tree model	Antonopoulos-Domis et al., [1988]	Concentration in plant parts and soil
Homeostatic model	Frissel [1994]	Activity in plant parts and soil
SPADE	FSA, formerly part of MAFF	Concentration in plant parts and soil
FARMLAND	NRPB	Dose to man

from Mitchell [2001]

Of these models, only SPADE (model 3) participated in the modelling exercises of the Fruits WG.

Different approaches have been taken in the development of mathematical models to simulate transfer through food chains to man and those adopted for fruit represent only a small sub-group of those now available. A pragmatic view is taken and existing fruit models are broadly grouped into three categories as follows:

(a) Simple mathematical functions describing declining concentration in fruit based on observations following deposition [Antonopoulos-Domis et al., 1988].

(b) Models that attempt to predict temporal distribution in soil–plant systems through descriptions of the processes involved, e.g. PATHWAY [Whicker and Kirchner, 1987] and Frissel [1994].

(c) Radiological dose assessment models that use a mixture of equilibrium and/or dynamic modelling approaches to predict concentrations in edible products, e.g. FARMLAND [National Radiological Protection Board, United Kingdom, NRPB; Brown and Simmonds, 1995], ECOSYS [Institut für Strahlenschutz, Germany, Müller and Pröhl, 1993] and SPADE [Food Standards Agency, formerly Ministry of Agriculture, Fisheries and Foods, United Kingdom, Thorne and Coughtrey, 1983].

Table 6 summarises the main endpoint of the models that are discussed in the following paragraphs. In each case the model provides a best estimate for transfer to fruit.

2.11.1. Model descriptions

A synthesis of model descriptions is reported here. For more details refer to Mitchell [2001].

There are issues that need to be addressed in a mathematical model for fruit crops. In particular: the potential capacity of some plant parts to accumulate radionuclides and their importance for contamination of fruit; the different types of crop and their inherent growth characteristics; and, the fact that although foliar interception will dominate transfer to fruit there is a need to include soil processes.

2.11.1.1. Model 1

Antonopoulos-Domis et al., [1990] developed a model structure for perennial fruit trees describing distribution, retention, transfer and rejection of activity, based on experimental determinations of ^{137}Cs in apricot fruit trees. The resulting model provided an indication of the relative importance of different pathways in the contamination of fruit from deciduous trees. The concept for the model was based on the fact that the leaves and fruits developing each year are only contaminated by a portion of the ^{137}Cs in the body of the tree. A fraction of this available reservoir is removed each year, part is lost from the tree through leaves and fruit and part becomes irretrievably associated with the body of the tree. A similar approach is used to describe the available fraction in soil.

A modified version of the model presented by Antonopoulos-Domis et al., [1990] was proposed under the IAEA VAMP programme. The model structure provides an alternative that, although more complex, will accept an analytical solution. The model has been adapted to provide separate compartments for leaf and fruit and all compartments have a common basis (Bq m^{-2}). A decision was made by Antonopoulos-Domis et al., [1990] not to split the leaf and fruit material based on their interpretation of the available data as showing similar concentrations in each of these tissues. However, there is a considerable range in the concentrations found in shoots, leaves and fruit [Antonopoulos-Domis et al., 1990; 1991] to the extent that although the data show increasing variability in later years the approach of using at least two compartments appears justified.

2.11.1.2. Model 2

A model for radiocaesium (Cs) transfer to tree fruit was presented by Frissel [1994]. This model considers the homeostatic control of potassium (K) within fruit trees. The model structure comprises four compartments and was designed to consider the long term fate of radiocaesium in soil as affected by changes in the supply of potassium to the soil. This model was presented in full at the 1994 IAEA VAMP meeting.

The model describes a growing tree. The four compartments are the soil (S), the easily accessible part of a tree (E), the poorly accessible woody part (W) and the fruit or leaf part (F). The model is homeostatic, i.e. all radiocaesium concentrations and fluxes are controlled by K concentrations and fluxes, respectively. In determining the various transfer parameters, it is assumed that there is no difference in the behaviour of K and Cs, but that discrimination occurs between the compartments (S) and (E), between (E) and (F), and between (E) and (W). All tree compartments are assumed to grow at the same relative rate. The growth of the tree is therefore reflected in the model as increasing quantities of K and Cs. Growth dilution is not therefore assumed to be a factor affecting concentrations. In common with other modelling approaches, Frissel [1994] used quantities per compartment to avoid taking into account the increasing volume of the tree and thereby to simplify the calculations. Radioactive decay was not considered in order to simplify calculations.

The addition of K fertiliser to the soil results in an immediate change in the Cs/K ratio in both the soil and the easily accessible plant parts. However, the Cs/K ratio in the woody part shifts only slowly. Also when there is an excess of Cs in the woody part of the tree it is released slowly. The supply of K fertiliser has an additional effect causing the tree to take up more K than before; this is called luxurious uptake of K. The assumption is therefore made that luxurious consumption of K occurs for all tree compartments; additional K fluxes also cause additional Cs fluxes. If no fertilizers or tracers are supplied, the whole system is assumed to be in homeostatic equilibrium.

The loss of plant material, termed debris by Frissel, via branches, leaf fall and fruit loss is included. This process causes an additional cycling of Cs through the system. The role of falling leaves as input to the soil is not modelled separately, this was not thought necessary because the concentration of Cs is completely homeostatically controlled and the Cs/K ratio in soils will be maintained.

Excess K fertiliser will be leached from the soil. The K concentration in the soil is assumed to be relatively constant except when fertiliser K is added. The same assumption is made for Cs concentration in the soil. It is therefore assumed that both Cs and K concentration in the soil are constant. Frissel [1994] stated that, compared to the large quantity of Cs in the soil, the uptake and release of Cs compensate each other.

2.11.1.3. Model 3

The SPADE suite of codes is used by the United Kingdom Food Standards Agency (formerly part of the UK Ministry of Agericulture, Fisheries and Food – MAFF) for regulatory purposes. Input parameters for the models are selected to provide realistic predictions that are towards the upper end of observed concentrations in food products. On this basis the output from SPADE is a best estimate prediction. This is reinforced by the use of scenarios that are likely to produce high concentrations, e.g. deposition to crops at a time when transfer to the edible component is likely to be greatest.

The fruit plant model in SPADE [Thorne and Coughtrey, 1983] consists of six compartments, representing internal leaf, external leaf, stem, fruit, storage organs and root. Movement of radionuclides within the plant model is controlled by empirically derived rate constants and parameters are derived for three broad categories of fruit plant: herbaceous, shrub and tree. Models are implemented in SPADE for 20 elements. and the following discussion considers the iodine models for fruit. Two experimental programmes have been undertaken in connection with the development of the SPADE fruit models for herbaceous and shrubby fruit crops [Kirton et al., 1987; Donnelly and Carini, 1998]. The data from these experiments provide valuable information for model validation.

Foliar absorption may be an important pathway for the uptake of radionuclides deposited on external plant surfaces, and is represented by transfers between the external leaf and internal leaf compartments. Not all compartments in the model are directly linked, and in some cases transfers occur in one direction only. Ten internal transfers occur in the standard fission/activation plant model.

Interception by plants takes account of changes in plant biomass with season. Depending on the model, plant or leaves are divided into external and internal components to allow particulate deposition to be distinguished from radioactive gases and vapours. Passage through the stomata and incorporation into the mesophyll is therefore represented by partitioning a fraction of the intercepted deposit to the internal compartment.

The original default parameters for iodine [Coughtrey and Thorne, 1983] were based largely on data for cereals, but were modified in the case of tree and shrub fruits to allow for more rapid transfer from stem to root so that the root store could serve as a reservoir through subsequent seasons. Loss of radionuclides from external plant surfaces to the soil is modelled as transfer to the surface layer of the soil model and include losses arising from leaf fall. The parameters for the three fruit models for iodine in SPADE (herbaceous, shrub and tree) are similar with the following exceptions. Differences for herbaceous fruit crops are as follows: the root store is switched off; there are crop-specific transfers from root to stem and from stem to internal leaf; and, internal to external leaf was chosen to reflect cereals rather than fruit crops. As concerns the other two fruit crop types the return from the root store reservoir is slower for tree fruit than for shrub fruit by an order of magnitude.

The process of root uptake is modelled as the transfer of radionuclides from soil solution to the plant root compartment. The transfer rate is also assumed to vary with soil layer depth, both as a function of the root distribution throughout the soil profile and as a function of the deposit distribution in soil. Consequently, the transfer of radionuclides from the soil solution to root is represented by a discrete transfer from each of the 10 layers in the soil model. The soil model is not considered further here.

2.11.1.4. Model 4

A generic model predicting the activity concentration of eight elements in fruit has been implemented within FARMLAND, the NRPB terrestrial food chain model used for assessing doses to man following radionuclide deposition to ground. Mayall [1995] described the models implemented in FARMLAND and presented model results obtained for ^{90}Sr, ^{137}Cs and ^{239}Pu. There is as yet no published comparison of the model predictions with experimental data, but the author reported that a current experimental programme would be used to validate the modelling approach.

The compartment structure was developed to model continuous deposition to apple trees and Mayall [1995] stated that it is applicable to other closely related fruit trees such as pears. The model comprises nine compartments, representing internal and external fruit, and five soil layers. The soil model describes transfer in an undisturbed soil. Transfer to external fruit occurs by direct deposition, and losses occur to the soil surface. Transfer to internal fruit is assumed to occur via root uptake and an internal fruit compartment exists for each soil layer from which uptake is assumed to occur. The five soil layers that are coupled to the fruit model are 0–1 cm, 1–5 cm, 5–15 cm, 15–30 cm and 30 cm–1.0 m depth. It was assumed that there is no root uptake from the 0–5 cm layers or at a depth greater than 1.0 m.

A deposit is assumed to occur to the ground and a fraction is deposited directly to the fruit surface. This fraction is described by the effective interception factor and is based on considerations of the normalized specific activity for experimental observations concerning fruit. In order to model weathering of radionuclides on plant surfaces, an effective retention half-time was derived at the same time as the effective interception factor. The other losses from fruit compartment are due to cropping. Transfer down to the soil profile is described by rate constants; the lower layer shows a loss from the system to deep soil.

3. DERIVATION OF A CONCEPTUAL MODEL

3.1. INTRODUCTION

The transfer of radionuclides to fruit is complex and involves many interactions between biotic and abiotic components. The preceding section summarises the findings of a recent review on the transfer of radionuclides to fruit and describes key interactions reported in the literature. This section describes a systematic approach to developing a conceptual fruit model and assessing the state of our knowledge for the dominant pathways.

The objective was to provide guidance for future development of a model representing the contamination of fruit following atmospheric deposition and identify gaps in our knowledge of key processes. A conceptual model can be considered as a list of the important components of the system the model represents and how they interact. It is often depicted by a model structure diagram. The approach used by the Fruits WG was adapted from the work of Avila and Moberg [1999] on ^{137}Cs migration in forest ecosystems.

It is important that model development takes account of the key processes that determine the transfer of radionuclides to fruit. Historically, food chain model development has been based on a combination of literature review and a supporting program of measurement and observation (monitoring or experimental programme). The subsequent model could be influenced by a number of factors including a bias towards the material available to the developer (literature and/or unpublished observations), the software available for implementation and the preconceptions held by the developer. Furthermore, one of the early stages of model development, from available information to conceptual model, is rarely documented.

The working group comprised representatives from a broad range of interests and disciplines and attempted to arrive at a consensus. Eighteen participants contributed to the development of a conceptual model described here for a fruit tree subject to a deposit from atmosphere.

3.2. BACKGROUND TO THE METHODOLOGY

A matrix is produced [x_{ij}], where the row number (i) and column number (j) are used to define the elements of the matrix (Figure 3). The elements of the leading diagonal (i=j) are the components of the system whose interactions are to be assessed in the off-diagonal elements (i≠j). The matrix is read clockwise, for example starting with the top left element, each column to the right denotes the influence of the top left element on the diagonal element below. Conversely, starting from the bottom right element, each element to the left denotes the influence of the bottom right element on the diagonal element above. Binary notation is used to denote an interaction (1) or lack of influence (0). All interactions between the leading diagonal elements are evaluated in this way. The analysis is most useful when the diagonal elements exhibit a large number of interactions.

The number of diagonal elements determines the resolution of the matrix. As the number of diagonal elements (n) increase the potential interactions that need to be evaluated n (n-1) also increase. The selection of the diagonal elements is a key part of this methodology. The working group adopted an iterative approach over several meetings and a consensus was reached eventually on the components that would be included. At each iteration of the matrix, the processes involved in the interactions were identified. These discussions were helped by agreeing a series of definitions to a set of keywords to describe the diagonal elements (Table 7) and the complex processes involved in interactions between diagonal elements (Table 8).

TABLE 7. ADOPTED DEFINITIONS OF DIAGONAL ELEMENTS IN FIGURE 3

Element	Definition
Air	Atmosphere above canopy where material is available for deposition.
Leaf	Includes both internal plus external parts.
Wood and stem	Includes both internal plus external parts, in the case of fruit trees includes trunks plus branches.
Soil	Those soil layers containing roots.
Ground Cover	Non-fruit vegetation within the stand.
Roots	Both internal and external parts, new and old roots.
Micro-organisms	Micro fauna and flora inhabiting rhizoplane and phylloplane.
Debris	All non-growing organic material on the soil surface.
Fruit	Edible portion of the crop.

TABLE 8. ADOPTED DEFINITIONS FOR INTERACTIONS BETWEEN DIAGONAL ELEMENTS IN FIGURE 3

Interaction	Definition
Bioturbation	Mixing caused by biological activity
Deposition	The total amount of material delivered per unit area of ground.
Dieback	The loss of leaf and stem as a result of senescence, disease.
Dissolution	The dispersion following breakdown of plant debris into soil and soil solution.
Excretion	Emission of material from micro-organisms.
Exudation	The release of material from roots.
Fruit fall	Loss of fruit from the plant to debris.
Interception	The capture of material by surfaces.
Irrigation	To include rainfall.
Leaf fall	The transfer of leaf material from plant to debris.
Pruning	The deliberate removal of stems/branches.
Resuspension	Movement of material from ground to atmosphere following deposition
Root uptake	The uptake of material by roots.
Splash	Movement of soil by the impact of water. Soil becomes attached to surfaces, e.g. of plants
Translocation	The transport of material within the plant.
Washoff	The removal of material from a surface under the action of water.

The relative strength of the interactions were scored semi-quantitatively from zero to five as follows:

0	no interaction
1	weak
2	light
3	medium
4	strong
5	critical

The ranked scores were then used to produce a graph of cause–effect relationships and model structure diagrams. The state of our knowledge about the highest ranking interactions was also assessed qualitatively using the following notation:

- Good process well understood
- Fair some understanding
- Poor very little information

3.3. IMPORTANT CONCEPTS AND PROCESSES

The leading diagonal agreed by the participants (Figure 3) was as follows:

- Air
- Leaf
- Wood and Stem
- Soil
- Ground cover
- Roots
- Micro-organisms
- Debris
- Fruit

The review presented earlier suggests that the leading diagonal should include air, leaf, wood and stem, soil, roots and fruit components. The working group considered that ground cover, microorganisms and debris should also be included, as these components are part of the overall system even though limited information is available in the literature. The role of micro-organisms remains uncertain; it is known they are important within the rhizosphere and on the phylloplane, but we do not yet have a good understanding of these interactions. Ground cover and debris represent two additional well defined components of the system and were included in order to maintain a mass balance within the model. The consensus was that these three components should be included on the diagonal but, as shown later, micro-organisms could probably be incorporated within the root and leaf elements without a major impact on the results obtained.

The matrix therefore represents a compromise. The resolution of the leading diagonal could be increased to include additional processes that are known to occur in each of the elements. For example, a matrix for radiocaesium could be expanded to include interactions within and between soil layers whereas this might not be justified for other radionuclides. Our intention was to develop guidance for a generic model, with respect to radionuclide, although it was recognised that the relative importance of different processes would be nuclide dependent.

3.4. CAUSE–EFFECT RELATIONSHIPS

The final matrix was used to collect participants' views on the relative strength of the interactions and a graph of cause and effect was produced. The sum of rows, showing how a component affects all other parts of the system (cause), and the sum of columns, the effect other components have on this diagonal element (effect), were plotted (effect against cause). This graphical representation of cause and effect is presented in Figure 4. The central line drawn from the origin shows C-E space where cause and effect are equal.

The longer the distance between the origin and the point for a component, the greater the sum of cause and effect, showing strengthening interaction between the component and the rest of the system. Points on or close to the line show the component being affected by the system as much as the component affects the rest of the system. Points above the diagonal line, indicate that the component influences the rest of the system less than the system influences them, i.e. they are subordinate components. Points below the diagonal line are dominant components that influence the system more strongly than the system influences them.

Air	deposition, interception	Deposition, interception, rainfall	Deposition, interception, rainfall	deposition, interception, rainfall		i = 1, j = 7 i,j = 1,7	deposition, interception, rainfall	deposition, interception, rainfall
resuspension	**Leaf**	translocation	wash-off	wash-off			leaf-fall, pruning	translocation
resuspension	translocation	**Wood and stem**	throughfall + stemflow	throughfall + stemflow	translocation		leaf-fall, pruning	translocation
resuspension	splash	splash	**Soil**	root uptake	root uptake	uptake		resuspension
resuspension	splash	splash	migration	**Ground cover**			leaf-fall, dieback	splash/ resuspension
		translocation	exudation	exudation, root uptake	**Roots**	exudate transfer, mycorrhiza	dieback	
			bioturbation	bioturbation, excretion	mycorrhizal processes	**Micro-orgs**	excretion	
resuspension	resuspension	splash	dissolution	root uptake, breakdown		uptake	**Debris**	resuspension
resuspension	translocation		fruit-fall	fruit-fall			wash-off	**Fruit**

Notes:

An example of the row and column notation is given in row 1 column 7.

FIG. 3. Interaction matrix with 9 diagonal elements describing the contamination of fruit trees following a deposit from atmosphere.

The diagram suggests that there are perhaps three clusters. The Soil component appears on its own to the far right above the central line (labelled 2), showing that soil interacts strongly with other components but is on balance subordinate to the rest of the system. The Air, Leaf and Wood and Stem components are in a cluster closer to the origin (labelled 3), showing a weaker interaction with the system as a whole than in the case of soil, but all of these are dominant components. The arc passing through this cluster is for a constant distance from the origin and is placed to highlight the fact that the participants thought the strength of interaction for both Air and Leaf with the rest of the system was similar.

The average scores (of 18 participants) for row and column totals are presented in Table 9 along with the relative standard deviation (RSD). The relative standard deviation gives a view on the differences in opinion within the working group. For example, although the participants were in agreement about the strength of the impact Air has on the system (RSD = 0.3) there was less agreement about the impact of the system on Air (RSD = 0.59). For Leaf (0.34 and 0.33, respectively) and Wood and Stem (0.37/0.38), their opinion appears more consistent. In the case of soil, participants were in agreement about the impact of the system on Soil (RSD = 0.37) but were in less agreement about the impact of Soil on the system (RSD = 0.43).

The final cluster (labelled 1) has the weakest interactions with the system and includes Ground cover, Roots, Micro-organisms, Debris and Fruit. This last cluster is where the participants showed most disagreement overall (RSD ranging from 0.44 to 0.89). The uncertainty in the result for Micro-organisms reflects our lack of understanding.

This analysis shows the strength of the interaction of specific components with the system as a whole. An interaction may be part of an important pathway, for example the impact of soil on plants is effected partly through the roots, but roots may score low overall, as there are relatively few interactions with other parts of the system. It is clear from the cause–effect diagram that a model for fruit will need to concentrate effort on the interaction of air, leaf, wood and stem with soil as a subordinate component. Although this is not an unexpected result for this scenario it is has been reached through consensus and is based on a systematic analysis of the problem.

TABLE 9. CAUSE EFFECT DATA SET (N=18) WITH RELATIVE STANDARD DEVIATION

	Average (n=18)	Relative standard deviation
Cause		
1. Air	21.0	0.3
2. Leaf	18.3	0.34
3. Wood and stem	15.6	0.37
4. Soil	17.9	0.43
5. Ground cover	9.4	0.68
6. Roots	9.8	0.65
7. Micro-organisms	9.0	0.89
8. Debris	11.2	0.52
9. Fruit	8.5	0.64
Effect		
1. Air	8.8	0.59
2. Leaf	13.8	0.33
3. Wood and stem	13.4	0.38
4. Soil	21.3	0.37
5. Ground cover	16.6	0.44
6. Roots	10.3	0.47
7. Micro-organisms	8.7	0.82
8. Debris	13.2	0.55
9. Fruit	14.7	0.51

TABLE 10. RANKING INTERACTION OF DIAGONAL ELEMENTS

Influence of	On	Strength of interaction (n=18)
Air	Leaf	4.9
Soil	Roots	4.2
Air	Soil	4.1
Air	Ground Cover	3.8
Leaf	Fruit	3.5
Leaf	Soil	3.4
Leaf	Debris	3.2
Leaf	Wood and Stem	3.1
Wood and Stem	Fruit	3.1
Roots	Wood and Stem	2.9
Air	Wood and Stem	2.9
Soil	Micro-organisms	2.9
Air	Fruit	2.8
Debris	Soil	2.8
Ground Cover	Wood and Stem	2.8
Soil	Ground Cover	2.7
Wood and Stem	Leaf	2.6
Wood and Stem	Soil	2.6
Micro-organisms	Roots	2.5
Wood and Stem	Roots	2.4
Leaf	Ground Cover	2.4
Air	Debris	2.3
Wood and Stem	Debris	2.3
Soil	Fruit	2.3
Debris	Ground Cover	2.3
Soil	Wood and Stem	2.2
Fruit	Soil	2.2
Soil	Air	2.0
Roots	Micro-organisms	2.0
Micro-organisms	Debris	2.0

3.5. RELATIVE IMPORTANCE OF INTERACTIONS AND PATHWAYS

The interactions that scored 2 or more (greater than or equal to a light interaction) are ranked in Table 10. A normalised ranking can also be obtained for each series of interactions that lead to the contamination of fruit (sum the scores and divide by the number of interactions contributing to the total). For example, air–leaf (4.9) plus leaf–fruit (3.5) produces a normalised value of 4.2 (8.4 divided by 2).

The normalised rankings that scored 2 or more for interactions that lead to fruit contamination are presented in Table 11. Conceptual models based on arbitrary thresholds of 4, 3 and 2 are presented in Figures 5 to 7, respectively.

The ranking in Table 10 shows where model development effort should be directed and, combined with an assessment of the state of our knowledge for each of the interactions, can be used as a basis for assigning priorities for experimental work.

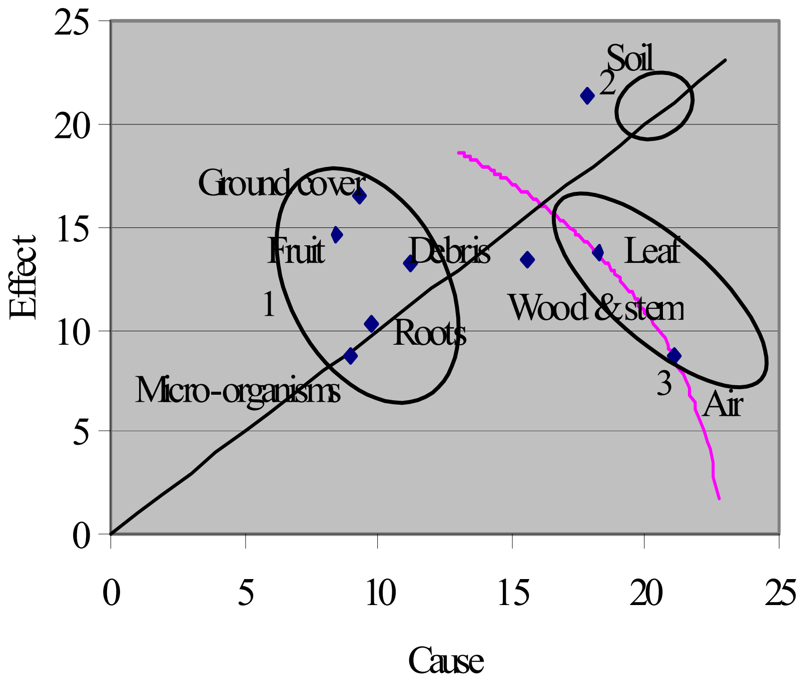

FIG. 4. Cause effect diagram.

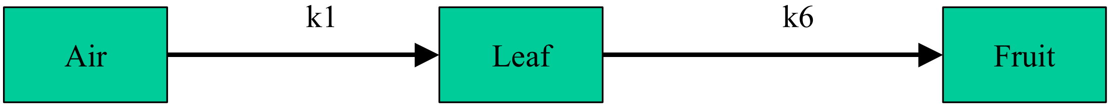

FIG. 5. Conceptual model for normalised score > 4.

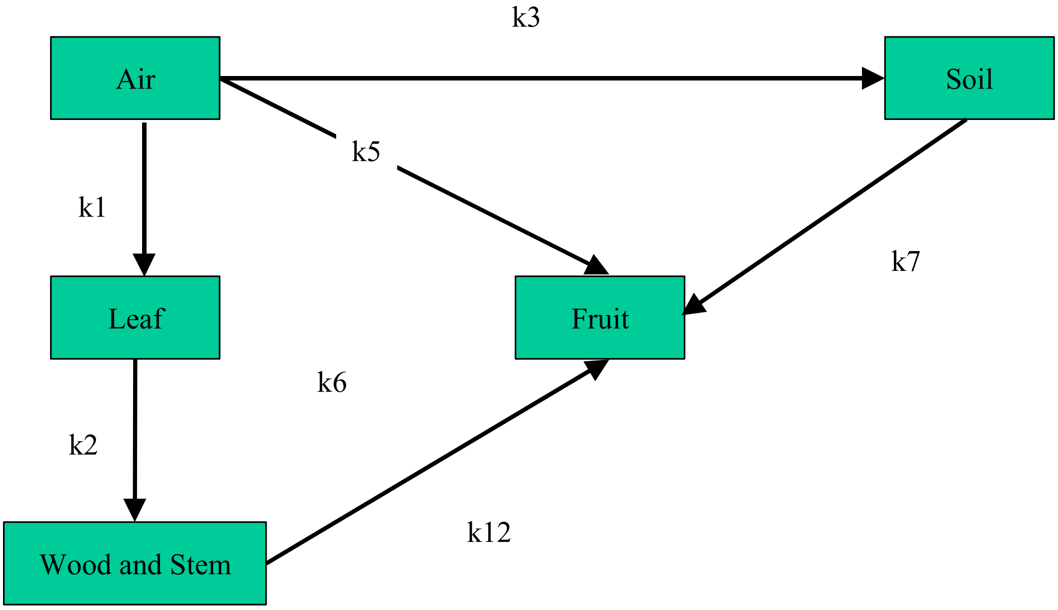

FIG. 6. Conceptual model for normalised score > 3.

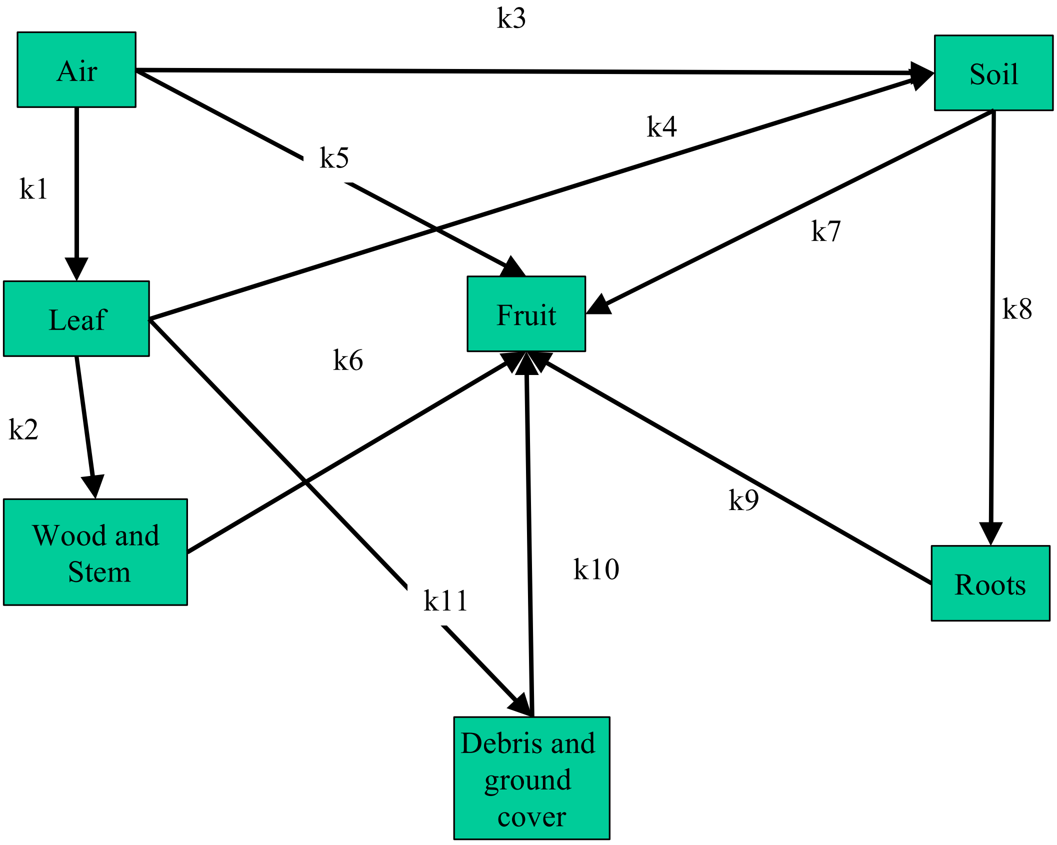

FIG. 7. Conceptual model for normalised score > 2.

TABLE 11. RANKING NORMALISED INTERACTIONS FOR PATHWAYS TO FRUIT

Pathway to fruit	Normalised value
air – leaf – fruit	4.20
air – leaf – fruit	4.20
air – leaf – wood and stem – fruit	3.70
air – leaf –wood – fruit	3.70
air – leaf – soil – fruit	3.53
air – leaf – wood – leaf – fruit	3.53
leaf – fruit	3.50
air – leaf – soil – wood – fruit	3.40
air – soil – fruit	3.25
air – soil – fruit	3.25
air – soil – leaf – fruit	3.20
air – leaf – wood – soil – fruit	3.20
air – soil – wood – fruit	3.17
leaf – wood – fruit	3.10
wood – fruit	3.10
air – leaf – air – fruit	3.10
leaf – wood – fruit	3.10
wood – fruit	3.10
leaf – wood –fruit	3.10
leaf – wood – leaf – fruit	3.07
air – leaf – soil – ground – fruit	3.05
air – leaf – debris – fruit	3.00
air – soil – roots –fruit	2.97
air – soil – air – fruit	2.97
air – wood – leaf – fruit	2.97
air – soil – roots – fruit	2.97
air – ground – soil – fruit	2.97
air – wood and stem – fruit	2.95
air – leaf – soil – micros – fruit	2.90
air – leaf – ground – fruit	2.87
leaf – soil – fruit	2.85
leaf – soil – fruit	2.85
air – ground – soil – roots – fruit	2.83
air – leaf – wood – debris – fruit	2.80
air – leaf – wood – roots – fruit	2.75
air – fruit	2.70
air – soil – ground – fruit	2.70
leaf – wood – soil – fruit	2.63
air – ground – fruit	2.55
air – ground – fruit	2.55
leaf – soil – ground – fruit	2.43
soil – root – fruit	2.35
leaf – debris – fruit	2.05
leaf – debris – fruit	2.05

The review of models available at the start of the Biomass programme shows that all fruit models include processes associated with air, leaf and fruit (Figure 5). The leaf and fruit are sometimes aggregated when deriving parameters but nearly all the models include a soil pathway as shown in Figure 6 which has many features in common with the models summarised in Section 2. In particular, plants are split into several components (fruit, leaf and woody material) with air and soil providing the source for entry into plants. Few of the reviewed models consider roots and none looked at debris and ground cover (Figure 7). However, in some cases the models went into greater detail considering soil layers, the distribution between soil and plant constituents and the impact of stable elements on radionuclide transfer. It would have been interesting to explore some elements of the leading diagonal in greater detail and determine if further sub-division was warranted. The models participating in the intercomparison exercises are summarised in Tables 26 and 27. The main process that is not represented by several of these models is the translocation of radionuclides within crop plants. None of the models consider debris and ground cover.

3.6. STATE OF KNOWLEDGE

A view on the state of knowledge for the key pathways shown in Figure 6 is presented in Table 12. The knowledge of the working group was assessed as good, fair or poor.

Taking this information alongside that provided in Tables 10 and 11 suggests there is a clear need for further research into the deposition of particulates onto fruit plants (in particular leaf) and on the transfer from leaf to fruit. This is the dominant pathway identified for a fruit tree model but the conclusion is also true for other fruit types. The analysis also highlights how poor our knowledge is on the movement of radionuclides within fruit plants.

3.7. CONCLUSIONS

The approach used to develop a conceptual model for tree fruit provided a means to arrive at a concensus within the working group and it provided a useful framework within which important processes were identified, discussed and assessed.

There were opportunities to further extend the leading diagonal to consider processes in greater detail. This would have involved a number iterations and was beyond the resources available to the group. For example, some current models consider soil as a series of discrete layers, look at internal and external plant surfaces or divide soil into available and unavailable fractions. These aspects could have been considered in greater detail.

Three model structures were identified by the analysis. The models are similar to those used for other crops and ecosystems and as such the results were not a surprise. However, even for the simplest model shown, understanding of the key processes involved was assessed as poor.

TABLE 12. KNOWLEDGE OF FRUIT TRANSFER PATHWAYS

Pathway	Knowledge for fruit
Air – leaf	Good for some gases Poor for particulates
Leaf – wood and stem	Fair
Air – soil	Good
Leaf – soil	Fair
Air – fruit	Poor
Leaf – fruit	Poor
Soil – fruit	Fair/Poor
Soil – roots	Poor
Roots – fruit	Depends on above processes
Debris and ground cover – fruit	Poor
Leaf – debris and ground cover	Fair/Poor
Wood and stem – fruit	Poor

4. EXPERIMENTAL STUDIES

4.1. BACKGROUND AND OBJECTIVE

The processes leading to the contamination of fruit after transfer of radionuclides into various fruit systems and the parameters analysed in experimental studies were discussed at the inception of the activities of the Fruits WG. The existing information was reviewed by the group and the state of the art at that time was presented in the Review Working Document [IAEA, 1999; JER, 2001], a summary of which is given in Section 2.

New information, from recently completed or ongoing experimental studies, or from those not included in the Review Working Document, was presented and discussed during meetings of the Fruits WG. The aims were to collect information additional to that summarised in the Review, to improve knowledge of processes, and to provide data valuable either for the further development of models or for the testing and validation of existing ones.

Some of the new research has been completed and some is still ongoing. Information on completed studies that were not included in the review and that have formed the basis for discussion in the Group is summarised in Section 4.2; description of ongoing research is summarised in Section 4.3.

4.2. STUDIES COMPLETED SINCE THE FORMATION OF THE FRUITS WORKING GROUP

Experimental studies already completed are summarised in Table 13. The most important results, in terms of data or understanding of processes are discussed in the following paragraphs.

TABLE 13. COMPLETED EXPERIMENTAL STUDIES

Institution/ Person	Fruit	Nuclide	Experimental conditions	Method of contamination	Endpoint
Imperial College (UK) C. Collins	Apple Raspberry Strawberry Blackcurrant	S-35 C-14 H-3	Field pots/Glass house	Aerial/ gaseous	Rate constants for transfer to leaves, fruit
IPSN (France) C. Madoz-Escande	Vine	Cs-137 Sr-90	Soil/large scale lysimeters in controlled conditions	Aerial/ dry aerosol	One measurement the first year on: grape (skin+seed, stalk, juice), wine Measurements in time for three years after deposition on: grape (skin+seed, stalk, juice), wine, shoots, leaves
Agricultural University of Athens (Greece) G. Arapis	Vine	Cs-134	Soil/field conditions	Aerial/ dry aerosol	One measurement the first year on: grapes from defoliated or non-defoliated plants, covered or non-covered grapes. One measurement the second year on defoliated or non-defoliated plants
Swiss Federal Research Station (Swiss) H.J. Zehnder	Vine	Cs-134	Hydroponic in greenhouse	Droplets on two leaves	Measurements in time of released Cs-134 and remaining K in the nutrient solution, and of Cs-134 and K uptake in the whole plant
National Institute of Radiological Sciences (Chiba, Japan) S. Uchida	Apple Mandarin	U Th Pb		Soil	Washed fruit

4.2.1. Deposition of gaseous radionuclides to fruit

Information reported in the Review on the uptake of gaseous pollutants by vegetation (Section 2.6) shows that, although uptake by vegetable crops has been studied fairly extensively, there has been relatively little investigation into uptake by fruit crops [Stewart et al., 2001].

Recent studies carried out at Imperial College (United Kingdom) supply new information on deposition, uptake, loss and translocation of $^{14}CO_2$, $CO^{35}S$ and $^{3}H_2O$ to apple, raspberry, strawberry and blackcurrant [Collins and Gravett, 1995]. Spiked compounds are routinely emitted by British nuclear installations. Fruit crops represent four different generic crops grown in the UK: a tree form (apple), a woody bush form (blackcurrant), an annual bush form (raspberry) and an herbaceous form (strawberry). They were exposed inside a wind tunnel for 12 hours, at selected times within the growth cycle, to determine the contribution of acute releases to the contamination of harvested fruits. The same plant varieties were established at a field site within the grounds of Hinkley Point B power station, where air, leaf and fruit concentrations were determined for radioactive gases released from the reactors, for comparison with the wind tunnel measurements.

The deposition velocity, as described by Stewart and co-workers [2001], was calculated per unit plant weight (Vg^{w}) and per unit area of the wind tunnel floor (Vg^{a}) for the above ground parts of the plant:

$$\mathrm{Vg^{w}} = \frac{\text{total activity in plant/total plant weight}}{\text{air concentration}} \left(\mathrm{cm}^3 g^{-1} s^{-1}\right)$$

$$\mathrm{Vg^{a}} = \frac{\text{total activity in plant/estimated plant area}}{\text{air concentration}} \left(\mathrm{cm}\, s^{-1}\right)$$

The deposition velocities of $^{14}CO_2$, $CO^{35}S$ and HTO (tritiated water) to apple, strawberry, blackcurrant and raspberry (Table 14) are of the same magnitude as those observed for other crops [Stewart et al., 2001]. Velocities observed for other crops are within the range 2×10^{-3} to 3.6×10^{-2} cm s^{-1}, 4.6×10^{-3} to 0.6 cm s^{-1} and 2.3×10^{-8} to 5×10^{-2} for $^{14}CO_2$, $CO^{35}S$ and HTO respectively [Salisbury, 1992; Winzeler, 1979; Brown, 1986; Taylor, 1983; Bunnenberg, 1990; Spencer, 1988]. The results are in the upper range and this is proposed to result from the wind tunnel exposure being undertaken in conditions optimal for gas exchange which would result in high deposition rates [Collins and Gravett, 1995].

The deposition velocity when expressed per unit weight is less variable than when expressed per unit area as a result of the increasing plant area per unit ground as the season progresses. The authors suggest that a single deposition velocity be used in assessment studies, which should be the highest value, unless a probabilistic approach is being pursued [Collins and Gravett, 1995].

TABLE 14. DEPOSITION VELOCITY VG^W AND VG^A TO APPLE, STRAWBERRY AND RASPBERRY [COLLINS AND GRAVETT, 1995]

Crop			$^{14}CO_2$		$CO^{35}S$		HTO	
			mean	CV%	mean	CV%	mean	CV%
Apple	Vg^w	Leaf	1.1	14.5	2.8	11.5	16.8	35.2
		Crop	$6.0\ 10^{-2}$	24.2	$1.9\ 10^{-1}$	24.2	$4.4\ 10^{-1}$	21.4
		Leaf (F)	1.5	23.0	nd	nd	$4.5\ 10^{-2}$	27.0
Strawberry		Leaf	$4.3\ 10^{-1}$	16.7	2.2	7.2	-	-
		Crop	$1.8\ 10^{-1}$	17.6	$9.5\ 10^{-1}$	8.9	-	-
		Leaf (F)	2.3	41.0	nd	nd	$2.4\ 10^{-2}$	35.0
Raspberry		Leaf	1.4	20.2	$5.3\ 10^{-1}$	20.4	nd	nd
		Crop	$6.3\ 10^{-1}$	26.0	$2.3\ 10^{-1}$	16.1	nd	nd
		Leaf (F)	1.3	41.0	nd	nd	$6.3\ 10^{-2}$	36.0
Apple	Vg^a	Crop	$2.9\ 10^{-2}$	28.3	$1.0\ 10^{-1}$	28.3	$3.2\ 10^{-1}$	51.1
Strawberry		Crop	$1.9\ 10^{-2}$	34.1	$1.5\ 10^{-1}$	25.1	-	-
Raspberry		Crop	$9.4\ 10^{-2}$	13.0	$5.4\ 10^{-2}$	31.8	nd	nd

CV: Coefficient of Variation = s/mean; F = field; nd = no data

4.2.2. Post deposition transport of radionuclides in fruit

4.2.2.1. Direct contamination of fruit

The processes of interception, retention and absorption of radioactive fallout can directly involve the fruit. Many variables contribute to the process of direct contamination of fruit: the plant physiological stage at time of deposition, the kind of radionuclide, the kind of deposit, wet or dry, the fruit surface properties, the fruit's physical exposure to the fallout and afterwards to weathering, and the time elapsed between deposition and harvest.

Information reported in the review shows that few data in literature allow for separation of the contribution of the activity directly deposited on fruit surface from that translocated from other plant components to fruit [Carini and Bengtsson, 2001]. New information on this topic has been supplied by two series of data on vines, presented during the meetings of the Group. It has been summarised in Table 15 along with the data previously reported in the review.

In the first study vines were grown in large scale lysimeters under controlled conditions at the Institute of Protection and Nuclear Safety (IPSN, France). They were contaminated by dry radioactive aerosols produced in an induction furnace and containing ^{137}Cs and ^{90}Sr. The contamination source was defined on the basis of an accidental scenario involving a 900 MW pressurised water reactor (PWR) [Madoz-Escande et al., 1998]. Contamination was effected at two vegetative stages, late flowering and beginning of ripening, and was followed by 8 rainfalls between the contamination and the harvest. Radionuclides were deposited onto the aboveground part of the plant and onto the soil surface. After deposition at the beginning of ripening, 50% of ^{137}Cs and 90% of ^{90}Sr activity in fruit at harvest is ascribable to direct deposition (Table 15). The different percent contribution of direct deposition of the two radionuclides to the fruit activity is due to the higher ability of ^{134}Cs than ^{85}Sr to translocate from leaves to fruits [Madoz-Escande et al., 1998].

TABLE 15. DIRECT DEPOSITION TO FRUIT AS PERCENTAGE OF THE WHOLE ACTIVITY IN FRUIT AT HARVEST

Plant	Contamination method	Growing stage at time of contamination	Experimental conditions	Cs %	Sr %	Pu %	Reference
Vine	dry aerosol	beginning of ripening	controlled	50	90	–	Madoz-Escande et al., 1998
Vine	dry aerosol	beginning of fruit formation	field	97.4	–	–	Arapis, 1999
Vine	wet	beginning of ripening	field	13.3	–	–	Carini et al., 1996
Apple	wet	41 days before harvest	controlled	5	1.4 (all in peel)	–	Bengtsson, 1992
		84 days before harvest	“	5	0.17 (all in peel)	–	Bengtsson, 1992
Orange	dry particles		field	–	–	approxim. 100	Pinder III et al., 1987

A second study was carried out on vines under field conditions by the Agricultural University of Athens (Greece) in co-operation with IPSN (France) and NCSR Demokritos (Greece). Dry deposition of ^{134}Cs was simulated on vines at the beginning of fruit formation, using a micro-air brush device. Some fruits were protected by plastic bags before deposition, to prevent their direct contamination. Results show that 97.4% of the total activity concentration in grapes at harvest is due to direct deposition and only 2.6% to leaf to fruit translocation (Tables 15 and 19) [Arapis, 1999].

Data on direct deposition on vines previously reported in the review [Carini and Bengtsson, 2001] concern wet deposition of soluble ^{134}Cs at the beginning of ripening. The contribution of direct deposition to the total grape activity at harvest, 13.3%, is considerably lower than that of leaf to fruit translocation, 86.7% [Carini et al., 1996] (Table 15).

A great variability of the contribution of direct deposition to the grape activity at harvest is shown by the results of the three experimental studies on vines. Direct deposition, expressed as per cent of the fruit activity at harvest, ranges from 5 to 97.4 for Cs and from 0.17 to 90 for Sr. This variability can be explained, not only by the different experimental devices employed to apply radionuclides and the different criteria taken to assess direct contamination of the fruit, but also by different experimental conditions – field or controlled – and presumably by a different architecture of plants, trained in different shapes according to variety, climate and geographical regions.

Direct deposition data on other fruits, such as apples contaminated with ^{134}Cs and ^{85}Sr and oranges contaminated with ^{238}Pu, already reported in the review [Carini and Bengtsson, 2001] are also summarised in Table 15 for comparison.

The little data collected show that the information available is mainly limited to radionuclides of Cs and Sr and to vine and apple systems (Table 15). The discussion of the experimental results reveals the difficulty of reproducing natural conditions and the complexity in data interpretation. An appraisal of the contribution of the different variables to fruit contamination at harvest is still difficult considering the scarce knowledge of the process of direct contamination of the fruit.

TABLE 16. ACTIVITY IN FRUIT AT FINAL HARVEST AFTER FOLIAR DEPOSITION

Fruit	Stage of development at time of contamination	Days after contamination at final harvest	Fruit activity at harvest% of the applied/intercepted activity					Reference
			^{14}C	^{35}S	^{3}H	Cs	Sr	
Apple	flowering	127	7	27	32	–	–	Collins and Gravett, 1995
“	fruitlet formation	84	21	9	18	–	–	Collins and Gravett, 1995
“	fruit development	32	61	25	43	–	–	Collins and Gravett, 1995
“	fruit ripening	5	38	6	42	–	–	Collins and Gravett, 1995
Vine	late flowering	final harvest	–	–	–	2.9	1.1	Madoz–Escande et al., 1998
“	beginning of ripening	2	–	–	–	3.0	3.7	Madoz–Escande et al., 1998
“	beginning of ripening	7	–	–	–	3.8	3.0	Madoz–Escande et al., 1998
“	beginning of ripening	20	–	–	–	3.8	2.7	Madoz–Escande et al., 1998
“	beginning of ripening	30 (final harvest)	–	–	–	6.9	4.0	Madoz–Escande et al., 1998

4.2.2.2. Translocation from the above ground parts to fruit

Data on radionuclide translocation from the aboveground parts to fruit have been discussed in the review [Carini and Bengtsson, 2001] and are summarised in Table 2 (Section 2 of this report). The data relate mainly Cs and Sr on apple, grapevine and strawberry, and, for a few sets of data, gooseberry, blueberry, orange, pear and redcurrant.

Recent experimental studies on gaseous depositions of $^{14}CO_2$, $CO^{35}S$ and HTO to apple, raspberry, strawberry and blackcurrant, as described in Section 4.2.1. [Collins and Gravett, 1995], provide new information on this subject. The proportion of activity found in apples at final harvest is reported in Table 16. It depends upon the stage of development at the time of fumigation and upon the radionuclide. The authors propose that the overall partition to fruits over time suggests a period of rapid uptake for fruits. For ^{35}S and ^{3}H this is from approximately 80–140 days after the initial fumigation, but for ^{14}C is over a shorter period of 100–140 days after initial fumigation [Collins and Gravett, 1995].

Another set of data from recent studies on dry deposition of ^{137}Cs and ^{90}Sr on vines, described in Section 4.2.2.1 [Madoz-Escande et al., 1998], derived the radionuclide concentration in fruit after deposition at two different phenological stages: late flowering and beginning of ripening. Results confirm that the time of contamination relative to production of the fruit plays a role in fruit contamination. Grape concentration at harvest is lower for both radionuclides after contamination at flowering (0.8 MBq kg^{-1} of ^{137}Cs and 0.3 MBq kg^{-1} of ^{90}Sr), than after contamination at the beginning of ripening, (2.7 MBq kg^{-1} of ^{137}Cs and 1.2 MBq kg^{-1} of ^{90}Sr). This difference is partially ascribable to the process of direct deposition to fruit, occurring at the stage of beginning of ripening, as discussed in Section 4.2.2.1. After allowing for the 50% ascribable to direct deposition, the activity content of ^{137}Cs in fruit is 1.7 times higher after deposition at the beginning of ripening than at flowering. The beginning of ripening is regarded by horticulturists as the stage of higher demand of fruits for photosynthetic products from leaves. That can explain the higher transport of ^{137}Cs from leaves to fruits, analogous to potassium. The same calculation for ^{90}Sr reveals that, after allowing for the 90% ascribable to direct deposition, the process of leaf to fruit translocation, although very low, increases with time from contamination to harvest. The ^{90}Sr concentration in fruit at harvest is in fact 2.5 times lower after deposition at the beginning of ripening than at flowering, in contrast to what occurs for ^{137}Cs. The process of soil to fruit transfer can also partially contribute to the ^{90}Sr concentration in fruit, given the lapse of time between late flowering and harvest.

The trend of ^{137}Cs and ^{90}Sr concentration in the grape was also studied from contamination at beginning of ripening to harvest [Madoz-Escande et al., 1998]. Grapes were picked 2, 7, 20 and 30 days after contamination. Results are reported in Table 16. The ^{137}Cs and ^{90}Sr activities in fruit two days after deposition can be attributed mainly to the process of direct contamination of the fruit. Thereafter ^{137}Cs activity increases with time due to the process of leaf to fruit translocation. On the other hand, ^{90}Sr activity decreases due to loss processes, but increases during the last ten days preceding harvest, presumably due to the process of leaf to fruit translocation [Madoz-Escande et al., 1998].

Fruit contamination is nuclide specific. ^{137}Cs concentration in the final harvest is higher than ^{90}Sr concentration: 2.7 times after contamination at flowering and 2.2 times after contamination at the beginning of ripening. The authors [Madoz-Escande et al., 1998] propose that the difference is mainly ascribable to the process of leaf to fruit translocation, which is significant for ^{137}Cs, but negligible for ^{90}Sr. The smaller difference at the beginning of ripening can be attributed, as described above, to the process of direct deposition.

Generally speaking, the final concentration of radionuclides in fruit in the year of deposition is probably due to the dominance of either the process of direct deposition onto fruit or that of leaf to fruit translocation. The latter, for those radionuclides mobile in the phloem, seems to occur to a greater extent from fruit development to ripening. It should also be verified to what extent the different pattern of fruit growth plays a role in determining the fruit contamination at harvest.

4.2.3. Residual activity

Little information on the residual activity of Cs and Sr in fruit in the years following deposition from the Chernobyl accident has been reported in the review [Carini, 2001]. Generally speaking, when the scenario is that of an acute deposition, the residual activity in the plant is regarded as deriving from soil as the donor compartment, through the processes of soil to plant transfer and/or resuspension and splash. Although this may hold true for annual plants, it is not always the so for perennial plants like fruit trees, in the case of, for instance, radiocaesium. Information collected in the review [Carini, 2001; Mitchell, 2001] provides some evidence that radiocaesium, once introduced into the plant, can be retracted from leaves at autumn into perennial organs of deciduous fruit trees, mainly wood and roots, and translocated the next spring toward leaves and fruits. This hypothesis is supported by data of various authors [Antonopoulos-Domis et al., 1988; Baldini et al., 1987; Frissel, 1997]. Therefore the processes involved in fruit contamination in the years following an acute deposition are a function of both the soil reservoir and the plant reservoir, whose relative importance changes in time.

TABLE 17. CARRY OVER OF ^{14}C, ^{35}S AND OBT IN FRUIT CROPS TO THE FOLLOWING SEASON [COLLINS AND GRAVETT, 1995]

Crop	Predicted total activity (Bq) immediately post-fumigation	Leaf concentration at end of season (Bq g^{-1} DWT)	Fruit concentration at end of season (Bq g^{-1} DWT)
Apple	3568	1.24 ± 0.06	0.06 ± 0.06
	862	BDL	BDL
	–	BDL	BDL
	3330	0.48	BDL
	50621	BDL	BDL
	–	BDL	BDL
Raspberry	35680	2.34 ± 0.08	BDL
	1044	BDL	BDL
	–	BDL	BDL
	33304	2.87 ± 0.23	BDL
	11643	BDL	BDL
	–	BDL	BDL

(BDL = below detection limit)

4.2.3.1. Residual activity after gaseous depositions

Studies carried out with gaseous deposition of $^{14}CO_2$, $CO^{35}S$ and $^{3}H_2O$ to apple, raspberry, strawberry and blackcurrant [Collins and Gravett, 1995] (Section 4.2.2.2.) supply new information on this topic. The residual activity of ^{14}C, ^{35}S and OBT in apple and raspberry investigated over the 1998/1999 growth seasons (Table 17) shows that the proportion of radionuclides carried over from one growth season to the next after gaseous deposition is very low: the concentrations of ^{35}S and OBT in crops during 1999 were below the detection limit [Collins and Gravett, 1995]. This is also reflected in the radionuclide levels detected at Hinkley Point power station B, which do not increase year upon year. The authors comment that it is probable that a high proportion of the deposited radionuclides are retained in the leaf throughout the growth season, and are then lost at the end of the season when the leaves fall from the plants. In addition, for ^{35}S the short half-life would limit radionuclide buildup, and for OBT the low deposition rate would mean high OBT levels are unlikely in the case of small, continuous HTO discharges from gas cooled reactors [Collins and Gravett, 1995].

4.2.3.2. Residual activity after dry deposition of caesium and strontium

4.2.3.2.1. Caesium

A second experimental study provides new information on the time dependence of fruit and juice activity of ^{137}Cs and ^{90}Sr for three years following dry deposition [Madoz-Escande et al., 1998]. Experimental details are reported in Section 4.2.2.1. ^{137}Cs and ^{90}Sr at the time of contamination were deposited onto the aboveground part of the plant and onto the soil surface. The authors ascribe the fruit contamination in the year of deposition to the process of leaf to fruit translocation and to direct contamination of fruit (Sections 4.2.2.1. and 4.2.2.2.) and the fruit contamination of the following three years to the process of soil to plant transfer. The ^{137}Cs activity in the grape decreases distinctly by a factor of 3 between the first and the second year and by a factor of 4 between the second and the third year after deposition. Similarly, ^{137}Cs activity in the grape juice decreases by more than one order of magnitude from the first to the third year. The same decreasing trend, one order of magnitude in three years, occurs for vine shoots and leaves.

To a certain extent, the results for ^{137}Cs can be ascribed not only to the process of soil to plant transfer, but also to that of re-translocation from storage organs to other plant components, as discussed above. These results are in agreement with those reported in the review on the concentration of ^{137}Cs after the Chernobyl accident in various perennial tree products [Carini, 2001]. Antonopoulos-Domis and co-workers [Antonopoulos-Domis et al., 1990] observed a reduction of ^{137}Cs in all new plant parts of apricot trees and of a wide variety of perennial tree products, by a factor of three between 1987 and 1988.

Results from a third study on vines in Greece [Arapis, 1999] also provide information on the activity of grapes one year after dry deposition of ^{134}Cs. Details are reported in the Section 4.2.2.1. Dry deposition of ^{134}Cs was simulated on vines at the beginning of fruit formation. The ^{134}Cs activity measured in grapes at ripening in the second year after deposition is up to 4 orders of magnitude lower than that in the first year (Table 19). Such reduction is considerably larger than that observed in grapes and apricots discussed above. Among the various factors that can be analysed to explain such a difference, such as soil and plant characteristics, the human management, such as pruning can remove a considerable portion of biomass along with radioactivity from the soil–plant system.

4.2.3.2.2. Strontium

Experimental studies reported in Section 4.2.2.1 on the time dependence of fruit and juice activity show that ^{90}Sr activity in whole grape, in contrast to ^{137}Cs, tends to increase by a factor of 2 between the first and the second year and by a factor of 3 between the second and the third year [Madoz-Escande et al., 1998]. A similar increase is found in grape juice. The corresponding transfer factors, expressed as (Bq kg^{-1})/(Bq m^{-2}) show the same trend. ^{90}Sr activity in vine leaves also increases regularly, by approximately 5 times in three years. However, ^{90}Sr activity in shoots decreases from the first to the second year, before increasing again in the third year [Madoz-Escande et al., 1998].

The above results can be compared with data on the time dependence of ^{90}Sr concentration in various fruits collected by Juznic after deposition from the Chernobyl accident [Juznic, 1989] and reported in the review [Carini, 2001]. In contrast to the results of Madoz-Escande and co-workers [1998], Juznic observed a reduction of transfer from soil to apples, pears and blackcurrants by a factor of 2 or more from 1987 to 1988. The different trend of ^{90}Sr transfer can be due to a different chemical form of the radionuclide – produced in experimental conditions or deriving from the Chernobyl fallout. The difference can also be due to differences in soil type, although this cannot be verified since details of the soils are not reported in either study.

4.2.4. Radionuclide transfer from soil to fruit

Additional information to the soil to fruit transfer discussed in the review [Carini, 2001] (summarised in Section 2 of this report) has been provided by the FAO/IAEA/IUR Co-ordinated Research Project (CRP) on “The Classification of Soil Systems on the Basis of Transfer Factors of Radionuclides from Soil to Reference Plants”. Data have been obtained by Sasaki, Tashiro and Gunji, and collected by Uchida [personal communication, 2001]. Soil to fruit Transfer Factors were reported by the authors for U, Th and Pb in apple and mandarin grown on twelve well fertilised and highly productive soils in Japan using natural radionuclides or stable elements. The TFs were reported on a dry weight basis according to the IAEA-IUR CRP protocol [IAEA-IUR, 1997], and were converted into fresh weight using a literature value of water content of 84.4% for apple and 86% for mandarin [Desai and

Salunke, 1991]. The ranges of soil to fruit Transfer Factors and the corresponding geometric means, expressed as Bq kg^{-1} f.w. fruit per Bq kg^{-1} d.w. soil are reported in Table 18.

TABLE 18. SOIL TO FRUIT TRANSFER FACTORS FOR U, Th AND Pb

	Transfer Factor Bq kg^{-1} f.w. fruit per Bq kg^{-1} d.w. soil					
	U		Th		Pb	
Product	geometric mean	range	geometric mean	range	geometric mean	range
Apple	5.3 10^{-6}	1.7 10^{-6}–1.1 10^{-5}	3.1 10^{-6}	9.0 10^{-7}–1.3 10^{-5}	1.2 10^{-4}	9.4 10^{-6}–4.7 10^{-3}
Mandarin	7.6 10^{-6}	4.1 10^{-6}–1.5 10^{-5}	4.7 10^{-6}	2.1 10^{-6}–8.5 10^{-6}	8.2 10^{-4}	1.1 10^{-4}–3.1 10^{-2}

[Uchida, 2001]

Both U and Th TFs are in the order of 10^{-6}, with U values on average higher than those of Th. The only TFs for U reported in the review are 1.1 × 10^{-3} for melon [Tsukada and Nakamura, 1998] and 3.7 × 10^{-3} for watermelon [data from Twining, in Carini, 2001], three orders of magnitude higher than those for apple and mandarin in Table 18. Similarly the TF for Th to melon reported in the review is 4.9 × 10^{-4} [Tsukada and Nakamura, 1998], two orders of magnitude higher than that for apple and mandarin. New information is given with TFs for Pb, two orders of magnitude higher than those for U and Th in apple and mandarin. Generally speaking soil to fruit TFs are higher in mandarin than in apple, particularly for Pb.

4.2.5. Countermeasures

4.2.5.1. Potassium fertilization following soil contamination

Generally potassium fertilization is used to decrease the caesium content of crops by a factor of about two, when applied to contaminated soils with low potassium availability. Fruit trees in the agricultural ecosystem are very well fertilized, therefore it is likely that further fertilization will not cause such a great reduction.

Some of the data on fruits from Robison and Stone [1992], illustrating the effect of potassium content of soil, were reported in the review [Carini, 2001] and are summarised here. The authors studied coconut palms, with a high requirement for potassium, growing on Bikini Atoll soils (Marshall Islands). The total potassium content of soil is low. Exchangeable or extractable potassium is highest in the 0–5 cm layer, but diminishes rapidly downwards. ^{137}Cs TFs in coconut are high, about 2.0 Bq kg^{-1} f.w. fruit per Bq kg^{-1} d.w. soil. A reduction by a factor of 7–8 was found following soil additions of potassium chloride at rates from 670 to 6270 kg potassium ha^{-1} [Robison and Stone, 1992].

4.2.5.2. Potassium fertilizations following foliar contamination

A recent experiment of Zehnder and co-workers [Zehnder et al., 1999] studied the possible reduction of radiocaesium in grape vines after foliar deposition by applying potassium via roots. Grape vines grown on nutrient solution were contaminated with ^{134}Cs in chloride form via the leaves. Radiocaesium was taken up through the leaf surface, transported to other plant parts and to some extent released from the roots. An increased supply of potassium in the nutrient solution caused a higher release of radiocaesium into the nutrient solution: 3.5 ± 0.9% of the applied ^{134}Cs was released in 16 weeks after a low (133 mg l^{-1}) potassium supply and 12.4 ± 2.2% of the applied ^{134}Cs was released after a high (661 mg l^{-1}) potassium supply. The authors concluded that well supplied grape vine plants released more radiocaesium than poorly supplied plants. However, they compared the radiocaesium activity of grapevine plants grown on the nutrient solution with a high potassium content with that of plants grown on soil or on the nutrient solution with a lower potassium content and found no significant difference between them. They concluded that a treatment of vines contaminated with ^{134}Cs via leaves with high doses of potassium via roots is not effective in causing a faster decontamination of the plants on the soil used [Zehnder et al., 1999].

4.2.5.3. Non-lethal defoliation following foliar contamination

Research on non-lethal defoliation of vines was undertaken by the Agricultural University of Athens (Greece) in co-operation with IPSN (France) and NCSR Demokritos (Greece). The aim of the project was to prevent or reduce the translocation of radionuclides from leaves to the other plant components, in order to protect vines after an acute release and to reduce the internal dose to man from ingestion of contaminated food.

Dry deposition of ^{134}Cs was simulated on vines at the beginning of fruit formation [Arapis, 1999] (Section 4.2.2.1.). Some fruits were covered during deposition and some plants were partially defoliated with two different agrochemicals after deposition. Vine defoliation is common practice in agriculture to improve the fruit quality. The concentration of ^{134}Cs was determined in fruits at ripening in the first and second year after deposition, as reported in Table 19.

Partial defoliation is effective in the year of deposition and reduces the ^{134}Cs activity per unit weight by approximately 50%, even in the case of protected grapes. This result demonstrates the importance of the process of leaf to fruit translocation for radiocaesium and, as a consequence, the effectiveness of partial defoliation to reduce the activity in fruit at harvest. The activity of grapes in the second year after deposition is up to 4 orders of magnitude lower than that in the first year, and it does not seem to be affected by the practice of defoliation.

Additional data on defoliation of vines grown in large scale lysimeters in controlled conditions and contaminated by dry radioactive aerosols containing ^{137}Cs and ^{90}Sr (Section 4.2.2.1.) are going to be produced at the Institute of Protection and Nuclear Safety (IPSN, France).

4.2.6. Food processing

Information on the effect of processing on radionuclide content of fruit has been discussed in the review [Green, 2001] and is summarised in Table 7 (Section 2 of this report). Additional information on the effect of processing grapes to make wine has been provided by Madoz-Escande and co-workers [Madoz-Escande et al., 1998] (Section 4.2.2.1.). The transformation of grape juice into wine results in an activity reduction of 30 to 35% for ^{137}Cs and of 45 to 60% for ^{90}Sr, depending on whether the deposition occurred at late flowering or at beginning of ripening.

From the data available it is not possible to calculate F*r*, the fraction of activity retained in the processed food, to compare results with those reported in the review [Green, 2001] (Table 7). It is however clear that the reduction of contamination is higher when deposition occurs at the beginning of ripening, because directly deposited radioactivity is probably removed with the skins.

TABLE 19. ^{134}CS CONCENTRATION IN GRAPES AT RIPENING

Year of harvest after deposition	Grapes	Plant	Fruit activity kBq kg^{-1}
1st year	non-protected	non-defoliated	11.6 ± 0.9
		defoliated	5.5 ± 1.1
	protected	non-defoliated	0.3 ± 0.1
		defoliated	0.15 ± 0.07
2nd year		non-defoliated	0.006 ± 0.005
		defoliated	0.006 ± 0.004

From Arapis [1999]

4.3. CURRENT EXPERIMENTAL STUDIES

Ongoing experimental studies are summarised in Table 20. Results provided by these activities will be useful for model validation studies and in some cases for model construction. They provide missing information, both on particular categories of fruit systems and on particular radionuclides or their chemical form.

TABLE 20. CURRENT EXPERIMENTAL STUDIES

Institution/ Person	Fruit	Nuclide	Experimental conditions	Method of contamination	Endpoint
NRPB (UK) N Green	Apple Blackcurrant Gooseberry Strawberry	Sr-90 Cs-137 Pu, Am	Soil/field Soil/pots Open tunnel	soil	One measurement in time
UCSC (Italy) F Carini	Olive	Cs-134 Sr-85	Pots/open field	leaves	One measurement in time: fruits, leaves, branches, stocks, roots, soil
	Blackberry	Cs-134 Sr-85	Pots/ventilated tunnel	soil or leaves	One measurement in time: fruits, leaves, canes, roots, soil.
	Strawberry	Cs-134 Sr-85	Pots/ventilated tunnel	old/or new leaves	Leaves and fruits in time
Westlakes Institute (UK) S Bradley	Apple Blackberry	I-129	Soil Field pots	soil	One measurement in time: fruit, leaves, soil, wood, air
Agricultural University of Athens (Greece) G Arapis	Olive	Cs-134	open field	leaves (dry)	Fruit, leaves
IPSN (France) C Madoz-Escande	Grapevine	Cs-137 Sr-90		leaves (dry) soil	Fruit, leaves, stalks, branches, soil
Demokritos (Greece) M Antonopoulos-Domis	Sweet cherries, apricots, pears, apples, peaches, olives	Cs-137	open field	Chernobyl deposition	Field measurements in time: fruit, leaves, wood, soil
Irrigation Research Institute and University of Veszprém (Hungary) M Oncsik	Strawberry	Cs-134	Field Pots	soil leaves fruits	Measurements in time: fruits, leaves, wood, roots
PSI (Switzerland) T Riesen	Apple	Cs-134 Co-57	Greenhouse	leaves fruits	fruit, leaves, wood, roots, soil, new buds
PE Institute of Radioecology, PSI (Ukraine/Switzerland) E Garger, T Riesen	Apple	Cs-134	open field	leaves fruits	fruit, leaves, twigs, jam, wood
GSF (Germany) G. Pröhl	Apple Strawberry Raspberry	^{137}Cs	pots in the open field	spray on leaves at 3–4 single application during the growth period	fruit, leaves (stalks)

4.4. FIELD DATA AFTER CHERNOBYL CONTAMINATION

Field data have been offered to the Fruits Working Group by the RIARAE, Obninsk, Russia (N Sanzharova). Data have been collected from the Bryansk region, Russia, at approximately 180 km from the Chernobyl NPP, since 1986 to 1998. They concern:

- level of ^{137}Cs contamination
- soil characteristics
- ^{137}Cs content in cultivated fruits and berries:
  - apple
  - blackcurrant
  - strawberries
  - raspberries
- ^{137}Cs content in wild berries:
  - wild strawberries
  - blackberries
  - raspberries
  - cranberries

4.5. CONCLUSIONS

New experimental information additional to that summarised in the Review has provided further results and knowledge.

Gaps in knowledge on deposition velocities of gaseous radionuclides have been filled by recent results on $^{14}CO_2$, $CO^{35}S$ and HTO (tritiated water) deposition to apple, strawberry, blackcurrant and raspberry. Deposition velocities are of the same magnitude as observed for other crops and are less variable when expressed per unit weight than per unit area.

Data concerning direct deposition onto fruit surfaces are still extremely limited. New information has been produced by two series of data on direct dry deposition of caesium and strontium to grapes. Results show the importance of direct deposition on fruit, but knowledge is still insufficient to draw some conclusions on the role of the different variables affecting this process.

Recent results on gaseous depositions of $^{14}CO_2$, $CO^{35}S$ and HTO to apple, raspberry, strawberry and blackcurrant as well as on dry deposition of ^{137}Cs and ^{90}Sr to vines provide new information on translocation of radionuclides from the aboveground part to fruit. This process, for those radionuclides mobile in the phloem, seems to occur to a greater extent during the time from fruit development to beginning of ripening.

The residual activity in apple and raspberry in the years following that of deposition is very low for ^{14}C, ^{35}S and OBT (organically bound tritium) after gaseous deposition. A high proportion of deposited radionuclides probably remains at the site of deposition, mainly the canopy, and is lost through leaf fall before dormancy.

The activity also decreases for caesium in the first years after deposition. In some experimental studies on vines caesium decreases by one order of magnitude in three years, following a trend similar to that reported in Chernobyl studies for apricots and various perennial tree products. The processes of retranslocation from storage organs to other plant components and of soil to plant transfer are assumed to be responsible for residual fruit contamination, but their respective roles have not yet been clearly defined. Results from other experimental studies on vines show a larger reduction of radiocaesium in the first years after deposition, suggesting that different crop management practices, particularly on vines, can remove a considerable portion of the contaminated biomass from the soil-plant system.

Data for the residual activity of strontium in the first years after deposition do not provide conclusive evidence for the processes affecting its redistribution in the soil–plant system. While after Chernobyl deposition the soil to fruit transfer of ^{90}Sr is reduced in apples, pears and blackcurrants from the second to the third year, in experimental conditions ^{90}Sr tends to increase in grapes and in grape juice in the second and third year after deposition. An understanding of the main factors affecting this scenario is one of the priorities for future experimental work.

Soil to fruit Transfer Factors have been provided for U, Th and Pb in apple and mandarin grown on twelve soils in Japan. They fill gaps in a field where only a very limited information had been collected previously on U and Th for melon and watermelon.

Countermeasures to reduce the radiocaesium content of fruit have been discussed. When the donor compartment is soil a great reduction cannot be expected by applying potassium fertilizations, because fruit trees in the agricultural ecosystem are very well fertilized. Potassium fertilizations can however be effective on soils poor in potassium and not fertilized, as demonstrated for the soil to coconut transfer of ^{137}Cs in the Marshall Islands.

When the donor compartment is the canopy, potassium fertilizations are not effective in reducing caesium concentration in fruit deriving from foliar uptake. The common agricultural practice of partial defoliation of vines has been demonstrated to be effective if applied in the year of deposition, reducing caesium activity in grapes by approximately 50%.

A reduction of activity in the final product for human consumption is also achievable by processing food. Processing of grapes to make wine causes a reduction of contamination, which is even more effective when fruit is also affected by direct deposition as a consequence of the removal of contamination with the skins.

5. THE FRUIT PARAMETER DATABASE

5.1. BACKGROUND

Data collated by the participants have been incorporated into the RADFLUX database [Mitchell, 2000] which represents a substantial collection of transfer parameters for use in models of soil–plant–animal systems.

It was intended to populate RADFLUX with rate constants (e.g. units: s^{-1}) representing net transfer between a donor compartment (field name “parameter from” in Table 21) and a receiving compartment (field name “parameter to”). These parameters are used in multi-compartmental models represented mathematically as a set of first-order linear differential equations. The values are simple to derive from observations on the fraction of a compartment transferred over a given time period. Supporting information is entered about the two compartments (mass or volume, soil depth, concentration) and experimental details (study period, elapsed time since radionuclide deposition). This additional information allows the database user to calculate alternative parameters, such as the amount of activity in each compartment (for example, activity distribution) or simple ratios between compartments (for example, soil-plant transfer factors).

The RADFLUX working group subsequently decided that other parameters could be entered as long as they were a function of time and described transfer between compartments (for example, Bq m^{-2} d^{-1}). It was also decided that previous data collected by IUR and other working groups would be made available through RADFLUX even when a flux could not be derived.

The database fields and short descriptions of the information that each contains are presented in Table 21. Overall, the number of fields adopted attempted to achieve a balance between a number of conflicting factors as follows:

the wealth of information that could be recorded from an experiment;
the diverse range of experiments and measurements that are performed;
the need to provide sufficient detail to make the exercise worthwhile; and,
the burden placed on contributors to enter information in database proforma.

RADFLUX contains over 18,000 records. It includes data both from the earlier IUR soil–plant transfer factor data set and the more recent tropical/sub-tropical data set provided from the IAEA/IUR Coordinated Research Programme entitled “Transfer of radionuclides from air, soil and freshwater to the food chain of man in tropical and subtropical environments”. These data were included so that they are not lost. The remaining components of the imported data set come from UK Food Standards Agency and represent flux data collated since 1980. The Fruits Working Group of the IAEA programme on Biosphere Modelling and Assessment (BIOMASS) also contributed data from their review of available literature.

The database now contains a substantial amount of data on radionuclide transfer. However, the database is not an expert system producing answers to defined questions and it does not produce a single parameter estimate based on an experimental protocol. The database can be used to answer specific questions, for example, relating to transfer mechanisms by looking for correlations between the information it contains and it can be used to estimate missing data for specific parameter types (e.g. as in the approach taken by Frissel, 1998). The database can also be used to estimate model specific transfer parameters and provide an audit trail from model parameters to the underlying body of experimental data.

TABLE 21. FIELDS DESCRIPTIONS

Field	Description
Animal code	A four character code to describe the parameter.
Chemical form	For elements that have either an ionic or an organic form (e.g. sulphur, carbon, tritium) the descriptors I or O are used, respectively. For particulate forms the character P is used. A second letter (S) is used if the form is soluble in water.
Comments	Any relevant information that is not covered in the database fields. For example, soil cation exchange capacity.
Concentration, units and statistics	Radionuclide concentration in the from compartment, in the to compartment and the units used (e.g. kg dw or g dw, or kg dw m^{-2} or g dw m^{-2}) and statistics. The units must also indicate if these are fresh weight or dry weight basis.
Contamination start and end dates	The date/time when the contamination event started and ended.
Crop established and harvest	These are the dates of planting and sampling the crop.
Cross reference	Identifies related parameters. This cross-reference is based on the name of the contributor (first four letters) and a number to identify related data sets.
Date	Date that the entry proforma was completed for each record.
Soil depth	The depth of the contaminated soil is indicated here (units; m).
Ecosystem	Description of the ecosystem, e.g. natural or agricultural ecosystems.
Element	The element identified by its chemical symbol.
Data grading	An automated scoring system. This provides a semi-quantitative assessment of information / data quality based on database entries.
Location	Latitude and longitude references should be given to show location, or if not known, climatic zone e.g. temperate, sub-tropical, tropical.
Mass and units	Mass of the from compartment, mass of the to compartment and the mass units used (kg dw or g dw, or kg dw m^{-2} or g dw m^{-2}). Uses the same basis, fresh weight or dry weight, as presented in the concentration fields.
New codes	Used in the Proforma to suggest the need for an additional code or filed.
Soil organic carbon	Measured value of soil organic carbon content (as % dw/dw), defined as loss on ignition at a defined temperature.
Parameter to / from	A two character code to describe the donor and the receiving compartment.
Parameter range, replicates, statistics	Data should be single values (in which case the range entries are not use). If a mean is provided give ranges (minimum and maximum), number of samples (Replicates) and the standard deviation (Stats parameter).
Parameter value and units	The numerical value of the coefficient or variable described by the to and from field entries and the units field.
Particle size	Soil particle size is input as percentages for sand (s), silt (z) and clay (c) in the format: s:z:c, for example: 30:20:50
Plant code	Three character code to identify crop groups to help in the analysis of transfer parameters, e.g. Barley is coded CCN (arable crop+cereal+non-leguminous).
Plant and animal type	The Latin name.
Radioisotope	Mass number of the radionuclide for which the parameter is specific.
Radionuclide source	Single character field that refers to the source from which the radionuclide arises, e.g. Chernobyl deposits, weapons testing fallout.
Record ID	A unique reference number for this database record.
Reference	Full scientific reference if this is available for the data. Otherwise identify presentation at working group meeting, or indicate data are from researchers' laboratory notes.
Soil bulk density	Soil bulk density (g dw m^{-3}) for the depth of soil considered.
Soil code	A character descriptor describing certain characteristics of a soil. At this time it only refers to waterlogging. Use "Soil type" for soil classification.
Soil pH	Measured mean of soil pH in H_2O.
Soil Plant Animal	Where transfer occurs between soil, plants, animals and/or atmosphere this refers to the type of receiving compartment.
Soil quality	Soils should be subjectively classified as poor, average or rich soils in terms of their agricultural productivity under local husbandry practices.
Soil type	FAO classification based on particle size.
Stable element data	If data are available on stable element concentrations then the elements should be listed here by chemical symbol with a 'comma space' separator.
Study type	Two character code describing the type of study producing the parameter values, e.g. monitoring relating to routine discharges, field experiment.
Treatments	Two character code describing biological, chemical or physical treatments to the donor or receiving compartments. For example, ploughing or washing treatments.

5.2. OVERVIEW OF DATA ENTRIES

RADFLUX now contains 18,199 records and the breakdown by receiving compartment is as follows:

Soil	3%
Plant	67%
Animal	30%

There is therefore a large bias towards records on radionuclide transfer to plants. This is due to the large amount of data originating from the IUR soil–plant transfer factor databases. A detailed discussion of the summary data is unnecessary but the following points are highlighted:

- Over half the records (52%) concern radiocaesium and the most frequently represented radionuclides thereafter are strontium (11%), cobalt (6%) and plutonium (5%). Other elements identified as being of interest to the fruit working group were poorly represented with iodine (1%) being most abundant.
- RADFLUX contains little information on carbon (3 entries) and sulphur (22 entries) with no data on tritium and chlorine.
- Over half the data are from field based experiments (54%). A large number of records are from lysimeter studies (24%) and about 12% of records are based on studies using pots.
- There are a large number of records deriving from studies of Chernobyl (34%) and other fallout (6%) but the majority of data comes from controlled experimental contamination (60%).
- The majority of records have total soil as the donor compartment (96%) with about 2% that consider the plant as the donor, and a small number that concern animals as donors.
- The receiving compartments are much more varied with 13 different plant parts found in 11,416 records.

The approach of grouping plant species into different classes shows that there are about 4,000 records for cereals, with a large number of data for leafy and non-leafy vegetables, animal pasture and tubers (all <1,000 records). The list of individual plant species (and common names) shows great diversity with single records for a number of exotic plants.

5.3. FRUIT PARAMETER ENTRIES

The fruit crops of particular interest to the working group are apple, blackcurrant and strawberry reflecting the interests of the majority of working group members. It is recognised that there are a large number of different species with many growth habits but these were chosen as representative of plants with tree, shrub and prostrate growth habits. Other crops of interest to individual working group members include blackberry, vines, orange, olive and pear.

The following analysis is based on the fruit data available in the RADFLUX database at the end of 2000 and these data are reproduced in Annex III. It does not include the most recent data identified in this report.

TABLE 22. DATA ON FRUIT IN RADFLUX: CROPS

Fruit crop	Records
Olives	50
Orange	43
Apple	41
Papaya	37
Watermelon	29
Breadfruit	27
Strawberry	27
Grape	20
Peach tree	13
Blackcurrant	6
Blueberry	6
Apricot	4
Gooseberry	4
Mango	4
Melon	4
Pear tree	4
Raspberry	4
Rhubarb	4
Sweet cherries	4
Damson	3
Redcurrant	3
Fig	2
Guava	2
Lemon	2
Mandarin	2
Pandanus	2
Pear	2
Platano	2
Kiwi fruit	1
Lime	1
Mayer lemon	1
Pawpaw	1
Pomegranate	1
Rambutan	1
Ruby grapefruit	1

There are data on 34 types of fruit crop available in RADFLUX (Table 22). Although there are a large number of crops there are many for which there is only one or two records. Table 22 illustrates that in RADFLUX the data are skewed towards information on olive, orange, apple, papaya and strawberry.

The BIOMASS working group also collated information on research in progress on fruit and developed the list presented in Section 4 (Table 20). This shows that new information is being produced on apple, apricot, blackberry, blackcurrant, cherry, gooseberry, olives, oranges, raspberry, strawberry, peach, pear and vines.

The seventeen elements for which there are data are listed in Table 23. This shows a large bias towards data for caesium (about 56% of values) and strontium (20%) and the majority of data are soil–plant transfer factors (98%). A more detailed analysis was performed for information on the three main crops of interest (Table 24). There are 17 values each for caesium and strontium, with a total of 21 values for apple, 11 for strawberry and 4 for blackcurrant. There are two records for iodine and these concern apple.

TABLE 23. DATA ON FRUIT IN RADFLUX: ELEMENTS

Element	Records
Cs	207
Sr	73
Pu	36
Am	22
I	6
Cm	4
U	4
Ce	3
Ru	3
Pb	2
Th	2
Co	1
Mn	1
Na	1
Np	1
Ra	1
Zn	1

Increased confidence can be placed in transfer parameters when data are produced by a number of different authors under different experimental conditions. However, when data are analysed by author it shows they come from only a small number of investigators (Table 25) with several authors contributing single values for a number of different crops. The data set from Green et al., [1997] provides multiple values for the crops selected by the working group.

The working group identified four radionuclides of importance for transfer to fruit crops, i.e. caesium, strontium, iodine and sulphur. Interest was also expressed in carbon and tritium. From the data presented here there is clearly a need for more information on the transfer of iodine and sulphur to fruit crops.

Table 20 lists new information being produced on americium, caesium, cobalt, iodine, plutonium, and strontium at the time of this report. Note also that much of this new information will be for single measurements and will not provide information on the changing distribution with time.

TABLE 24. SUMMARY OF DATA IN RADFLUX ON SELECTED CROPS

Fruit crop	Element	Records
Apple	Cs	10
	I	2
	Sr	9
Blackcurrant	Cs	1
	Sr	3
Strawberry	Cs	6
	Sr	5

TABLE 25. DATA ON FRUIT IN RADFLUX: AUTHORS

Author	Records
Antonopoulos-Domis, M., Greece	3
Boone, F.W., USA	7
Coughtrey, P.J., UK	2
Delmas, J., France	5
Green, N., UK	36
Juznic, K., Yugoslavia	5
Klepper, B., USA	1
Ng, Y.C., USA	4
Pimpl, M., Germany	8
Roussel, S., France	1
Topocouglo, S., Turkey	2

5.4. CONCLUSIONS

The working group makes no specific recommendations for the fruit crops that should be studied. This is a decision for those who commission research and/or the investigator.

Data sets now being generated or only recently compiled show that there is a considerable amount of interest in radionuclide transfer to fruit crops. For example the data being generated by Carini [1997] for Cs and Sr in strawberry and blackberry will add considerably to our knowledge for these crops.

For conclusions of this section see Section 7.2.

6. MODELLING

6.1. BACKGROUND

Fruits may become contaminated with radioactive material from nuclear facilities during routine operations, as a consequence of nuclear accidents, or due to migration of radionuclides from radioactive waste disposal facilities through the biosphere. The processes and pathways by which radionuclides enter the fruit system are complex and require models based on clear understanding of the main issues.

Those models available at the start of the BIOMASS programme have been reviewed in Section 2 (Section 2.11). Some of them deal specifically with the transfer of radionuclides to fruit and others are adaptations of models for agricultural crops such as leafy green vegetables. In Section 3 a systematic approach to developing a conceptual fruit model is described, where important processes were identified, discussed and assessed.

This section describes the modelling studies that were undertaken by the BIOMASS Fruits WG: two model–model intercomparison studies and a model validation study. The objective was to identify and investigate significant areas of uncertainty and differences in approach between models.

Prospective models were identified from the Questionnaire that was circulated amongst radioecologists at the inception of the activities of the Fruits WG (Section 1.3). Only one of the models identified in the Review and presented in Section 2 (Section 2.11), the SPADE model, participated in the current study.

The fruits that were modelled were chosen according to the classification of fruits as discussed in Section 2 (Section 2.2), i.e. apples (woody tree), blackcurrants (bushes) and strawberries (herbaceous plants), as these represented three different morphological types.

The radionuclides were chosen among those indicated in Section 2 as being relevant for transfer to fruit (Section 2.5), and for which models had been designed. Most of the participating models had been developed for simulation of ^{137}Cs. Some models could also simulate strontium and iodine. It was therefore decided to focus on these radionuclides for the initial intercomparison studies. ^{35}S was also considered, but it is of interest only in the context of releases from UK gas cooled reactors and very few models had been developed for ^{35}S.

All the participating models were designed for atmospheric deposition, but very few of the models could simulate a terrestrial source (such as a nuclear waste repository). Thus, for the initial intercomparison study, an atmospheric source term was chosen.

6.2. DISCUSSION OF PARTICIPATING MODELS

A total of six models participated in the model intercomparison and model validation studies (Table 26). Five of these models were developed by Government Agencies for regulatory assessment of radionuclide concentration in fruits and risk resulting from their consumption.

The nature of intercomparison scenarios required all models to provide dynamic outputs for radionuclide concentration. Nevertheless, the degree of treatment of temporal processes does vary across the models. For example, only two models (RUVFRU and SPADE) explicitly consider plant growth, while others assume constant plant biomass. Incorporation of time varying parameters does vary across the models (Table 27). Four models are designed to provide point estimates for activity concentrations and risk. The DOSDIM model is capable of incorporating stochastic calculations, while FRUITPATH is the only model that incorporates probabilistic Monte-Carlo simulation and predicts probability distribution for radionuclide concentrations at different time scales.

Table 27 lists the most important processes for radionuclide transport within plants and their representation in models. They are not necessarily the same suggested by the conceptual modelling and ranking exercise, reported in Section 3. Some of the processes are treated similarly by most of the models. For example, an interception fraction is used by four of the participating models, while SPADE and FRUTI-CROM use the deposition rate as well as an interception fraction. Radionuclide loss from vegetation was modelled using residence half-time (i.e. first order differential equation) by four models. SPADE models radionuclide losses by considering residence half-lives for external and internal plant surface layers and thus the loss dynamic is more complex. RUVFRU models losses from vegetation by weathering and resuspension factors.

Other redistribution processes in fruit systems are handled very differently by the models. SPADE considers translocation among seven vegetation compartments, while DOSDIM and ASTRAL consider translocation to fruits only. FRUITPATH and RUVFRU do not consider these processes and model fruit as a part of the plant. Radionuclide speciation in soils is another area of divergence in modelling. FRUITPATH and RUVFRU consider labile and fixed pools of radionuclides in soil where sorption and desorption processes occur. Radionuclide half-times in these compartments are used in modelling. SPADE considers these processes over several soil layers. DOSDIM models the radionuclide concentration in the root zone by taking into account leaching and radioactive decay. The soil distribution coefficient is used to calculate radionuclide concentration in the soil solution.

Plant uptake of radionuclides from soil is an area of large uncertainty in modelling the transfer of radioactivity to fruits. FRUITPATH and RUVFRU use plant uptake rates from the labile soil compartment. DOSDIM, FRUTI-CROM and ASTRAL use equilibrium transfer factors. In SPADE, transfers from soil to plant occur via root uptake from soil solution and transfer rates are assumed to vary with soil layer depth as a function of the root distribution throughout the soil profile. Consequently the transfer of radionuclides from soil to root is represented in SPADE by a single transfer rate, normalised for each of the ten layers in the soil model according to root distribution.

The models that participated in the studies of the Fruits WG are listed in Table 26. More detailed model descriptions for some of them are provided in Annex I.

TABLE 26. PARTICIPATING MODELS

Model	Organization/contact person	Model purpose	Type	Predictions	Comments
SPADE	Z Ould-Dada Foods Agency (formerly MAFF), UK	Dose assessment	Dynamic	Activity and concentration in soil and plant. Conservative scenarios using best estimate parameters.	Incorporates site and crop specific parameter selection and plant growth curves. First order processes for soil, plant and animal transfer and distribution between organs in animals.
FRUTI-CROM	Robles B. and Suañez A. CIEMAT, SPAIN	Calculation of radionuclide concentration and Assessment of radiological impact to man from routine and accidental releases	Compartments in equilibrium	Activity and concentration in soil and plant. Conservative using best estimate parameters	Incorporates site and crop specific parameter selection. Considers translocation to fruit, and leaves, losses by leaching, growing and pruning.
FRUITPATH	Linkov & Burmistrov, USA	Generic Dose and Risk Assessment	Probabilistic dynamic	Probability distributions, conservative estimates as 95th percentile	Incorporates site–specific model calibration through Bayesian updating techniques.
RUVFRU	Eged, Kis, Kanyar, Szederkenyi HUNGARY	Calculation of radionuclide concentration and dose assessment	Dynamic	Point estimates	Considers seasonality, sigmoidal growth curves, mass-dependent transport coefficients
DOSDIM	Zeevaert, Sweeck BELGIUM	Assessment of radiological impact to man from routine and accidental releases	Partly dynamic, partly equilibriummodel , compartmental	Deterministic and stochastic calculations	Considers time-dependency of translocation to fruit, losses by leaching
ASTRAL	IPSN FRANCE	Dose and concentration assessment	Dynamic	Point estimates	

TABLE 27. MODEL REPRESENTATION OF MAJOR PROCESSES

Model	Deposition	Loss From Vegetation	Translocation Within Vegetation	Soil Transport	Radionuclide Speciation	Uptake From Soil
SPADE	Ground deposition rate and air concentration. Deposition to fruit not considered	From vegetation surface to internal plant and soil (split between solution and organic).	Translocation between roots, stem, storage organ, internal leaf, external leaf and fruit considered.	Soil solution, inorganic and organic matter considered in 10 layers of 3 cm depth each. Considers effect of inorganic and organic matter distribution in soil profile.	Partition in soil. Uptake by plant at vegetation surface.	Root distribution in profile used to calculate depth dependant root uptake rate constants.
FRUTI-CROM	Interception fraction for fruit and leaves	Decrease rate due to radioactive decay, growth and pruning.	Translocation from external plant surface on to internal part plant is considered	No transport inside the soil compartment is considered. Consider losses by radioactive decay, leaching and other processes	Not considered	Equilibrium transfer factor for root uptake
FRUITPATH	Interception fraction (fruit and leaves)	First order process with specified half-time	Not considered	First order process among organic layer, labile, fixed and deep soil compartments	Sorption and desorption within labile and fixed soil compartments	First order process
RUVFRU	Interception fraction (fruit and leaves)	Weathering and resuspension factors	Not considered	First order process among four soil comparments	Sorption and desorption within labile and fixed soil compartments	First order process with corrections for moisture content
DOSDIM	Interception fraction (fruit, not leaves)	First order differential equations for translocation, weathering	Only translocation to fruit was considered	First order process in root zone (loss from root zone through leaching)	Exchange between soil solution and solid soil phase given by distribution coefficient	Equilibrium transfer factor for root uptake
ASTRAL	Interception fraction (as an aggregated transfer factor to leaves)	Decrease rate due to weathering	Translocation to the edible organ (in previously mentioned aggregated transfer factor)	No transport inside the soil compartment considered. Ploughing taken in consideration and giving homogeneous concentration.	A decrease rate for bio-availability in soil (fixation and migration in soil) is radionuclide dependent.	Transfer factor from soil concentration to edible organ concentration (=aggregates root absorption and translocation processes)

A short description follows of the general approach adopted by each modeller in applying the model to the studies of the Fruits WG.

6.2.1. The SPADE model (Annex I–1)

SPADE (**S**oil **P**ant **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. Radionuclide inputs to SPADE are results from atmospheric dispersion calculations, measured or assumed concentrations in air (Bq m^{-3}) and/or deposition rates (Bq $m^{-2}s^{-1}$) to ground. The quantity of radionuclides reaching the above ground compartments of the plant from atmospheric sources is determined according to 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. Radionuclide distribution in plants depends on both the physiological characteristics of the plant and the physico-chemical properties of the radionuclide. Material lost from the plant by wash-off is partitioned between either soil solution and organic matter, or ‘soil available’ and ‘soil unavailable’, as appropriate. Transfers from soil to plant occur via root uptake and are assumed to vary with soil layer depth, as a function of the root distribution throughout the soil profile. Consequently the transfer of radionuclides from soil to root is represented in SPADE by a single transfer rate, normalised for each of the ten layers in the soil model according to root distribution.

SPADE models radionuclide uptake by three types of fruit crops: herbaceous, shrubs and trees. Parameter values used in SPADE are those specified in the scenarios where appropriate. Where parameter values for some processes were not provided in the scenarios, SPADE default values were used. Pruning was considered for both blackcurrants and apple trees according to information supplied in the scenarios. Strawberry plants were replaced every two years and debris was removed from the field.

6.2.2. The FRUTI-CROM model (Annex I–2)

FRUTI-CROM is a fruit-specific model that was developed by CIEMAT (Spain) during participation in the Fruits WG. FRUTI-CROM started from an existing model CROM (vegetable sub-model) designed to evaluate radionuclide concentration in different compartments of the environment and to assess the radiological impact to man from routine and accidental releases.

The model considers the following processes: dry or wet deposition, interception by vegetation surfaces, translocation from external surfaces to edible part of plant, root uptake, adhesion of soil particles onto vegetation surfaces. To simplify the model, a number of these processes are taken into account by use of composite parameters that describe the effect of two or more interaction processes. Processes that can lead to the reduction of radionuclide concentrations in vegetation include radioactive decay, growth dilution, wash-off, pruning, harvesting, leaching and soil fixation.

6.2.3. The FRUITPATH model (Annex I–3)

The FRUITPATH model is a generic fruit-specific model for radionuclide accumulation in fruits that was developed by I Linkov and D. Burmistrov (USA) during participation in the Fruits WG FRUITPATH calculates a time series of inventories for a specific radionuclide distributed within the fruit system compartments. The number of compartments can be defined by the user for specific fruit types. For example, apple can be represented by the Tree, Organic Layer, Labile Soil, Fixed Soil and Deep Soil.

FRUITPATH focuses on a generic ecosystem application. It is a wholly probabilistic model that incorporates uncertain model parameters as probability distributions and predicts distribution for the output radionuclide concentrations in fruit compartments. For generic model application, uncertain model parameters are estimated from literature that includes different fruit and soil types. For site–specific applications, the available literature data are limited to the ecosystems similar to the site under consideration; site–specific parameters are thus estimated. Further model calibration, based on site–specific measurements, can be accomplished by using Bayesian updating procedures.

The radionuclide source term in FRUITPATH is total deposition to the ground (Bq m^{-2}). Partioning of radionuclides between plant and soil organic layer compartments is based on the plant interception fraction. Material removal from the plant is characterised by the time-dependent removal time. Transfer from soil to plant is described by the uptake rate that depends on plant biomass and plant type. The FRUITPATH framework is flexible to include scenario-specific conditions, for instance, for the BIOMASS calculations, modelling of pruning was added.

6.2.4. The RUVFRU model (Annex I–4)

The RUVFRU model is a fruit-specific model that was developed by the University of Veszprem (Hungary) during participation in the Fruits WG. The model includes most of the dynamic processes by means of a compartmental system, starting from acute deposition. These are described by first order differential equations. The endpoint of the model is the activity concentrations of the compartments that represent the air and the parts of the soil and the fruit bearing vegetation for each radionuclide and for each fruit. These can be used as input data to estimating doses in the case of countermeasure planning after a nuclear emergency.

The growth of vegetation (mass and interception) is described by sigmoidal curves. The rate constants between compartments generally depend on seasonality (temperature). Some of these are mass-dependent. The model can consider several agricultural activities such as ploughing, replanting and pruning.

Most of the parameter values originate from IAEA and Hungarian publications presenting results of post Chernobyl measurements carried out in Europe. Several values were derived from generic models (FARMLAND, SPADE).

6.2.5. The DOSDIM model (Annex I–5)

The DOSDIM model is an example of a non-fruit specific model that was used to calculate the transfer of radionuclides to fruit. Only calculations for strawberries were carried out. For plant specific parameters, those for leafy vegetables were used to estimate interception by the strawberry plant and those for root vegetables to calculate the translocation rate. The parameter for root uptake was derived from the TF values given in the Fruit Review (Section 2).

Only translocation from external plant surfaces to fruit was considered. For deposition during flowering time, it was assumed that the translocation parameters from external plant surfaces to blossoms are the same as for fruit and all radioactivity translocated to blossoms will eventually be found in the fruit (conservative approach). Pruning or processing was not considered.

6.2.6. The ASTRAL model (Annex I–6)

ASTRAL is an IPSN bespoke software designed for a single (acute) deposition and dedicated to assessing post-accident situations in the environment. Starting from deposition it calculates concentrations of radionuclides in food products, enables comparisons with regulatory levels and calculates radiation doses received by man through ingestion, inhalation of particles after resuspension, and external exposure to radionuclides deposited onto the soil.

ASTRAL, has no fruit specific sub-model, but there is a sub-model that is used for fruit vegetables: it is assumed that fruit are produced throughout the year (market garden scenario). The model and parameters for the fruit vegetable class have been chosen, as this class covers a wide variety of plants, from vegetables such as tomatoes and beans, to strawberries.

6.3. MODEL INTERCOMPARISON STUDIES

6.3.1. Background

This section describes the two model–model intercomparisons that were undertaken by the Fruits WG. The main objective was to compare model results and to serve as a baseline against which model–data validations can be viewed.

Two hypothetical scenarios were developed using realistic descriptions of fruit ecosystems. The first scenario was designed to simulate an acute release (Annex II–1. Model–model intercomparison study – acute source term) and the second to simulate a continuous release (Annex II–2. Model–model intercomparison study – continuous source term). Three radionuclides (^{137}Cs, ^{90}Sr and ^{129}I) and three fruit bearing crops (strawberries, blackcurrants, apples) were considered for each scenario. An attempt was made to account for differences in phenology, morphology and horticultural practice. The two scenarios used for model intercomparison are summarised in Table 28.

6.3.2. Results and discussion from the acute deposition scenario

6.3.2.1. Strawberries

The acute source term simulates the situation of an accidental radionuclide release that has been of regulatory concern over the last few decades. Recent attention to acute contamination developed after the Chernobyl accident. Strawberry is a very common and popular agricultural fruit for many European countries and thus is represented in many models. Five groups submitted results for the acute deposition scenario for strawberries.

Results of radionuclide concentrations in strawberry fruit, plant and soil are presented in Figures 8 to 11. All five models predicted a fast short term concentration decline with much slower decrease in concentrations in the long term. The difference in the absolute concentration values is greatest for the short term predictions (over four orders of magnitude) and range over two orders of magnitude in the long term predictions. The large difference for the short term predictions can be explained by the large model uncertainty for this time frame: all models took very different approaches to predict short term effects. The two order of magnitude difference in the long term predictions can be partially attributed to the model uncertainty, but more likely to the differences in model parameterisation: generally, models that predict high initial concentrations still overpredict long term concentration in comparison to other models.

TABLE 28. SUMMARY OF MODEL INTERCOMPARISON SCENARIOS

Atmospheric release	Acute			Continuous		
Contaminants	^{137}Cs and ^{90}Sr (both as sub-micron diameter particulates); ^{129}I – as methyliodide (vapour)					
Source	1 kBq m^{-2} total deposition to ground (soil plus plant)			1 kBq m^{-2} per year uniform deposition to ground (soil plus plant)		
Soil type	Temperate loam					
Fruits	Strawberry	Blackcurrant	Apple	Strawberry	Blackcurrant	Apple
Deposition times	1. During flowering time 2. 24 hr before harvest	1. During flowering time 2. 30 days before harvest 3. 24 hr before harvest	1. During flowering time 2. 7 weeks after flowering 3. 24 hr before harvest	1 April 1991		
Ploughing	20cm annually	No	No	20cm annually	No	No
Pruning	Replacement every 2 yrs	10%	10%	Replacement every 2 yrs	10%	10%
Spacing	0.75m×0.5m	1.5m×1.5m	3m×2m	0.75m×0.5m	1.5m×1.5m	3m×2m
Height	15cm	1 m	2m	15cm	1 m	2m
Fruit yield	1.30 kg m^{-2}	2.22 kg m^{-2} per season	3.33 kg m^{-2}	1.30 kg m^{-2}	2.22 kg m^{-2} per season	3.33 kg m^{-2}
Harvest date	July	July	October	July	July	October
Endpoints	At harvest date: 1.Concentration in edible fruit (Bq kg^{-1} fresh weight) 2. Total Bq m^{-2} in soil 3. Total Bq m^{-2} in the plant			At harvest date: 1.Concentration in edible fruit (Bq kg^{-1} fresh weight) 2. Total Bq m^{-2} in soil 3. Total Bq m^{-2} in the plant		

The influence of deposition date on concentration in fruits in the first two years is reflected in the results of the SPADE, FRUTI-CROM and RUVFRU models that explicitly incorporate the deposition date in the calculation. The radionuclide deposition just prior to harvest results in a relatively high accumulation in fruits in year 1 and even slightly higher accumulation in year 2 because of the redistribution of radionuclides in the soil during the first year and their enhanced root uptake in year 2. Deposition of radionuclides occurring after the harvest in July results in low contamination of the first year fruits and in higher contamination for the second year fruits.

The biannual plant replacement is considered by the SPADE, FRUTI-CROM and RUVFRU models and results in cycles in predicted fruit concentration: second year plants are more contaminated than freshly planted plants because of the radionuclide accumulation in the plant after the first year. The other models do not explicitly incorporate the biannual replacement of the plants. They adjust average annual concentration in fruit and plants according to the overall removal of radionuclides from the system.

Model predictions are quite consistent for soil. This is because soil is considered to be a major accumulating compartment in most of the models. Only SPADE predicts comparable radionuclide inventories in fruit and soil compartments. Removal from soil is controlled by well defined processes such as pruning and radionuclide decay. The more uncertain removal with crops is less pronounced and therefore the predictions for soil contamination by the different models are in good agreement.

6.3.2.2. Apples and blackcurrants

Four groups attempted to simulate apples and blackcurrant (Figures 8, 12 to 5). Because fewer studies have been undertaken for apples and blackcurrants, the uncertainty for model parameters is larger for these species than that for strawberries. Modellers therefore had to modify parameters known for other fruit and/or plant species or to use the information available from the few studies on these fruits.

In addition, transport processes within blackcurrant bushes and apple trees are of greater complexity than in strawberry plants. For instance, part of the initial inventory accumulated until the end of the vegetation period may be incorporated in woody structures to the extent that little is subsequently available for new growth. A portion of the available contaminant is removed by the next generation of leaves and fruits and is lost from the system. Information about the magnitude of this re-translocation is rare and difficult to interpret. Furthermore, part of the initially available activity continues to be fixed and becomes trapped into the internal matrix. The rate at which this process takes place is not well known, but is almost certainly governed by the physiology of the plant as well as by the specific biochemistry of the radionuclide.

The difference between the models is even larger for these fruit species as compared to strawberries (Figure 9). It is as high as five orders of magnitude for short term predictions to about three orders of magnitude for the long term prognosis. All the models were consistent in predicting long term changes for strawberries, while two groups can be envisaged in respect of long term changes for apples and blackcurrants: SPADE and RUVFRU predicted a relatively fast decrease in the long term, whereas FRUITPATH and FRUTI-CROM exhibited a much slower decline. The difference may be attributable to the much higher concentration of radionuclides in fruits predicted by SPADE and RUVFRU and thus their faster removal from the system following harvest.

The highest difference in predictions is for the short term time scales. Similar to the results for strawberries, SPADE, FRUTI-CROM and RUVFRU incorporate the deposition date. The increase in radionuclide concentration in apples for the second year predicted by FRUITPATH and SPADE can be attributed to radionuclide migration to the root zone and subsequent enhanced uptake. In contrast, FRUTI-CROM predicted a rapid decrease at year 2 because external contamination is considered insignificant compared to soil contamination after the second year. The contribution from the soil contamination to fruit is very low.

6.3.3. Results and discussion from the continuous deposition scenario

Fewer modellers submitted results for the continuous than for the acute deposition scenario: four groups submitted results for strawberries and three for apples and blackcurrants. The probable reason for this is that more experimental data and field observations are available for acute deposition of radionuclides.

Model predictions are presented in Figures 16 and 17. Even though the uncertainty in model parameters values is considerable, the models provided consistent predictions for radionuclide accumulation. In general, the difference between models is less than two orders of magnitude for all end points, much less than for the acute deposition scenario. There are two possible reasons for such consistency. First is the lack of data for model calibration, i.e. all modellers used the same set of experimental studies to test and calibrate their models. Second, which is more likely, is that continuous deposition models are greatly simplified as compared to acute deposition scenario models. All the short term processes that greatly affect the equilibrium radionuclide concentration in fruits and plants are excluded from consideration for the continuous deposition scenario. Equilibrium partition of radionuclides among compartments of fruit ecosystems is thus controlled by the partitioning parameter (or equation) set up in the model.

6.3.4. Conclusions on model intercomparison studies

The Fruits WG has provided a unique opportunity to test the performance of existing and newly developed models for predicting radioactivity in fruits. The results of the study show that even for this simple and well defined scenario the differences in model predictions may be quite large. In this exercise, the differences between models were as high as five orders of magnitude for short term predictions following the acute radionuclide deposition. For the long term consequences and for the continuous deposition scenario, the differences between models were about two orders of magnitude.

Predicted levels of radionuclide concentrations in three types of fruit selected for this study were found to be very similar. The difference between apple, strawberries and blackcurrant contamination predicted by one model is far less than the difference in prediction of contamination for a single plant species given by different models. The large difference between model predictions reveals the current uncertainty in predicting future radionuclide concentrations in fruits once contamination occurs. The parameter uncertainty associated with a selected model is likely to be much lower than model uncertainty.

In conclusion, the results of model–model intercomparisons clearly indicate the need for further development of existing models for the fate and transport of radionuclides in fruit ecosystems. This will not only result in reducing model uncertainty but will also provide a knowledge base with which other pollutants, such as heavy metals and organic chemicals, as well as nutrients could be modelled.

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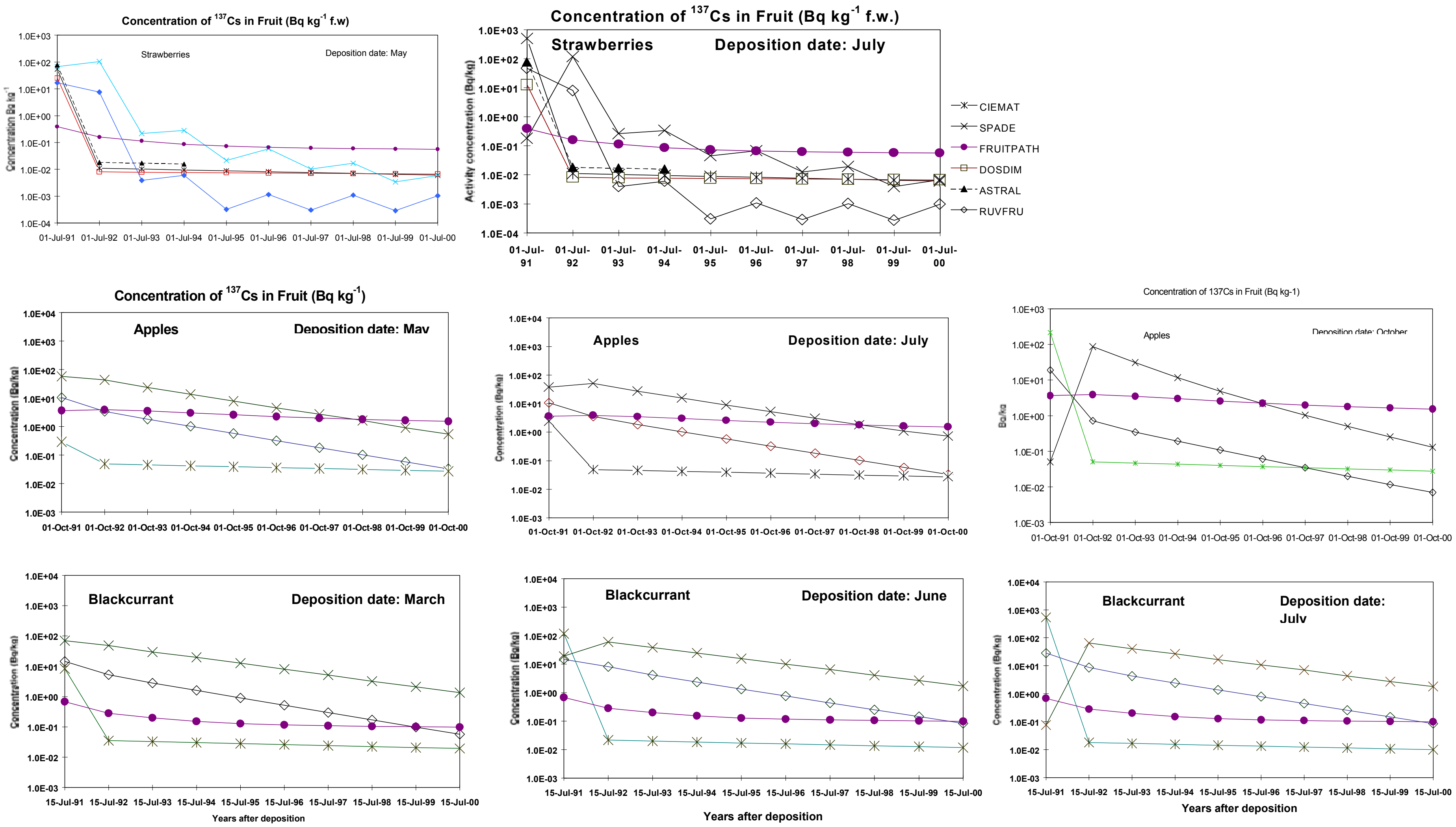

FIG. 8. Predicted concentration of ^{137}Cs in fruit for an acute source term.

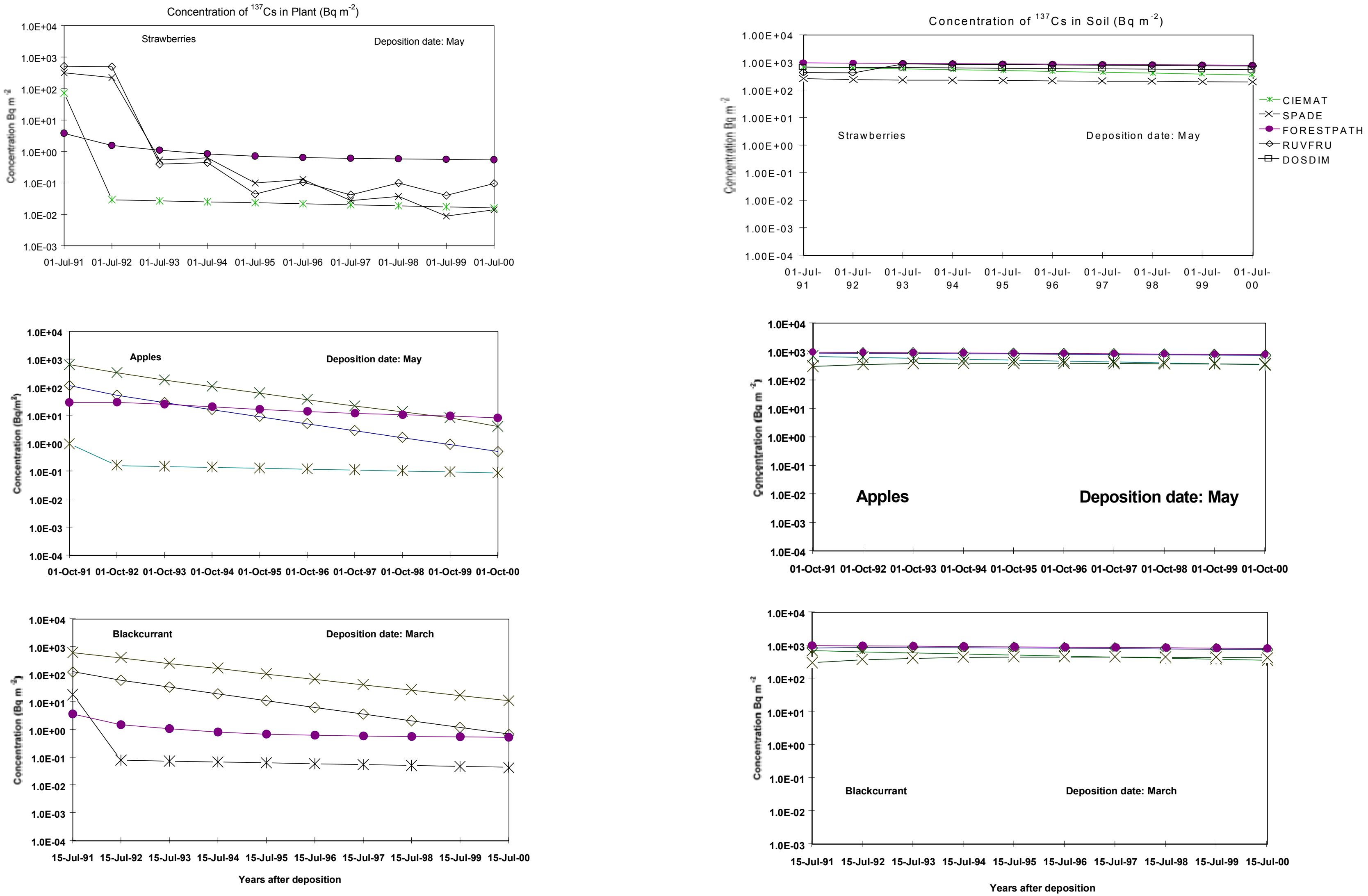

FIG. 9. Predicted ^{137}Cs in plant and soil for an acute source term.

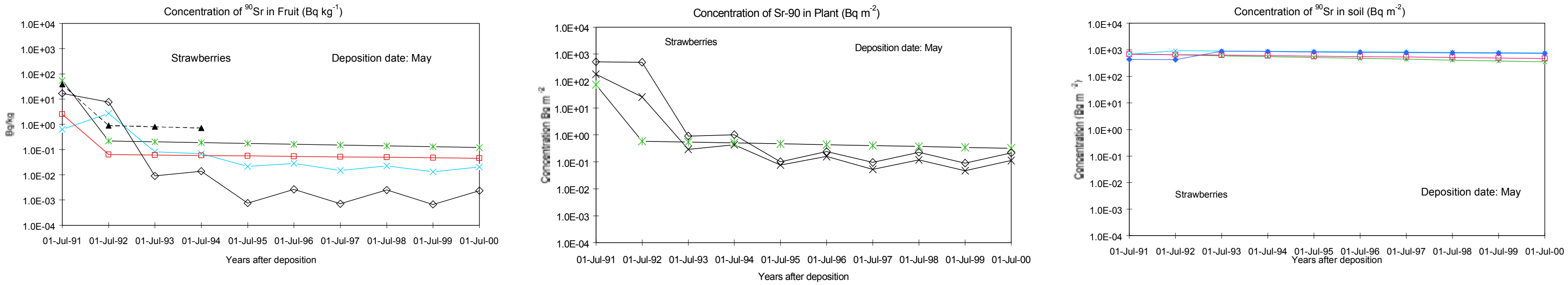

FIG. 10. *Predicted ^{90}Sr in strawberry fruit, plant and soil for an acute source term.*

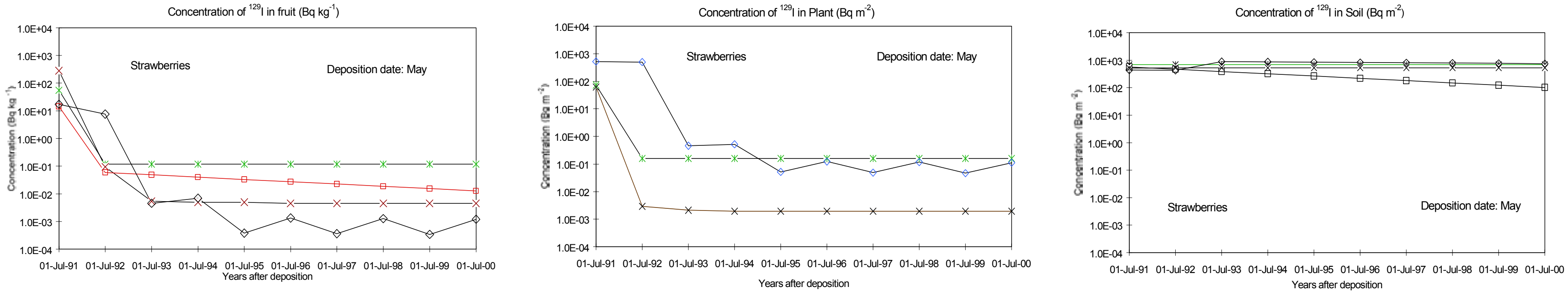

FIG. 11. *Predicted ^{129}I in strawberry fruit, plant and soil for an acute source term.*

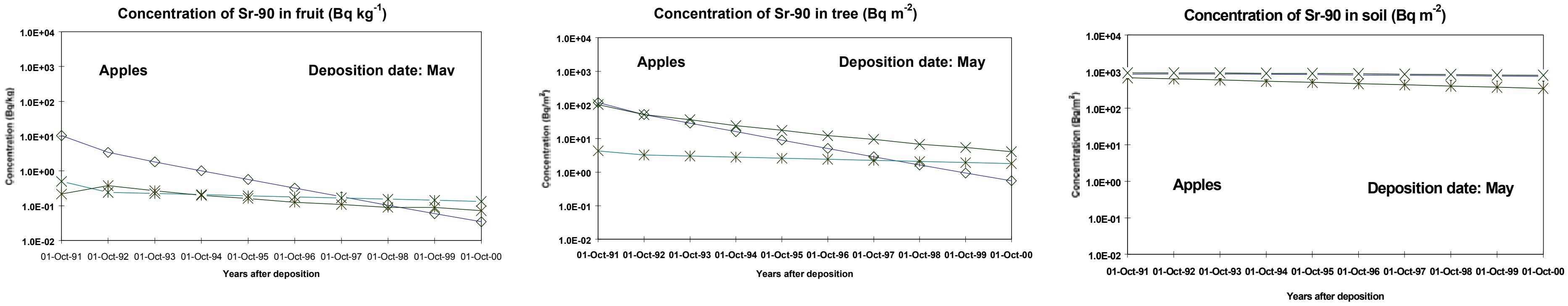

FIG. 12. Predicted ^{90}Sr in apple fruit, tree and soil for an acute source term.

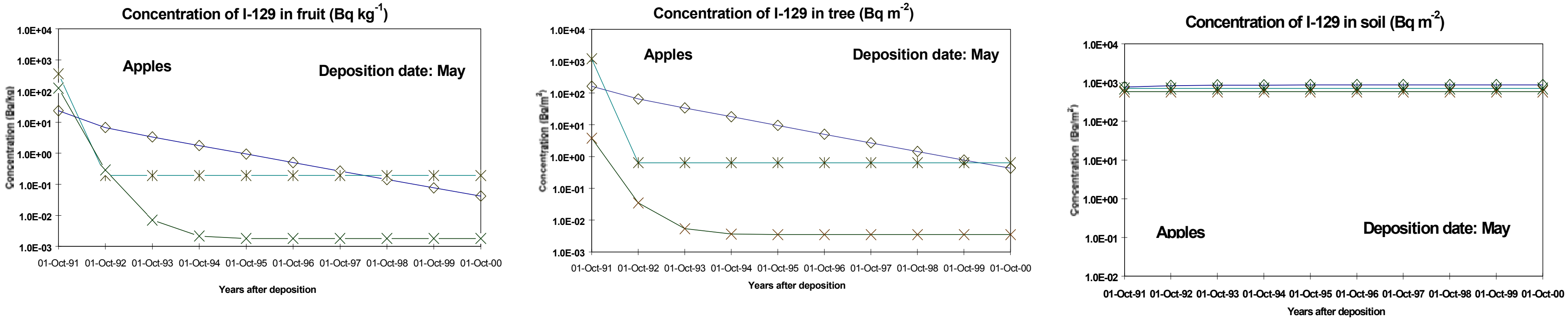

FIG. 13. Predicted ^{129}I in apple fruit, tree and soil for an acute source term.

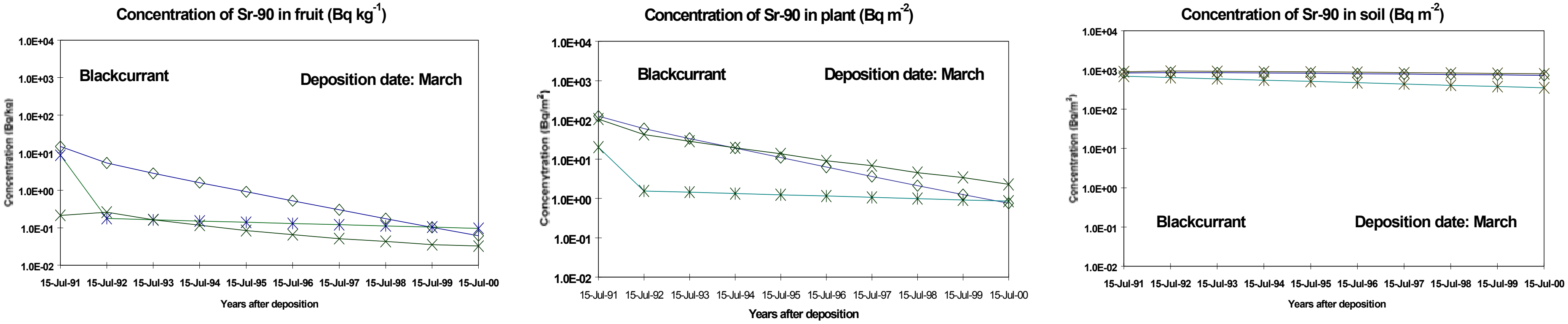

FIG. 14. Predicted ^{90}Sr in blackcurrant fruit, plant and soil for an acute source term.

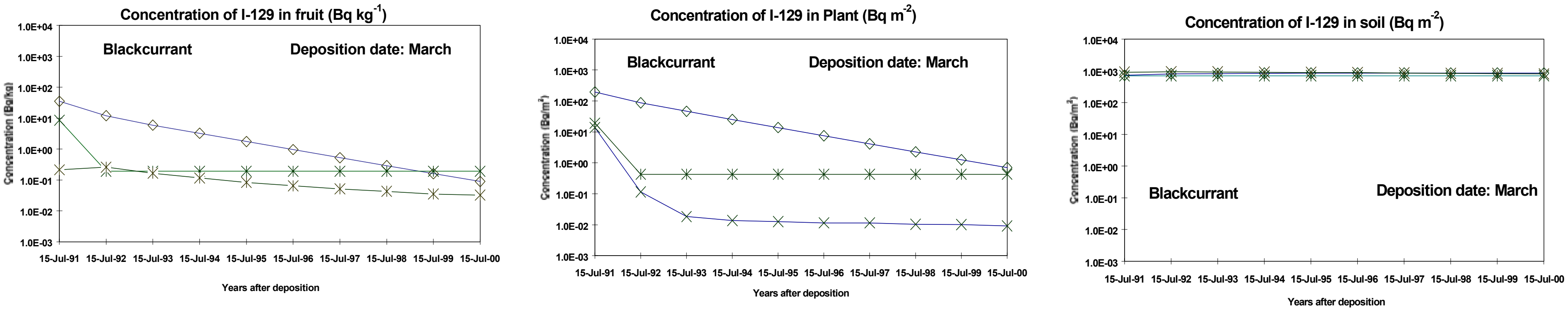

FIG 15. Predicted ^{129}I in blackcurrant fruit, plant and soil for an acute source term.

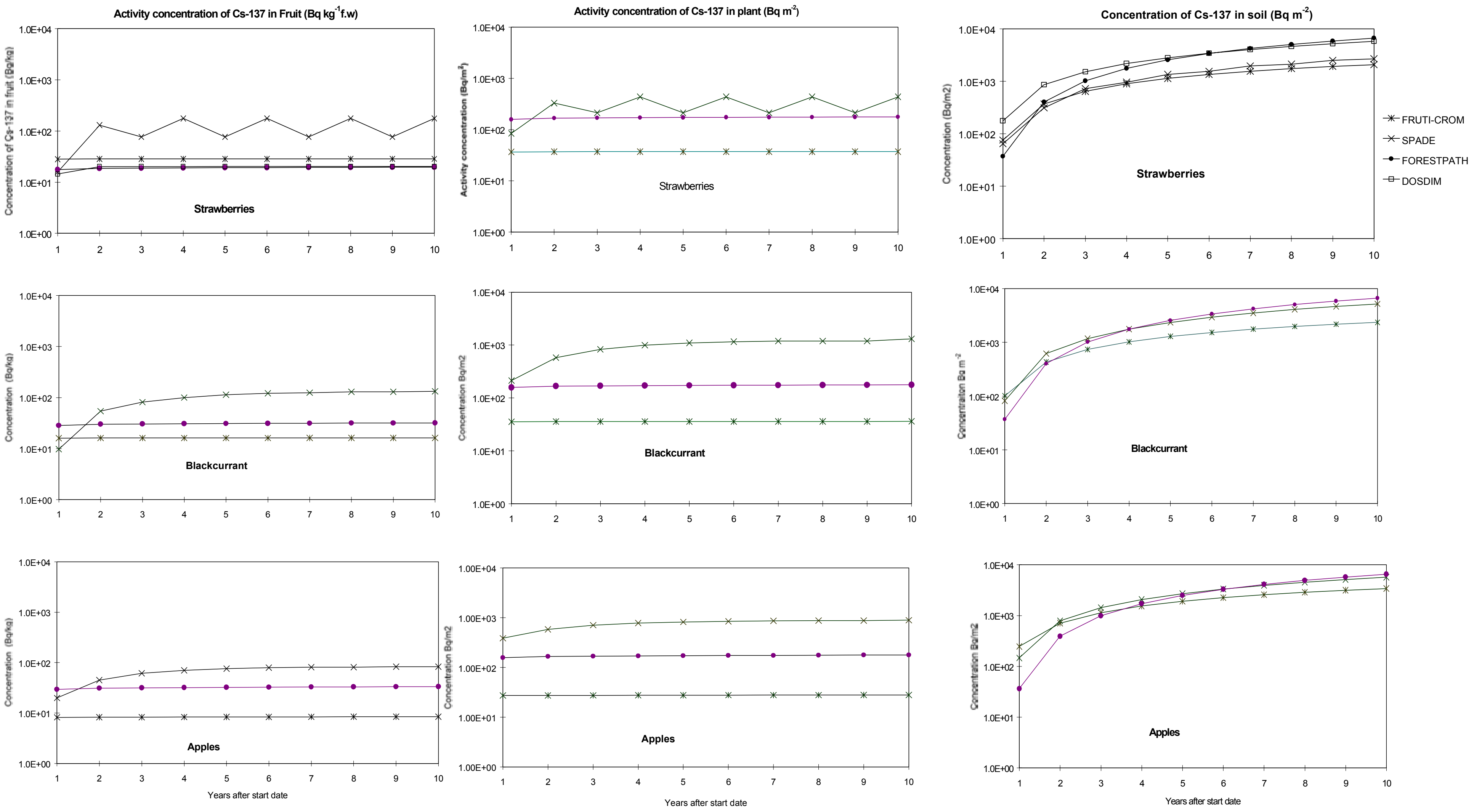

FIG. 16. Predicted ^{137}Cs in fruit, plant and soil for a continuous source term.

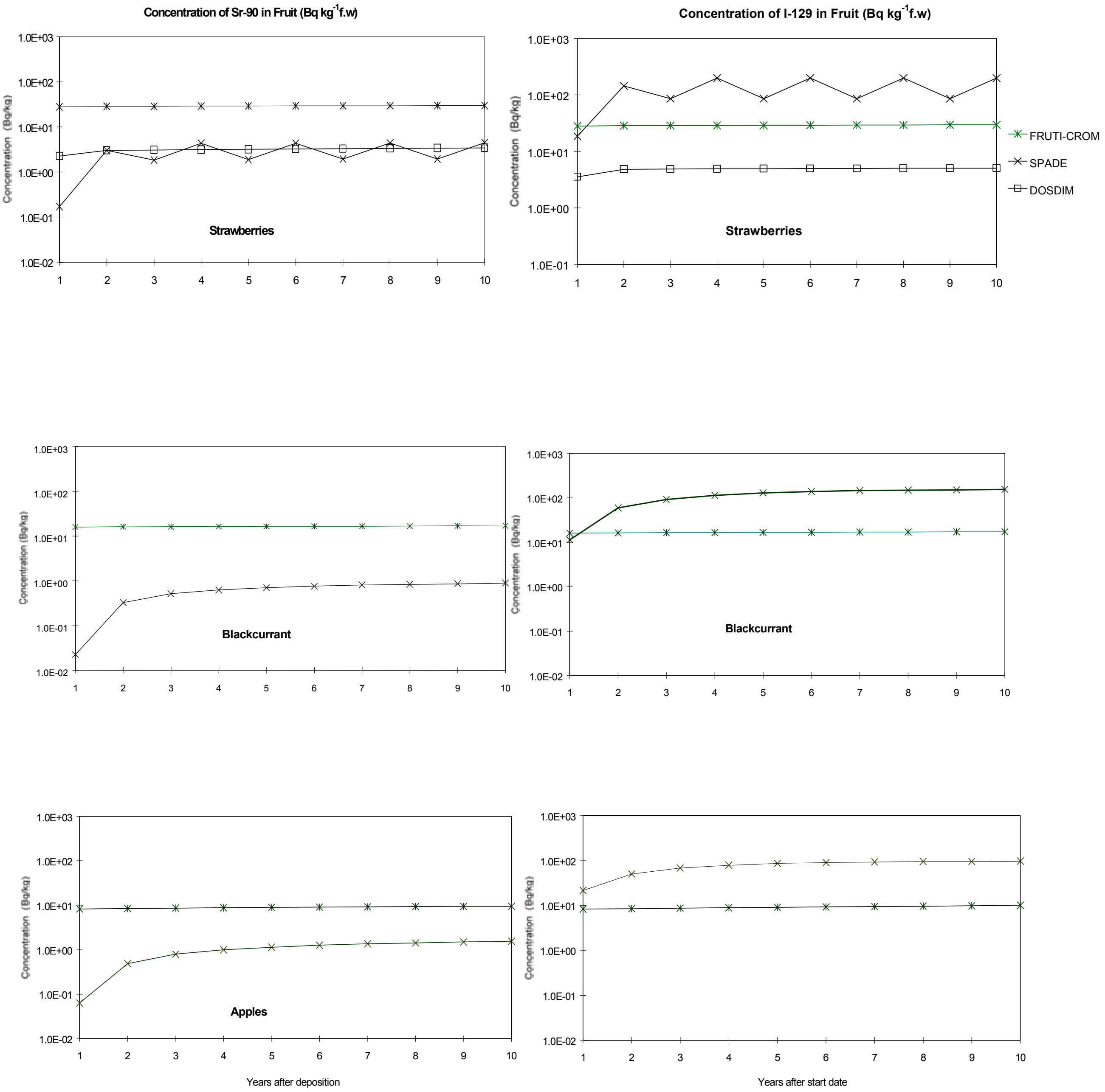

FIG. 17. Predicted ^{90}Sr and ^{129}I in fruit for a continuous source term.

6.4. MODEL VALIDATION STUDIES

6.4.1. Background

This section describes the model–data intercomparison studies that were undertaken by the Fruits WG. The objective of the validation exercise was to test model predictions against an independent data set.

Various experimental datasets are available, but it is difficult to find a complete series of data describing the fluxes of radionuclides, from deposition to distribution with time within the compartments of fruit ecosystems, with supporting yield data. Three datasets on apples, blackcurrants and strawberries were provided by participants. After discussion of possible scenarios, the dataset on strawberry contamination with ^{134}Cs and ^{85}Sr was chosen and finalised for the validation exercise.

The six models that participated in this exercise are listed in Table 26.

6.4.2. Scenario overview

The scenario description for the validation exercise is presented in full in Annex II–3. Model–data intercomparison study. It is based on experimental work carried out at Università Cattolica del Sacro Cuore of Piacenza (Italy), that investigated the transfer of ^{134}Cs and ^{85}Sr via leaf–to–fruit and soil–to–fruit at short term in strawberry plants after an acute release. A synopsis of the scenario is presented below.

Strawberry plants were grown in pots filled with a peat substrate under a ventilated tunnel in a field, reproducing horticultural growing conditions in Italy. They were contaminated by application of ^{134}Cs and ^{85}Sr in the form of chlorides in aqueous solution, either to the above ground part of the plant (foliar contamination) or to soil (soil contamination). Foliar contamination was effected at two phenological stages, anthesis and ripening, while soil contamination was effected only at the anthesis stage (Table 29).

TABLE 29. EXPERIMENTAL DESIGN DATA FOR MODEL VALIDATION STUDY

Contaminated compartment		Above ground plant part	Above ground plant part		Soil	
Code		1st foliar	2nd foliar		soil	
Phenological stage at time of contamination		anthesis	ripening		anthesis	
Date of deposition		22th April 1998	18th May 1998		27th April 1998	
Radionuclide		^{134}Cs	^{134}Cs	^{85}Sr	^{134}Cs	^{85}Sr
Sprayed activity	kBq m^{-2}	805.1	890.8	776.6	–	–
	kBq $plant^{-1}$	155.1	171.6	149.6	–	–
Intercepted activity	Leaves	36.7 ± 0.9	29.2 ± 1.7	30.3 ± 1.5	–	–
	Fruits	0.23 ± 0.07	1.16 ± 0.22	1.20 ± 0.24		
(% of the sprayed)	Whole above–ground part	36.9 ± 1.0	30.3 ± 1.8	31.5 ± 1.6		
Deposited activity	kBq m^{-2}	–	–	–	765.5	1698.2
	kBq $plant^{-1}$	–	–	–	147.5	327.2

6.4.2.1. First foliar contamination scenario

The first foliar contamination was effected on 22 April 1998. Plants were at anthesis and had well developed leaves, flowers and a few green fruitlets. They were sprayed with an aqueous solution containing ^{134}CsCl to simulate a wet deposition; ^{85}Sr was not included in the first scenario. The soil surface of each pot was protected from deposition during spraying. The radioactivity sprayed, was calculated as kBq $\cdot$m^{-2}, using a plant density of 5.19 plants m^{-2}, and is reported in Table 29, along with the corresponding values expressed as kBq.plant^{-1}.

In order to determine the activity intercepted by plant components, the above ground part of 4 plants was harvested as soon as they were dry after spraying, and separated into leaves and green fruits, albeit small. The activity intercepted by leaves and fruits, expressed as percentage of that sprayed, is reported in Table 29.

6.4.2.2. Second foliar contamination scenario

The second foliar contamination was effected on 18 May 1998. Plants were at the ripening stage, bearing green and red fruits and very few flowers. The contamination was effected with an aqueous solution containing both ^{134}CsCl and ^{85}SrCl$_2$, following the same methodology reported for the first foliar contamination (6.4.2.1). The radioactivity sprayed and that intercepted by leaves and fruits are reported in Table 29.

6.4.2.3. Soil contamination scenario

Soil contamination was effected on 27 April 1998. Plants were at the anthesis stage, had well developed leaves, flowers and a few small green fruits. The soil of each pot was moistened over the entire surface with 150 mL of an aqueous solution containing both ^{134}CsCl and ^{85}SrCl$_2$. After treatment the soil surface was covered with a layer of expanded clay to separate the leaves from the soil and prevent their direct contamination. The deposited activity, expressed as kBq $\cdot$m^{-2} and as kBq $\cdot$plant^{-1} is reported in Table 29.

6.4.2.4. Endpoints

Ripening of strawberries is a scalar process. Fruit were picked plant by plant when ripe, and grouped into two nominal harvests: 1st harvest (20 May 1998) and 2nd harvest (2 June 1998). The whole plant was harvested at the end of the fruit season. For technical reasons the whole plant was sampled approximately one month after the last fruit harvest. After separation of fruits, the plant was divided into leaves, crowns and roots.

TABLE 30. YIELD FACTORS

Code Endpoint	Date of harvest	Unit	1st foliar yield	 dry matter (%)	2nd foliar yield	 dry matter (%)	soil yield	 dry matter (%)
Fruit, 1st harvest	20 May 1998	kg ww $\cdot$ m^{-2}	1.169	6.2	1.109	6.4	1.088	6.7
Fruit, 2nd harvest	2 June 1998	kg ww $\cdot$ m^{-2}	1.621	7.2	1.595	8.1	0.888	8.0
Leaf	1–14 July 1998	kg dw $\cdot$ m^{-2}	0.214	36.2	0.221	36.9	0.195	39.5
Crown	1–14 July 1998	kg dw $\cdot$ m^{-2}	0.058	25.4	0.048	21.1	0.052	25.2
Root	1–14 July 1998	kg dw $\cdot$ m^{-2}	0.036	18.7	0.042	16.1	0.033	18.9

Yield values were calculated using a plant density of 5.19 plants·m^{-2} and expressed as kg ww·m^{-2} for fruits and kg dw·m^{-2} for the other plant components. Average yields and standard errors representing 9 replicates for foliar contamination and 12 replicates for soil contamination are listed in Table 30 together with the corresponding dry matter content.

Generally speaking the radionuclide concentration in edible products or in other plant components is expressed on a dry weight basis, to allow comparisons between values derived from different experimental or climatic conditions and/or from products with different water content. At the inception of the Fruits WG activities it was agreed to express the radionuclide concentration in fruit on a wet weight basis, given that fruit consumption is as fresh product. The parameters useful to assess the radioactive concentration in fruits, such as transfer or translocation factors have therefore been reported in the review (summarised in Section 2 of this report) on a wet weight basis. They can be converted into dry weight by the dry matter content.

Discussing the endpoints of modelling exercises, participants agreed to express experimental and calculated results on a wet weight basis for fruit and on a dry weight basis for leaves. Radionuclide concentrations in fruit, expressed as Bq·g^{-1} wet weight, were to be predicted at the two times of harvest: 20 May and 2 June 1998. Radionuclide concentrations in leaves, expressed as Bq·g^{-1} dry weight, were to be given at 1 July 1998 for the 1st foliar and the soil contamination scenarios and at 14 July 1998 for the 2nd foliar contamination scenario.

6.4.3. Results and discussion

6.4.3.1. First foliar contamination scenario

There is some evidence that fruit activity for ^{134}Cs at harvest after deposition at anthesis, when fruit is absent or very small, is mainly ascribable to the process of leaf to fruit translocation (Section 2). Experimental results also support the hypothesis that the process of leaf to fruit translocation finds its highest expression from anthesis to beginning of ripening, results supported by horticultural and plant physiology studies.

In the derivation of a conceptual model (Section 3) leaf has been identified by the Fruits WG as a dominant component along with air, and the pathway leaf–to–fruit has been recognized to have one of the strongest interactions on the system as a whole. Notwithstanding this, the Group recognised that the knowledge of the pathway leaf–fruit is still poor, and that the main process not represented by several of the models participating in modelling studies (Tables 26 and 27) is the translocation of radionuclides within crop plants (Section 3.6).

Predicted and measured ^{134}Cs activity concentrations in fruit and leaves after the 1st foliar contamination are presented in Table 31 and Figure 18.

6.4.3.1.1. ^{134}Cs fruit activity

The activity intercepted by the green fruitlets at time of deposition was 1.8 kBq m^{-2} (0.23% of the sprayed activity), while that measured in fruit corresponded to 31.5 and 40.5 kBq m^{-2} in the first and second harvest respectively. The total, approximately 70 kBq per m^{-2}, was 40 times higher than the activity directly intercepted by fruitlets. Measured values therefore supported the hypothesis that the fruit activity after deposition at anthesis is mainly due to the process of leaf to fruit translocation.

TABLE 31. FIRST FOLIAR CONTAMINATION: MEASURED AND PREDICTED ACTIVITY CONCENTRATION OF ^{134}Cs

	Plant component	Fruit 1st harvest 20/5/98 (Bq g^{-1} ww)	Fruit 2nd harvest 2/6/98 (Bq g^{-1} ww)	Leaf 1/7/98 (Bq g^{-1} dw)
Radionuclide		^{134}Cs		
Measured		(2.7±0.2)E+01	(2.5±0.2)E+01	(5.1±0.3)E+02
Predicted	SPADE	1.5E+01	5.6E+00	9.3E+01
	FRUTI-CROM	1.6E+00	1.1E+00	4.8E+02
	FRUITPATH	1.6E+02	7.7E+01	2.0E+02
	RUVFRU	9.7E+00	1.5E+01	6.7E+02
	DOSDIM	2.2E+01	1.9E+01	5.0E+01
	ASTRAL	9.1E+00	6.1E+00	–

Predicted values for fruit activity, both for the first and the second harvest, covered two orders of magnitude: from 1.1E+00 to 1.6E+02 Bq ·g^{-1} ww. Comparison of predicted with observed values, (2.5–2.7±0.2)E+01 Bq ·g^{-1} ww, revealed, however, differences of only one order of magnitude between calculated and observed results. In particular, predicted values were within factors of 0.6–0.2 of the observed value for SPADE, of 0.4–0.6 for RUVFRU, of 0.8 for DOSDIM, and of 0.3–0.2 for ASTRAL. The lowest underprediction was for FRUTI-CROM, between factors of 0.04 and 0.06 of the observed values, and the highest was for FRUITPATH, between 3.1 and 5.6 of the observed values. Results indicated that, apart from FRUITPATH, modelling values tended to underestimate the ^{134}Cs concentration in fruit after an acute release.

Most of the models, with the exception of RUVFRU, predicted a decrease of ^{134}Cs concentration in fruit from the first to the second harvest, from a maximum of 2.7 times for SPADE to a minimum of 1.2 for DOSDIM. Experimental values showed a very small decrease of a factor of 1.1 from the first, (2.7±0.2)E+01 Bq·g^{-1} ww, to the second harvest, (2.5±0.2)E+01 Bq·g^{-1} ww, well within the range of the standard error.

6.4.3.1.2. ^{134}Cs leaf activity

Leaf activity for ^{134}Cs at harvest results from the contribution of the various processes (Sections 2 and 3) of interception, loss, absorption, resuspension and translocation to other plant components. Measured values showed an activity concentration lower than that intercepted during deposition. It corresponded to 109.1 kBq m^{-2}, 37% of that intercepted. The remaining 63% was lost through internal translocation towards fruits, crowns and roots and through external loss for processes of weathering and growth. As discussed in Section 6.2, processes of interception, loss and translocation are handled very differently by the participating models.

Results from the modelling exercises reveals, however, that models performed better for leaf than for fruit, predicting values that showed a lower variation than those for fruit. Predicted values for leaf activity covered one order of magnitude, from 5.0E+01 to 6.7E+02 Bq·g^{-1} dw. The measured ^{134}Cs concentration in leaf, (5.1±0.3)E+02 Bq ·g^{-1} dw, was close to the highest calculated values.

The FRUTI-CROM model prediction, 4.8E+02 Bq ·g^{-1} dw, was in perfect agreement with the measured value. The model takes into account interception fraction by the leaf component, loss due to growth and pruning, and translocation from external to internal plant part. RUVFRU calculated a value of 6.7E+02 Bq·g^{-1} dw, overpredicting by a factor of 1.3. It takes into account interception by leaves, models loss as weathering from leaves but does not consider internal translocation. No results were provided by ASTRAL for the leaf compartment because the model calculates translocation only to the edible organ, as an aggregated transfer factor.

The other models underestimated the leaf concentration. SPADE, 9.3E+01 Bq·g^{-1} ww, underestimated by a factor of 0.2 and FRUITPATH, 2.0E+02 Bq·g^{-1} ww, by a factor of 0.4. Both model loss of activity from the whole system, internal for SPADE followed by translocation, and external for FRUITPATH. DOSDIM predicted the lowest value, 5.0E+01 Bq·g^{-1} ww, underestimating by a factor of 0.1. DOSDIM codes do not consider interception fraction by leaves and only account for translocation to fruit.

6.4.3.2. Second foliar contamination scenario

This scenario considers foliar deposition at ripening. Fruit harvests occur 2 and 15 days after deposition. The concentration of radionuclides in fruit can result from the contribution of processes of direct deposition on fruit and of leaf to fruit translocation, whose importance depends, as discussed in Section 2, on the radionuclide of interest.

Experimental results on fruit interception for ^{134}Cs gave values of 10.3 kBq m^{-2}. The first harvest showed a fruit concentration of 2.8 kBq m^{-2} and the second harvest of 19.1 kBq m^{-2}. The process of loss affecting fruit activity in the first two days was then overwhelmed by that of leaf to fruit translocation, so that fruit activity increased by a factor 2. During 57 days leaf activity decreased by a factor of 1.7, from 260.1 to 152.5 kBq m^{-2}.

Measured fruit interception for ^{85}Sr showed a value of 9.3 kBq m^{-2}, similar to that for ^{134}Cs. Fruit activity was 1.9 kBq m^{-2} and 3.5 kBq m^{-2} at the first and the second harvest respectively. The loss process affected ^{85}Sr fruit concentration in the first days, but leaf to fruit translocation played a lower role than for ^{134}Cs, confirming the results discussed in the review (Section 2). Leaf activity decreased by a factor of 2.4, from 235.3 to 97.2 kBq m^{-2}, higher than that of ^{134}Cs.

Table 32 and Figure 18 summarise the measured and predicted ^{134}Cs and ^{85}Sr activity concentrations in fruit and leaves for the second foliar contamination scenario.

6.4.3.2.1. ^{134}Cs fruit activity

Predicted values for ^{134}Cs concentration in fruit at the first harvest, 2 days after deposition, covered a range of more than two orders of magnitude, from 2.5E-01 to 9.5E+01 Bq·g^{-1} ww. A comparison of predicted with measured values, (2.5±0.9)E+00 Bq·g^{-1} ww, revealed that, with the exception of SPADE that underpredicted the fruit content of ^{134}Cs by one order of magnitude, in general models overestimated the fruit ^{134}Cs concentration at the first harvest. FRUTI-CROM overpredicted by a factor 3.6, and DOSDIM by 4.4. ASTRAL and RUVFRU overpredicted by a factor of 9.2 and 16.8 respectively, and FRUITPATH by a factor of 38. However, the standard error associated with the average measured value was quite high, so that most of the results fell within the standard error range.

Most of the models predicted a decrease of ^{134}Cs activity in fruit from the first to the second harvest, except SPADE, that predicted an increase of one order of magnitude, and DOSDIM an increase of a factor 1.2.

TABLE 32. SECOND FOLIAR CONTAMINATION: MEASURED AND PREDICTED ACTIVITY CONCENTRATION OF ^{134}Cs AND ^{85}Sr

	Plant component	Fruit 1st harvest 20/5/98 (Bq g^{-1} ww)		Fruit 2nd harvest 2/6/98 (Bq g^{-1} ww)		Leaf 14/7/98 (Bq g^{-1} dw)	
	Radionuclide	^{134}Cs	^{85}Sr	^{134}Cs	^{85}Sr	^{134}Cs	^{85}Sr
	Measured	(2.5±0.9)E+00	(1.7±0.6)E+00	(1.2±0.1)E+1	(2.2±0.3)E+0	(6.9±0.5)E+2	(4.4±0.3)E+02
Predicted	SPADE	2.5E–01	2.3E–01	4.5E+00	4.1E+00	1.0E+02	9.6E+01
	FRUTI-CROM	9.1E+00	6.4E+00	6.3E+00	3.9E+00	3.9E+02	1.6E+02
	FRUITPATH	9.5E+01	–	5.3E+01	–	2.6E+02	–
	RUVFRU	4.2E+01	3.7E+01	3.1E+01	2.4E+01	7.5E+02	3.9E+02
	DOSDIM	1.1E+01	9.5E+00	1.3E+01	4.6E+00	8.7E+01	8.5E+01
	ASTRAL	2.3E+01	9.3E+00	1.5E+01	5.5E+00	–	–

The rather low prediction of SPADE at the first harvest was probably reflected also in the second harvest, where it was 4.5E+00 Bq·g^{-1} ww, albeit one order of magnitude higher than the first harvest, still underpredicted the measured values by a factor 2.7.

The smaller range of estimated values showed a better agreement between predicted and measured ^{134}Cs concentration in fruit in the second harvest than in the first. The data ranged over one order of magnitude, from 4.5E+00 to 5.3E+01 Bq·g^{-1} ww. The measured value, (1.2±0.1)E+01 Bq·g^{-1} ww, fell in the higher part of the range, but was very close to the predictions of various models, such as DOSDIM (1.3E+01) and ASTRAL (1.5E+01). The RUVFRU prediction (3.1E+01) was higher by a factor of 2.6, and FRUITPATH (5.3E+01) by 4.4. FRUTI-CROM, as well as SPADE, underpredicted by a factor 0.5.

The results indicate that, in contrast with the first foliar contamination scenario, most of the models tended to overpredict the ^{134}Cs activity concentration in fruit in the second foliar contamination scenario.

6.4.3.2.2. ^{134}Cs leaf activity

A comparison of predicted values in leaf with the observed values, (6.9±0.5)E+02 Bq g^{-1} dw, revealed a spread of results similar to that observed after the first foliar contamination. Predicted values ranged from 8.7E+01 to 7.5E+02 Bq g^{-1} d.w.

As in the first scenario, all models, except RUVFRU, underpredicted the leaf activity concentration. The results suggest an overestimation of the loss from leaves by the majority of modellers. However, the scenario simulates a growing system where strawberries are kept under open tunnels, in order to protect fruit production against large temperature ranges during Spring nights. After the Chernobyl NPP accident even strawberries grown under such controlled conditions in Italy became contaminated by the radioactive cloud. After cloud deposition, loss from the leaves is presumably lower in plants growing under a tunnel than under field conditions. It is quite likely that this is the reason for the general underprediction of leaf concentration at harvest.

6.4.3.2.3. ^{85}Sr fruit activity

Contamination with ^{85}Sr was only effected in the second foliar scenario. Table 32 and Figure 18 show the predicted and measured ^{85}Sr activity concentrations in fruit and leaves.

Predicted activity concentrations of ^{85}Sr in fruit in the first harvest ranged from the lowest value of 2.3E–01 (SPADE) to the highest of 3.7E+01 Bq g^{-1} dw (RUVFRU). The measured activity, (1.7±0.6)E+00 Bq g^{-1} dw, was approximately the mean of the two limit values of the range. FRUITPATH does not model Sr.

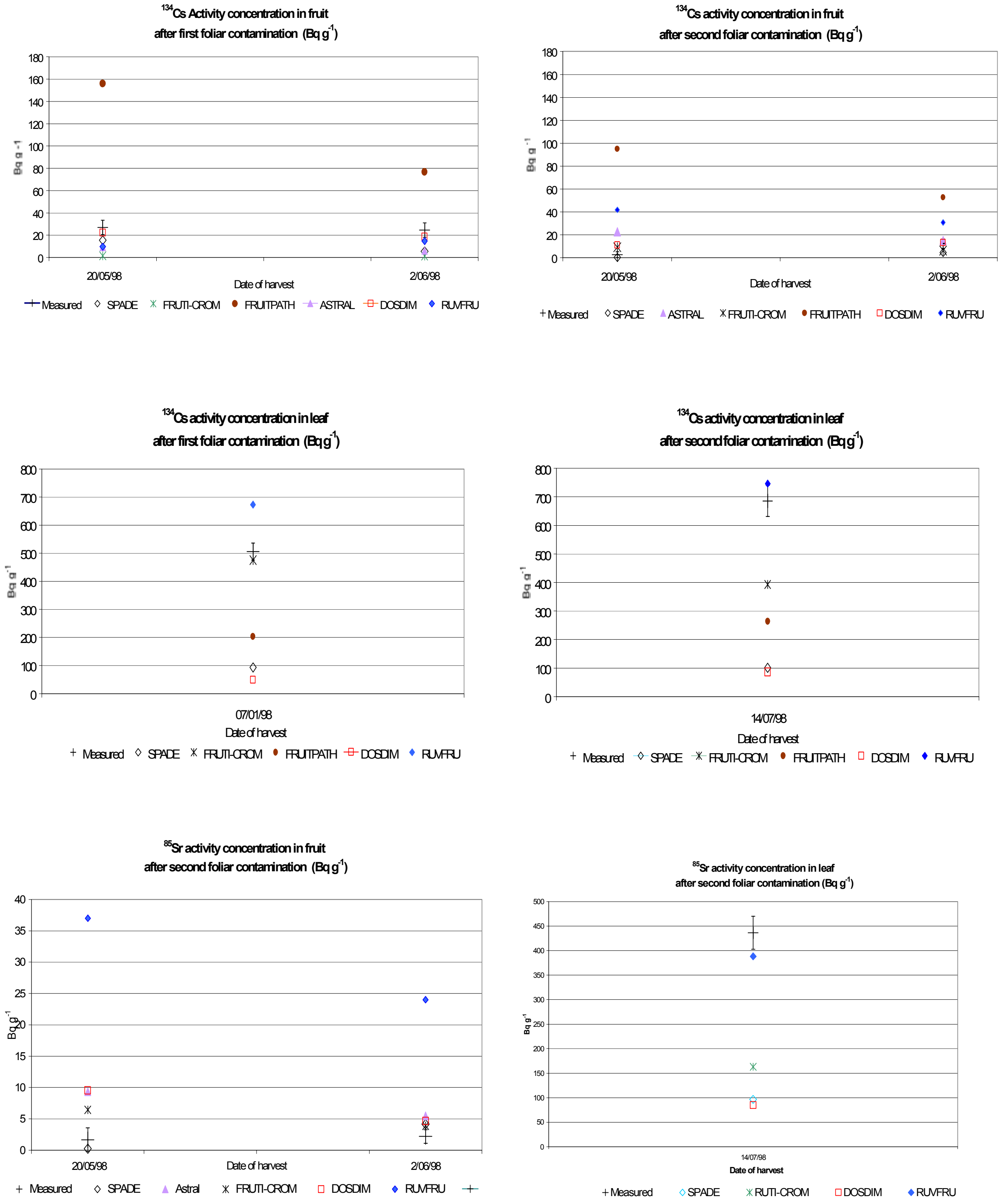

FIG. 18. Measured and simulated concentrations of ^{134}Cs and ^{85}Sr in strawberry fruit (fresh weight) and leaf (dry weight) after foliar contamination.

All the models predicted a reduction of ^{85}Sr fruit concentration from the first to the second harvest, except for SPADE that, similarly to ^{134}Cs predictions, predicted an increase of one order of magnitude. The measured value increased from the first harvest, (1.7±0.6)E+00 Bq g^{-1} ww, to the second, (2.2±0.3)E+00 Bq g^{-1} ww, although the variation in concentration was within the error range. The predicted results for the second harvest compared better with the measured value than the predicted results for the first harvest.

Although the spread of predicted ^{85}Sr results in fruit was less than that of predicted ^{134}Cs values, the trend for ^{85}Sr is very similar to ^{134}Cs. All the models predicted lower concentrations in fruit for ^{85}Sr than for ^{134}Cs, as well as predicting lower concentrations in the second than in the first harvest, except for SPADE, whose processes have been discussed above.

6.4.3.2.4. ^{85}Sr leaf activity

All the models underpredicted ^{85}Sr activity in leaf. The predicted values ranged from 8.5E+01 to 3.9E+02 Bq g^{-1} dw as opposed to the measured value of (4.4±0.3)E+02 Bq g^{-1} dw. The trend was the same as has been discussed for ^{134}Cs, although the spread of predicted values for ^{85}Sr was smaller than that for ^{134}Cs. As discussed above, modeller choices, scenario interpretation and priorities given to processes are as important as model differences.

6.4.3.3. Soil contamination scenario

The soil scenario describes the pot soil surface contamination at anthesis. Model predictions in fruits and leaves together with experimental values for ^{134}Cs and ^{85}Sr are shown in Table 33 and Figure 19.

6.4.3.3.1. ^{134}Cs fruit activity

Predicted values for ^{134}Cs in fruit ranged over two orders of magnitude, from 1.3E–02 to 1.2E+00 Bq g^{-1} ww, for the two harvests. They were from one (FRUITPATH values) up to three (RUVFRU, ASTRAL values) orders of magnitude lower than observed values: (1.4±0.3)E+01 and (2.0±0.6)E+01 Bq g^{-1} ww for the first and the second harvest respectively.

Plant uptake of radionuclides from soil has been envisaged by the Fruits WG as an area of large uncertainty in modelling the transfer of radioactivity to fruits (Section 6.2). Results from this validation exercise confirm this aspect. Various models use equilibrium transfer factors and the scenario described does not suppose steady state of radionuclides in soil, but considers fruit contamination at a very short term. Moreover, the model parameters aggregate several factors and thus are very uncertain.

The peat growing substrate ranks among those organic soils that show a considerably enhanced availability for caesium uptake. The discussion of scenarios for validation has probably analysed in greater detail the aerial pathway, whose processes had been discussed in the context of conceptual modelling. The soil pathway has probably not been supplied with a sufficient description of the substrate and, as already discussed in the section on foliar results, the scenario interpretation may cause mispredictions and remarkable differences between model estimates.

TABLE 33. SOIL CONTAMINATION: MEASURED AND PREDICTED ACTIVITY CONCENTRATION OF ^{134}Cs AND ^{85}Sr

Plant component		Fruit 1st harvest 20/5/98 (Bq g^{-1} ww)		Fruit 2nd harvest 2/6/98 (Bq g^{-1} ww)		Leaf 1/7/98 (Bq g^{-1} dw)	
Radionuclide		^{134}Cs	^{85}Sr	^{134}Cs	^{85}Sr	^{134}Cs	^{85}Sr
Measured		(1.4±0.3)E+01	(1.1±0.5)E+0	(2.0±0.6)E+1	(2.4±1.7E)+0	(1.9±0.3)E+2	(1.2±0.1)E+2
Predicted	SPADE	1.9E–01	4.1E–01	3.9E–01	8.8E–01	5.5E+00	3.8E+00
	FRUTI-CROM	5.7E–01	2.6E+00	5.6E–01	2.3E+00	2.8E+00	8.4E+00
	FRUITPATH	1.2E+00	–	1.0E+00	–	5.0E+00	–
	RUVFRU	1.3E–02	3.8E–02	2.9E–02	8.8E–02	1.8E+00	5.1E+00
	DOSDIM	8.0E–02	1.8E+00	8.0E–02	1.8E+00	–	–
	ASTRAL	1.5E–02	1.3E+00	1.5E–02	1.1E+00	–	–

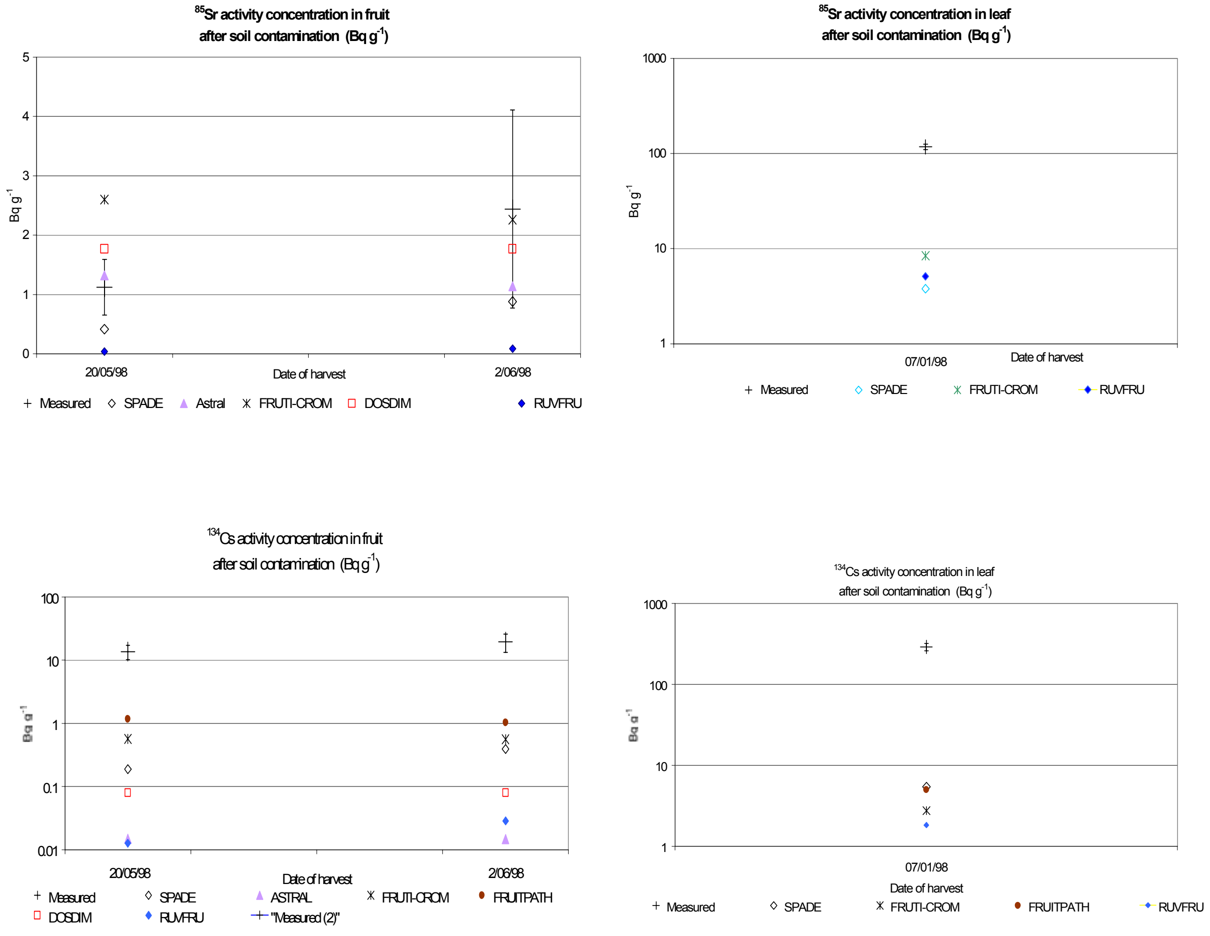

FIG. 19. Measured and simulated concentrations of ^{134}Cs and ^{85}Sr in strawberry fruit (fresh weight) and leaf (dry weight) after soil contamination.

6.4.3.3.2. ^{134}Cs leaf activity

The same discussion for fruit applies to the comparison between predicted and measured values in leaves. All the models underestimated leaf ^{134}Cs concentration by two orders of magnitude. Notwithstanding this, model predictions were rather uniform, showing a difference of a factor 3 between the highest (5.5E+00 Bq g^{-1} dw) and the lowest (1.8E+00 Bq g^{-1} d.w) estimated value. However, no such close agreement on predictions was observed for fruits, where differences between estimates were reported up to two orders of magnitude. This highlights that processes described by different models to assess plant contamination are affected by a greater uncertainty when the plant component under study is fruit rather than leaf.

6.4.3.3.3. ^{85}Sr fruit activity

A comparison of model predictions with experimental values for fruit contamination showed that three models, FRUTI-CROM, DOSDIM and ASTRAL, predict ^{85}Sr concentration well, giving values of the same order of magnitude both in the first and the second harvest. SPADE underpredicted by one order and RUVFRU by two orders of magnitude. However, the high error of measured values should be taken into account: 45% of the arithmetic mean for the first, (1.1±0.5)E+00, and 71% for the second harvest, (2.4±1.7E)+00 Bq g^{-1} ww, respectively. In particular, the error of the measured value for the second harvest was rather large, and all the model values fell within the standard deviation range (Figure 19). The spread of predicted values for ^{85}Sr was much smaller than that observed for ^{134}Cs in fruit after soil contamination.

6.4.3.3.4. ^{85}Sr leaf activity

There were only three predicted values for ^{85}Sr in leaves. Although fairly similar, they all underestimated measured values by a factor of 15 to 30. They exhibit a pattern similar to that for ^{134}Cs, therefore the discussion reported above also applies to this case.

6.4.4. Conclusions on model validation study

Model predictions in fruit and leaf of strawberry contaminated with ^{134}Cs and ^{85}Sr were tested against experimental results. The first two scenarios described foliar contamination at two phenological stages, anthesis and ripening, the third considered soil contamination at anthesis. In general models performed reasonably well within the constraint of this particular scenario.

6.4.4.1. Foliar contamination scenarios

Predicted values in fruit are generally in good agreement with the measured values, both for ^{134}Cs and ^{85}Sr. Predicted values for ^{134}Cs and ^{85}Sr in fruit differed by one order of magnitude from observed results. Most of the models tended to overestimate ^{134}Cs concentration in fruit (mainly in the second foliar scenario), but the predictions fell within the range of the error of measured values. The majority of models predicted a reduction of fruit activity from the first to the second harvest both for ^{134}Cs and ^{85}Sr, although an increase was observed in the measured results.

Most of the models underpredicted the ^{134}Cs concentration in leaf and all models underpredicted that of ^{85}Sr in leaf. The trend for ^{85}Sr was the same as for ^{134}Cs, even though the spread of predicted values was smaller for ^{85}Sr compared to that for ^{134}Cs. The interpretation of the scenario by the individual modeller could explain underpredictions of leaf concentration at harvest.

6.4.4.2. Soil contamination scenario

In the case of soil contamination the agreement between modelled and measured values was not so good as models tended to underpredict, especially for ^{134}Cs. Predicted values for ^{134}Cs in fruit were one to three orders of magnitude lower than measured values. The same applied to leaf estimates. The spread of predicted values for ^{85}Sr in fruit was much smaller than that for ^{134}Cs. Uncertainties were higher for fruit than for leaf predictions, for all models. Predicted values for ^{85}Sr in leaves underestimated the observed values but are rather similar for all models.

The reason for the underestimation of ^{134}Cs concentration in the case of soil contamination could be that many model parameters (distribution coefficient, transfer factors, etc.) refer to steady state conditions and the scenarios are far from the equilibrium state. Another important reason could be the type of growing substrate, peat mixed with Agriperlite, used to grow the strawberry plants, that may have favoured high radiocaesium uptake. In addition, strawberry plants were grown in pots which makes root growth and leaching different to field conditions.

6.4.4.3. General conclusions

Differences in model predictions may be explained by the difference in modelling approaches. For example, some modellers used direct deposition to fruit whereas others used deposition to total plant and this might explain over predictions for Cs and Sr by some models. The effect of weathering was considered differently by modellers. Some modellers gave less importance to this effect to reflect the fact that plants were sheltered under a tunnel during the experimental work. In some models the same parameter value was used for Cs and Sr transfer from external to internal leaf although different values should have been used.

The tendency for the models to underpredict leaf concentrations for both radionuclides after foliar contamination and fruit concentration for ^{134}Cs after soil contamination emphasizes the need for a better understanding of the processes that influence radionuclide concentrations in fruit and fruit bearing plants.

Although models performed reasonably well for these scenarios, the same performance may not be guaranteed for other scenarios particularly those involving other radionuclides and other fruit crops. Confidence in the use of models will increase if they continue to show good performance with a variety of testing and validation scenarios.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS

The overall aim of the Fruits Working Group activities was to improve understanding of the processes affecting the migration of radionuclides in the fruit system and reduce the uncertainties associated with modelling the transfer of radionuclides to fruit. This would improve the robustness of the models that are used for radiological assessment and increase the confidence with which they are applied. The overall aim was met by a programme of work with six subsidiary objectives, whose fulfilment is examined in this section.

The first objective was to combine modelling and experimental activities in order to obtain maximum benefit both from research and modelling. The Group has been a collaborative effort that has brought together people and organisations from approximately 20 countries with common interests in modelling and experimental studies in the field of radionuclide transfer to fruits. The programme has acted as a forum for the exchange of ideas, experience and information related to the transfer of radioactivity in fruit. Both experimentalists and modellers participated in this programme and participants have been meeting twice a year to present the state of the art of the various activities, discuss deliverables and plan future work. Recent or ongoing experimental results have been presented, forming the basis for discussion of important processes, parameters and pathways. Scientists involved in related sciences have also been introduced in order to ensure that models of the Fruits Working Group, as well as the experimental data on which these models are based, consider ancillary knowledge from these related sciences.

The second objective was to review what has been done in the field of radionuclide transfer to fruit, and related fields, with respect to research, development and application of models, and specification of data for application to radiological assessments. This objective has been fulfilled by two actions. A questionnaire, designed and circulated to a wide number of people, allowed collection of information on fruits, radionuclides and pathways in different types of radiological assessment. At the same time a review of experimental, field and modelling information on the transfer of radionuclides to fruit was carried out, with the valuable contribution of 16 individuals representing 10 organisations. A first very comprehensive Working Document "A critical review of experimental, field and modelling information on the transfer of radionuclides to fruit" was issued by the IAEA in September 1999. A further, more complete, version of the Review Working Document has been published by the Journal of Environmental Radioactivity in 2001.

The development of a database of model parameters for use in fruit models was the third objective. Participants provided data that have been incorporated into the RADFLUX database. The database can be used to answer specific questions, to estimate missing data or model specific transfer parameters, and to provide an audit trail from model parameters to the underlying body of experimental data. Although there is a large number of crops, 34, there are many for which there is only one or two records. 17 elements are represented, but there is a large bias towards data for caesium and strontium and the majority of data are soil–plant transfer factors that are not of great value in improving our understanding of the transfer to fruit, unless supported by additional information such as that required for RADFLUX entries.

The fourth objective of the study was to undertake model intercomparisons to identify and investigate significant areas of uncertainty and differences in approach between models.

Difficulties encountered by the Fruits Working Group in meeting this objective have been the lack of models specifically designed to model radionuclides in fruits and models designed for continuous releases. As a result several new models have been developed especially for fruits and some existing models have been extended. Other models have been adapted from modelling acute to continuous releases. The Working Group also provided participants with the opportunity to present and explain their models to a diverse audience and compare them with other models.

A total of six models participated in the model–model intercomparisons. Two scenarios were developed by the Group, one for acute releases and one for continuous releases. They reflected the views of the Group participants in terms of fruit crops (apple, blackcurrant and strawberry) and radionuclides (Cs, Sr and I). Results showed large differences in model predictions of radionuclide accumulation in fruits for the long term time scales, while short term predictions can be satisfactory modelled with uncertainty of about one order of magnitude. A comparison of differences in the assumptions in the various models reveals that some of the processes are treated similarly by most of the models, while others are treated very differently. Results clearly indicate the need for further development of models for the fate and transport of radionuclides in fruit ecosystems.

The fifth objective of the study was to identify, encourage and co-ordinate additional experimental studies on the transfer of radionuclides to fruit so as to maximise the benefits of current or new experimental research in this field. The Review carried out by the Group at a first stage of its activities has proved to constitute a valuable background and a tool to identify areas where information is lacking and to give priorities for experimental studies. Discussion on data and processes has given input to the setting up of new experimental programmes, where practicable, to readdress these deficiencies. This field has greatly benefited from the exchange of ideas between modellers and experimentalists throughout this programme.

The sixth objective of the programme was to undertake testing and validation of existing or new models against independent datasets. One of the difficulties encountered, however, has been the lack of data useful for a validation study. A scenario was developed based on an experimental acute release of Cs and Sr on strawberry plants. This was the first model validation exercise for fruit crops. Participants were able to assess their model performance and benefited from discussions on processes and assumptions. Models performed reasonably well within the constraint of this particular scenario, even though models tend to under predict in the case of soil contamination, especially for Cs.

In addition to the fulfilment of these objectives, the Fruits Working Group developed a fruit conceptual model. The scenario is that of a fruit tree subject to a deposit from atmosphere. The systematic approach adopted in model development (based on the matrix concept) takes account of the views of a number of experts on the key processes that determine the transfer of radionuclides to fruit. The results are reached through consensus and are based on a systematic analysis of the problem. The exercise provided participants with the opportunity to gain valuable experience and to identify gaps in their knowledge of key processes. The conceptual model provides guidance for future development of a model in the same context. Results show where model development efforts should be directed and, combined with an assessment of the state of our knowledge for each of the interactions, can be used as a basis for assigning priorities for experimental work.

Information gained from the activities of the Fruits Working Group should benefit both experimentalists and modellers and contribute to improving the accuracy of risk assessment tools.

7.2. RECOMMENDATIONS FOR EXPERIMENTAL STUDIES

Target measurements and experiments must be designed with the aim of obtaining data that will enable the reduction of uncertainties of predictive techniques, mainly predictive models.

The Working Group makes no specific recommendations for the fruit crops that should be studied. This is a decision for those who commission research and/or the investigator. In general, there is a need for composite data sets that provide information as follows:

- Deposition to crops of interest and how it is affected by growth form.
- Absorption by above ground parts of the plant.
- Distribution in the plant–soil system and its components (following interception).
- Loss of radionuclides from the system.
- Loss of mass, leaves, fruits and branches, from the above ground part, including pruning.
- Change in distribution with time (i.e. radionuclide inventory with supporting yield data).
- Data for shrub type fruits in particular.

There is a need for research into fruit crops to drive model development not parameterise existing models. Research should therefore focus on understanding the key processes. Experiments can be undertaken to validate existing models but it is hoped that the output from these studies will be time dependent data showing how the distribution varies with time rather than data sets comprising single end points such as concentration in fruit.

There are so few data for fruit that any experiments will improve our capability. The greatest improvement for the range of approaches used will be achieved if data are reported in a format that does not predetermine for what it is used. For example, data reported as TF or Tag values is not of great value in improving our understanding of the transfer to fruits unless supported by additional information such as that required for RADFLUX entries.

In terms of the crops and radionuclides of interest more data are required even on caesium and strontium to verify observations due to data from single researchers in some cases or few observations for crops of interest. It is also clear that there are many radionuclides for which no data exist that may be important in certain situations, e.g. radium (contaminated land), chlorine (waste disposal).

7.3. PRIORITIES FOR MODELLING

Further developments in modelling the transfer of radionuclides to fruits are needed to reduce uncertainties and these may include the following:

- Most soil to fruit transfer processes are included in current models but represented by different parameter values. More work is needed to identify appropriate parameter values to be used in fruit modelling.
- Root uptake is an important uncertainty in model prediction. More work is needed to investigate the dependence of the prediction on the characteristics of the soil.

- A great uncertainty is connected with short term processes, mainly for fruit trees and shrubs, such as fruit direct deposition, translocation, phenological stage at time of deposition, that needs to be investigated and discussed in fruit modelling.
- Current models are being tuned to weapons testing fallout and Chernobyl scenarios. Development is needed to model the transfer of radionuclides from waste disposal sites and contaminated land to fruit crops. Model intercomparisons need to be done with scenarios of waste repositories.
- Consideration needs to be given to modelling other fruits (e.g. orange, olives) that are of nutritional importance, and economically significant to Mediterranean countries, and radionuclides others than Cs and Sr. It is also prioritaire to address other countries/climatic regions such as tropical and asiatic countries.
- More validation scenarios are needed to test performance of models particularly in the case of fruit shrubs and trees.

More in general modelling improvement should include:

- to undertake model uncertainty analysis, probabilistic modelling and sensitivity.
- to process models (dependence on environmental variables, eg soil type, reference crop)
- to compare model complexity and requirements for regulation
- to implement and test the conceptual model with the outputs from Theme 1 of BIOMASS.

7.4. BIOSPHERE MODELLING AND REFERENCE CROP

One of the main issues that need to be addressed has been raised in the framework of the BIOMASS Theme 1 and also expresses the requests of other modellers. The question to be answered is:

- does fruit uptake give rise to significantly different impact from that associated with uptake into other crops, assuming the same deposition?
- does fruit consumption give a considerable contribution to total dose to humans for some radionuclides in comparison to other exposure pathways?
- which factors (radionuclides, fruits, pathways, fruit consumption, agricultural practices, climate) related to fruits can result in a dose to humans different from that resulting from other crops?

These questions have not yet been answered. Future work, in the framework of the priorities summarized above, has to be developed with the aim of producing information useful for evaluation of dose to humans.

Bearing in mind this goal, the Fruits WG discussed the need to develop future activities including a reference crop in the fruit system, both in modelling and, where practicable, in experimental studies. The reference crop can serve as an analogue where there is a lack of data on fruits, in order to model biosphere processes.

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ANNEX I

MODEL DESCRIPTIONS

I–1. SPADE

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SPADE (***S***oil ***P***ant ***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. Radionuclide inputs to SPADE are results from atmospheric dispersion calculations, measured or assumed concentrations in air (Bq m^{-3}) and/or deposition rates (Bq $m^{-2}s^{-1}$) to ground. The quantity of radionuclides reaching the above ground compartments of the plant from atmospheric sources is determined according to 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. Radionuclide distribution in plants depends on both the physiological characteristics of the plant and the physico-chemical properties of the radionuclide. Material lost from the plant by wash-off is partitioned between either soil solution and organic matter, or 'soil available' and 'soil unavailable', as appropriate. Transfers from soil to plant occur via root uptake and are assumed to vary with soil layer depth, as a function of the root distribution throughout the soil profile. Consequently the transfer of radionuclides from soil to root is represented in SPADE by a single transfer rate, normalised for each of the ten layers in the soil model according to root distribution.

SPADE models radionuclide uptake by three types of fruit crops: herbaceous, shrubs and trees. Parameter values used in SPADE are those specified in the scenarios where appropriate. Where parameter values for some processes were not provided in the scenarios, SPADE default values were used. Pruning was considered for both blackcurrants and apple trees according to information supplied in the scenarios. Strawberry plants were replaced every two years and debris was removed from the field.

The SPADE suite of codes is used by the United Kingdom Food Standards Agency (formerly part of the UK Ministry of Agericulture, Fisheries and Food – MAFF) for regulatory purposes. Input parameters for the models are selected to provide realistic predictions that are towards the upper end of observed concentrations in food products. On this basis the output from SPADE is a best estimate prediction. This is reinforced by the use of scenarios that are likely to produce high concentrations, e.g. deposition to crops at a time when transfer to the edible component is likely to be greatest.

The fruit plant model in SPADE [Thorne and Coughtrey, 1983] consists of six compartments, representing internal leaf, external leaf, stem, fruit, storage organs and root. Movement of radionuclides within the plant model is controlled by empirically derived rate constants and parameters are derived for three broad categories of fruit plant: herbaceous, shrub and tree.

Models are implemented in SPADE for 20 elements. and the following discussion considers the iodine models for fruit. Two experimental programmes have been undertaken in connection with the development of the SPADE fruit models for herbaceous and shrubby fruit crops [Kirton *et al.*, 1987; Donnelly and Carini, 1998]. The data from these experiments provide valuable information for model validation.

Foliar absorption may be an important pathway for the uptake of radionuclides deposited on external plant surfaces, and is represented by transfers between the external leaf and internal leaf compartments. Not all compartments in the model are directly linked, and in some cases transfers occur in one direction only. Ten internal transfers occur in the standard fission/activation plant model.

Interception by plants takes account of changes in plant biomass with season. Depending on the model, plant or leaves are divided into external and internal components to allow particulate deposition to be distinguished from radioactive gases and vapours. Passage through the stomata and incorporation into the mesophyll is therefore represented by partitioning a fraction of the intercepted deposit to the internal compartment.

The original default parameters for iodine [Coughtrey and Thorne, 1981] were based largely on data for cereals, but were modified in the case of tree and shrub fruits to allow for more rapid trasfer from stem to root so that the root store could serve as a reservoir through subsequent seasons. Loss of radionuclides from external plant surfaces to the soil is modelled as transfer to the surface layer of the soil model and include losses arising from leaf fall. The parameters for the three fruit models for iodine in SPADE (herbaceous, shrub and tree) are similar with the following exceptions. Differences for herbaceous fruit crops are as follows: the root store is switched off; there are crop-specific transfers from root to stem and from stem to internal leaf; and, internal to external leaf was chosen to reflect cereals rather than fruit crops. As concerns the other two fruit crop types the return from the root store reservoir is slower for tree fruit than for shrub fruit by an order of magnitude.

The process of root uptake is modelled as the transfer of radionuclides from soil solution to the plant root compartment. The transfer rate is also assumed to vary with soil layer depth, both as a function of the root distribution throughout the soil profile and as a function of the deposit distribution in soil. Consequently, the transfer of radionuclides from the soil solution to root is represented by a discrete transfer from each of the 10 layers in the soil model. The soil model is not considered further here.

I–2. FRUTI-CROM

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FRUTI-CROM is a fruit-specific model that was developed by CIEMAT (Spain) during participation in the Fruits WG. FRUTI-CROM started from an existing model CROM (vegetable sub-model) designed to evaluate radionuclide concentration in different compartments of the environment and to assess the radiological impact to man from routine and accidental releases.

The model considers the following processes: dry or wet deposition, interception by vegetation surfaces, translocation from external surfaces to edible part of plant, root uptake, adhesion of soil particles onto vegetation surfaces. To simplify the model, a number of these processes are taken into account by use of composite parameters that describe the effect of two or more interaction processes. Processes that can lead to the reduction of radionuclide concentrations in vegetation include radioactive decay, growth dilution, wash-off, pruning, harvesting, leaching and soil fixation.

Deposition

$$d_t = d_d + d_w$$

$$d_d = v_g * C_a$$

$$d_w = \omega * H * I * C_a$$

where:

d_t.	is the total deposition (Bq m^{-2} d^{-1});
d_d.	is the dry deposition (Bq m^{-2} d^{-1});
d_w.	is the wet deposition (Bq m^{-2} d^{-1});
v_g.	is the dry deposition velocity (m d^{-1});
C_a.	is the air concentration (Bq m^{-3});
ω.	is the washout rate (mm^{-1});
H.	is the atmospheric mixing height (m); and
I.	is the precipitation rate (mmd^{-1}).

Concentration due to direct contamination on vegetation

$$C_{v,1} = \frac{d_t * \alpha * (1/Y) * \left[1 - \exp(-\lambda_E^v * t_e)\right]}{\lambda_E^v}$$

$$\lambda_E^v = \lambda_i + \lambda_w$$

where:

$C_{v,1}$.	is the activity concentration due to material deposited (Bq kg^{-1} fresh weight);

α. is the fraction of deposited activity intercepted by edible portion of plant (m^2 kg^{-1});
Y. is the yield factor (kg m^{-2});
λ^v_E. is the effective rate constant for reduction of activity in crop (d^{-1});
λ_i. is the radioactivity decay constant (d^{-1});
λ_w. is the rate constant for reduction of concentration due to processes other than radioactive decay (d^{-1}); and
t_e. is the period of time that crop are exposed to contamination during the growing season (d).

Indirect contamination caused by uptake from the soil:

$$C_{v,2} = F_v * C_s$$

$$C_s = \frac{d_t * (1-\alpha) * \left[1 - \exp\left(-\lambda_E^s * t_b\right)\right]}{P * \lambda_E^s}$$

$$\lambda_E^s = \lambda_i + \lambda_s$$

where:

$C_{v,2}$. is the plant activity concentration due to soil contamination (Bq kg^{-1} fresh weight);
F_v. is the concentration factor for uptake from soil by edible part and adhesion of soil (Bq kg^{-1} fresh);
Cs. is the activity concentration in soil (Bq kg^{-1} dry weight);
λ^s_E. is the effective rate constant for reduction of activity in soil (d^{-1});
λ_i. is the radioactivity decay constant (d^{-1});
λ_s. is the rate constant for reduction of concentration due to processes other than radioactive decay (d^{-1});
t_b is the radioactive material discharge period (d); and
P. is the standardised surface density for the effective root zone in soil (kg dry m^{-2}).

Total activity concentration in plant

$$C_v = \left(C_{v,1} + C_{v,2}\right) * \exp\left(-\lambda_i * t_h\right)$$

where:

t_h. is the interval time between harvest and consumption of the fruit (d).

Parameter	Unit	Value			Reference
		Strawberries	Blackcurrant	Apples	
v_g	d^{-1}	173	173	173	Till and Meyer
ω	mm^{-1}				SS57
Cs-137		0.59	0.59	0.59	
Sr-90		0.59	0.59	0.59	
I-129		0.396	0.396	0.396	
H	m	500	500	500	
I	mm d^{-1}	1.78	1.78	1.78	BIOMASS Scenario
λ_E^v	d^{-1}				
Cs-137		0.05	0.05	0.05	
Sr-90		0.06	0.06	0.06	
I-129		0.05	0.05	0.05	

Parameter	Unit	Value			Reference
		Strawberries	Blackcurrant	Apples	
λ_ι	d^{-1}				
Cs-137		6.330E–05	6.330E–05	6.330E–05	
Sr-90		1.372E–02	1.372E–02	1.372E–02	
I-129		7.931E–03	7.931E–03	7.931E–03	
λ_ω	d^{-1}	5.00E–02	5.00E–02	5.00E–02	SS57
λ_E^s	d^{-1}				
Cs-137		2.03E–4	2.03E–4	2.03E–4	
Sr-90		1.39E–02	1.39E–02	1.39E–02	
I-129		1.21E–10	1.21E–10	1.21E–10	
λ_s	d^{-1}				SS57
Cs-137		1.4E–04	1.4E–04	1.4E–04	
Sr-90		1.4E–04	1.4E–04	1.4E–04	
I-129		0	0	0	
α	$m^2\ kg^{-1}\ d^{-1}$	0.3	0.3	0.3	SS57 Till and Meyer
Y	Kgm^{-2}	1.33	2.22	3.33	
F_v	Bq kg^{-1} fresh				ECOSYS
Cs-137		0.01	0.02	0.02	
Sr-90		0.2	0.1	0.1	
I-129		0.1	0.1	0.1	
P	kg dry m^{-2}	260	260	260	SS57
t_h	d	1	1	1	

I–3. FRUITPATH

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I. Linkov,
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The FRUITPATH model is a generic fruit-specific model for radionuclide accumulation in fruits that was developed by I Linkov and D. Burmistrov (USA) during participation in the Fruits WG FRUITPATH calculates a time series of inventories for a specific radionuclide distributed within the fruit system compartments. The number of compartments can be defined by the user for specific fruit types. For example, apple can be represented by the Tree, Organic Layer, Labile Soil, Fixed Soil and Deep Soil.

FRUITPATH focuses on a generic ecosystem application. It is a wholly probabilistic model that incorporates uncertain model parameters as probability distributions and predicts distribution for the output radionuclide concentrations in fruit compartments. For generic model application, uncertain model parameters are estimated from literature that includes different fruit and soil types. For site-specific applications, the available literature data are limited to the ecosystems similar to the site under consideration; site-specific parameters are thus estimated. Further model calibration, based on site-specific measurements, can be accomplished by using Bayesian updating procedures.

The radionuclide source term in FRUITPATH is total deposition to the ground (Bq m^{-2}). Partioning of radionuclides between plant and soil organic layer compartments is based on a the plant interception fraction. Material removal from the plant is characterised by the time dependent removal time. Transfer from soil to plant is described by the uptake rate that depends on plant biomass and plant type. The FRUITPATH framework is flexible to include scenario-specific conditions, for instance, for the BIOMASS calculations, modelling of pruning was added.

I–4. RUVFRU

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The RUVFRU model is a fruit-specific model that was developed by the University of Veszprem (Hungary) during participation in the Fruits WG. The model includes most of the dynamic processes by means of a compartmental system, starting from acute deposition. These are described by first order differential equations. The endpoint of the model is the activity concentrations of the compartments that represent the air and the parts of the soil and the fruit bearing vegetation for each radionuclide and for each fruit. These can be used as input data to estimating doses in the case of countermeasure planning after a nuclear emergency.

The growth of vegetation (mass and interception) is described by sigmoidal curves. The rate constants between compartments depend generally on seasonality (temperature) and some of them are mass-dependent. The model can take into consideration several agricultural activities like ploughing, replanting and pruning.

Most of the parameter values originate from IAEA and Hungarian publications presenting results of post Chernobyl measurements carried out in Europe. Several values derive from generic models (FARMLAND, SPADE).

I–4.1. THE COMPARTMENTAL MODEL

The model has been developed to assess the concentrations of radionuclides in agricultural systems producing fruits, to simulate transport processes in apple trees, blackcurrant, redcurrant and strawberry plants. The model has 13 compartments (Figure I–1) and assumes steady state growing conditions. The quantitative relationships of the dynamic processes are described by first order ordinary differential equations. The compartments and kinetic processes are described in the following pages.

1. Air (A1):

Both the initial and resuspended radionuclides are in soluble chemical form. The deposition of atmospheric aerosol and methyl-iodide vapour can be carried out in dry and wet forms while the resuspension in soluble form from upper soil layer, ground cover (if it exists) and from surfaces of leaves, bark and fruits.

2. Upper soil layer, soluble form (S1):

The contamination of the upper soil layer is governed in the short term by atmospheric deposition, weathering from leaves, bark and fruits and activity removed by fallen leaves (dashed lines), while in the long term it is governed by resuspension, fixation, root uptake and diffusion downwards.

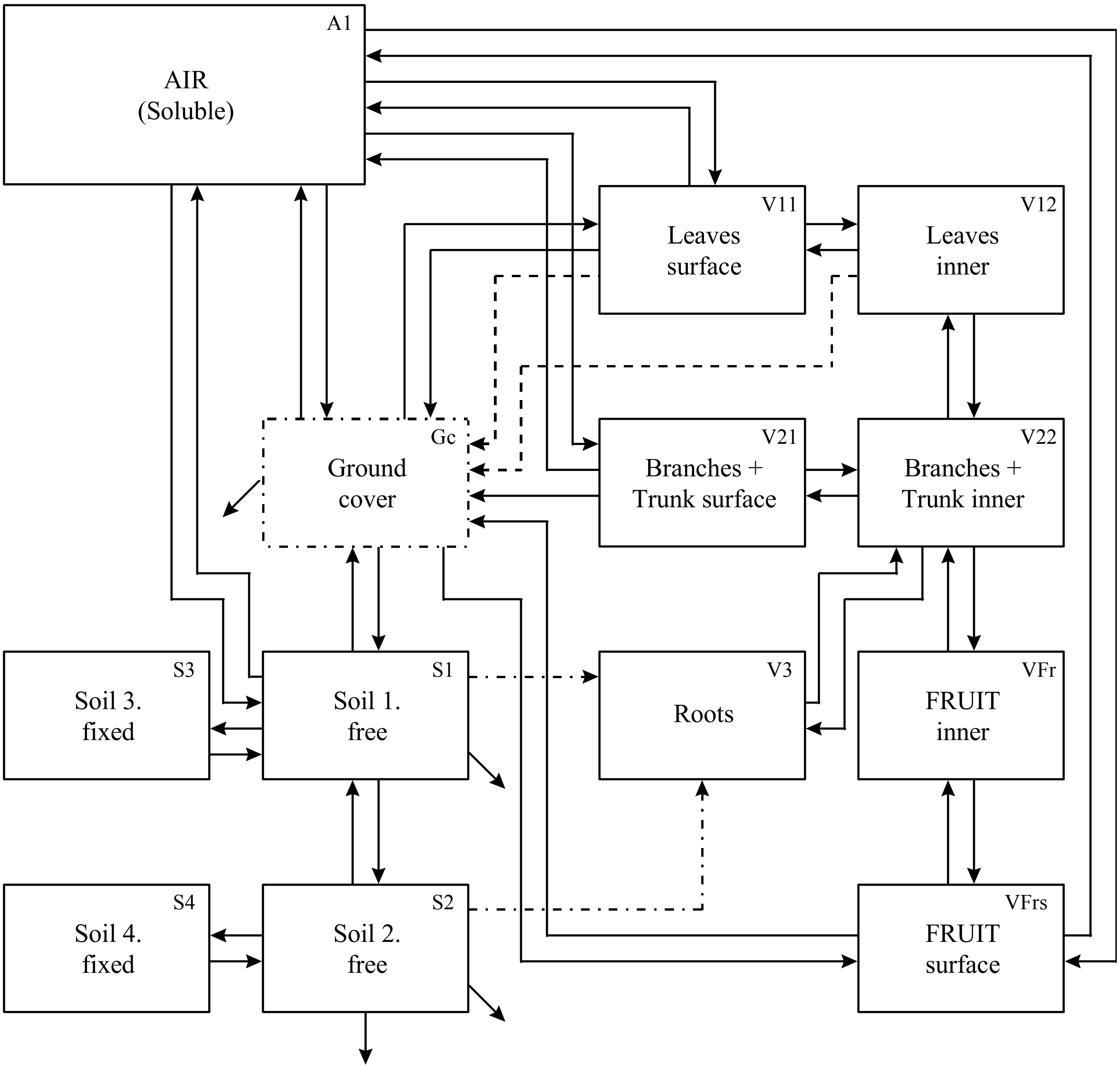

FIG. I–1. Compartmental system used.

3. Lower soil layer, soluble form (S2):

The contamination of the lower soil layer is determined by the activity of the upper soil layer and fixation. In addition, some runoff of the soluble form due to erosion is assumed in both upper and lower soil layer.

4. Upper soil layer, fix form (S3)

The contamination of this layer is determined by fixation of radionuclides from the S1 soil layer.

5. Lower soil layer, fix form (S4):

The contamination of this layer is determined by fixation of radionuclides from the S2 soil layer.

6. Surface of leaves (V11):

The contamination of leaf surface is governed mainly by the following: atmospheric deposition, interception, weathering loss, resuspension and transport to the inside of the leaves. The interception factor depends basically on vegetation periods. A considerable amount of activity is carried to the soil by leaf falling (temporary connection). In the case of plants like strawberry rainsplash has some contribution to the surface activity.

7. Surface of bark (V21):

The contamination of bark surface is similar to leaf surface, without bark falling and rainsplash, but with different transport coefficients.

8. Inner part of the plant (V22):

The activity content of this compartment is governed by the following compartments: inner part of leaves and fruit, root and bark surface. The transport coefficients are mass-dependent except for the bark surface.

9. Inner part of leaves (V12):

The inner part of leaves is connected to the surface of leaves and inner part of plant during the whole vegetation period. The connection to soil and ground cover (if it exists) is temporary as it is in the case of leaf surface.

10. Root (V3):

The activity of roots is determined by the soluble form of the soil layers taking into account the moisture of the soil, weighting factor of the soil layers and weight of plant.

11. Inner part of fruits (VFr):

The activity of the inner part of the fruit depends on the mass-dependent transport coefficient connecting this compartment to V22 and on the activity of the fruit surface.

12. Fruit surface (Frs):

The activity of the fruit surface is governed by interception, resuspension, weathering, rainsplash and transport to and from the inner part of fruit.

13. Ground cover (Gc):

The use of ground cover is optional. This compartment can partly or entirely cover the first soil compartment. Therefore the weathering, resuspension and rainsplash can proceed through this compartment as well. There is assumed to be a considerable loss from this compartment by the effect of runoff.

The transport coefficients used in the compartmental model are derived mainly from literature and some of them from personal communications and scenario description. Whatever the origin, a seasonal change based on temperature is taken into consideration for the majority of rate constants.

I–4.2. KINETIC PROCESSES MODELLED IN SPECIAL WAY

I–4.2.1. Sigmoid-type description of the vegetation growth

The change of the mass and surface of the vegetation can be described by the solution of the following differential equation:

$$\frac{dZ}{dt} = \alpha_1 \cdot Z - \alpha_2 \cdot Z^2 \tag{1}$$

Where Z(t) is the variable of the process, α_1 and α_2 are parameters that depend on the type and climate. The quotient $\frac{\alpha_1}{\alpha_2}$ equals the theoretical value $Z_{\infty,\mathrm{th}}$ when $t \to \infty$. Since the solution of the differential equation should reach the value ($Z_{t,\exp}$) given in the description of the scenario, the theoretical value $\frac{\alpha_1}{\alpha_2}$ should be set larger. One possible solution for this is as follows:

$$Z_{\infty,\mathrm{th}} \equiv \frac{\alpha_1}{\alpha_2} = B \cdot Z_{t,\exp} \tag{2}$$

Where B is constant (B>1) and it is connected to the above mentioned difference.

The general solution of eq. (1) can be written as:

$$Z(t) = \frac{\alpha_1}{\alpha_2} \cdot \frac{e^{\alpha_1 \cdot t}}{e^{\alpha_1 \cdot t} - \frac{1}{C}} \tag{3}$$

Where C is determined by the initial value $Z(t_0)$. It is easy to see from eq. (1) that $Z(t_0)$ should not be zero, otherwise the solution will be constantly zero. Therefore the initial value should be chosen to be a small positive number (e.g. $Z(t_0)=0.001$) to obtain a solution that is negligibly different from the real growth process. If $Z(t_0)$ is finite, the constant C (now denoted by C_0) is given by the following expression:

$$\frac{1}{C\_0} = e^{\alpha_1 \cdot t_0} \left(1 - \frac{\alpha_1}{\alpha_2 \cdot Z(t_0)} \right) \tag{4}$$

I–4.2.1.1. Sigmoid curves to assess interception

The total interception of the vegetation is given by the following expression:

$$R = R_{11}(t) + R_{21}(t) + R_{Fr}(t) \tag{5}$$

Where R_{ii}s are related to the interception of leaves, branches and fruits, respectively. In the case of R_{11} and R_{21} the interception factors are calculated by subtraction of a sigmoid curve from an other one which is shifted in time. The parameters make it possible that the increasing and decreasing periods of the curve obtained be different according to the differences between growing and loss of leaves. It is possible to apply this kind of curve at the description of interception of branches. The interception factor of fruit is governed by the weight of fruit because there was detailed information in the scenario description on the fruit growing.

I–4.2.1.2. Applying sigmoid curves to describe the weight of plant species

The total weight of plant is described by the following equation:

$$M = M_{11}(t) + M_{21}(t) + M_{Fr}(t) + M_3, \tag{6}$$

Where indices refer to leaves, branches, fruit and roots, respectively. The weights of leaves and branches are derived by the means of the 3/2nd power of their interception factor and suitable proportional constants.

$$m_{leaf} = K_{leaf} \cdot R_{11}^{\frac{3}{2}}(t) \qquad m_{br} = K_{br} \cdot R_{21}^{\frac{3}{2}}(t) \tag{7a and 7b}$$

The weight of fruit in time originates from the direct solution of the above mentioned differential equation, while the weight of root is considered to be constant.

I–4.2.2. Other kinetic processes

I–4.2.2.1. Activity loss by leaf falling

The activity carried by leaf falling can be divided into two parts. One is the activity carried on the surface and the other is the activity carried inside of the leaves. The concentration on the surface and the inside of leaves can be described by the following equations:

$$c_{11}(t) = \frac{y_{11}(t)}{A_{leaf}(t)} \qquad c_{12}(t) = \frac{y_{12}(t)}{m_{leaf}(t)} \tag{8a and 8b}$$

Where y_{11} aned y_{12} are the activities of compartments, A_{11} is the area of leaves. The loss of leaf surface in unit time is proportional to the change of its interception factor:

$$\dot{A}_{leaf,loss} = -k_1 \cdot \dot{R}_{11} \tag{9}$$

The activity being carried due to this process is then:

$$\dot{y}_{11}(t) = c_{11} \cdot \dot{A}_{leaf,loss} = \ldots = -\frac{\dot{R}_{11}(t)}{R_{11}(t)} \cdot y_{11}(t), \tag{10}$$

Applying similar considerations the activity being carried inside the leaves during leaf fall is the following:

$$\dot{y}_{12}(t) = -\frac{3}{2} \cdot \frac{\dot{R}_{11}(t)}{R_{11}(t)} \cdot y_{12}(t). \tag{11}$$

I–4.2.2.2. Seasonality

The majority of transport coefficients have seasonality dependence based on the temperature characteristic to that month. This means that transport coefficients above ground surface depend on average air temperature.

I–4.2.2.3. Agricultural cultivations

There are possibilities to take into account the effects of pruning, planting and ploughing. In the cases of the first two the radioactivity of the plant is removed partially or totally. Ploughing is taken into consideration by mixing the non-uniform activity pattern in soil layers. The effect is a uniform activity concentration in the soil layers ploughed.

In the case of strawberry, the activity of the old plant is ploughed into the soil in a soluble form every second year and becomes available for the processes (e.g. fixation, root uptake) which take place in soil layers.

I–4.2.3. Parameters

The parameters used are derived partly from literature and partly from Hungarian experiences after Chernobyl.

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments, Technical Reports Series No. 364, IAEA, Vienna (1994).
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Validation of Models Using Fallout Data from the Central Bohemia Region of the Czech Republic, IAEA-TECDOC-795, Vienna (1995).
[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Validation of Models Using Fallout Data from Southern Finland, IAEA-TECDOC-904, Vienna (1996).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, A critical review of experimental, field and modelling information on the transfer of radionuclides to fruit, Working Document BIOMASS/T3FM/WD01, Version 1.2, September, IAEA, Vienna (1999).
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I–5. DOSDIM

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The DOSDIM model is an example of a non-fruit specific model that was used to calculate the transfer of radionuclides to fruit. Only calculations for strawberries were carried out. For plant specific parameters, those for leafy vegetables were used to estimate interception by the strawberry plant and those for root vegetables to calculate the translocation rate. The parameter for root uptake was derived from the TF values given in the Fruit Review (Section 2).

Only translocation from external plant surfaces to fruit was considered. For deposition during flowering time, it was assumed that the translocation parameters from external plant surfaces to blossoms are the same as for fruit and all radioactivity translocated to blossoms will eventually be found in the fruit (conservative approach). Pruning or processing was not considered.

I–5.1. MODEL INTERCOMPARISON EXERCISE (ACUTE SOURCE)

I–5.1.1. Strawberries

For the direct deposition on the fruit, it was assumed that the fruit surface is 5% of the green plant surface. Furthermore, it was assumed that the plants were nearly 1 year old at the time of deposition. To calculate the root uptake we used a soil concentration in the root zone averaged over the growth period. For the deposition during flowering time, two processes were considered: translocation and root uptake. For the deposition 1 day before harvest two processes were considered: direct deposition and translocation. The root uptake was assumed to be negligible.

I–5.1.1.1. Input parameters

dv (root zone depth) = 0.2 m
φ (soil density) = 1420 kg m^{-3}
θ (volumetric water content of root zone) = 0.32
V_w (infiltration rate root zone) = 0.1 m y^{-1}
R = 0.31(interception on green part of the plant; value for leafy vegetables was chosen))
R_f = 0.015 (fruit)
R_g = 0.69 (ground)
Y_f (yield fruit) = 1.30 kg m^{-2}
t_{gr} (growth period of plant) = 0.75 y
λ_i decay rate; λ_w weathering rate; λ_{tr} translocation rate; λ_l leaching rate

	^{137}Cs	^{129}I	^{90}Sr
λ_i (y^{-1})	2.31E–02	4.42E–08	2.42E–02
λ_w (y^{-1})	14.9	31.2	14.9
λ_{tr} (d^{-1})	5.53E–03	5.53E–03	5.01E–04
λ_l (y^{-1})	3.6E–05	2.87E–01	2.66E–02
K_d (loam) ($m^3\ kg^{-1}$)	9.8	1E–03	1.3E–02
TF (dw/fw)	5E–03	4E–02	4E–02

I–5.1.1.2. Equations

Concentration in strawberries (Bq kg^{-1}) due to direct deposition:

$$C_{dir} = D \cdot \frac{R_f}{Y_f} \cdot exp\left\{-\left(t_h - t_{dep}\right) \cdot \left(\lambda_i + \lambda_w\right)\right\}$$

where:

D is the deposition amount (Bq m^{-2});
R_f is the direct interception on fruit;
t_h is the harvest time; and
t_{dep} is the deposition time.

Concentration in strawberries (Bq kg^{-1}) due to translocation:

At the first harvest: at the deposition time, fruit was present or in development:

$$C_{tr} = D \cdot \frac{R}{Y_f} \cdot exp\left\{-\lambda_i\left(t_h - t_{dep}\right)\right\} \cdot \frac{\lambda_{tr}}{\lambda_{tr} + \lambda_w} \cdot \left[1 - exp\left\{-\left(\lambda_{tr} + \lambda_w\right) \cdot \left(t_h - t_{dep}\right)\right\}\right]$$

At following harvests: C_{tr} is negligible at the second harvest. Since plants are replaced every two years, $C_{tr} = 0$ after the second harvest

Concentration in strawberries due to root uptake:

Root uptake:

Mean concentration $C_s^m(n)$ in root zone (Bq kg^{-1}) at the first harvest (with time period $t < t_{gr}$ (growth period of plant)):

$$C_s^m(1) = \frac{D}{dv \cdot \varphi} \cdot R_g \cdot \left(\frac{1 - exp\left\{-\left(\lambda_i + \lambda_l\right) \cdot t\right\}}{\left(\lambda_i + \lambda_l\right) \cdot t}\right\}$$

Mean concentration in root zone (Bq kg^{-1}) for following harvests during the year n:

$$C_s^m(n) = \frac{D}{dv \cdot \varphi} \cdot R_g \cdot exp\left\{-\left(\lambda_i + \lambda_l\right) \cdot t_{n-1}\right\} \cdot \left(\frac{1 - exp\left\{-\left(\lambda_i + \lambda_l\right) \cdot t_{gr}\right\}}{\left(\lambda_i + \lambda_l\right) \cdot t_{gr}}\right\}$$

Mean soil concentration is calculated for the growth period of the plant, during which radionuclides are taken up from soil; t_{n-1} = year n-1.

Concentration in strawberries (Bq kg^{-1}):

$$C_r = TF \cdot C_s^m(n)$$

I–5.2. MODEL INTERCOMPARISON EXERCISE (CONTINUOUS SOURCE)

To calculate the concentrations in fruit by a continuous release, the formulas for the spike release were used assuming that there is an acute deposition each day during the next 10 years. We assumed that there was a uniform deposition of 1000 Bq/m^2 each year, translated to an acute deposition of 1000/365 = 2.74 Bq m^{-2}/day. By taking the sum of the concentrations in fruit for all acute depositions, we approached the concentrations in fruit due to continuous release. We assumed that each year the blossom stage started the 1st of March and that fruit became important the 15th of May. No pruning or processing was assumed.

I–6. ASTRAL

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ASTRAL is an IPSN bespoke software designed for a single (acute) deposition and dedicated to assessing post-accident situations in the environment. Starting from deposition it calculates concentrations of radionuclides in food products, enables comparisons with regulatory levels and calculates radiation doses received by man through ingestion, inhalation of particles after resuspension, and external exposure to radionuclides deposited onto the soil.

ASTRAL, has no fruit specific sub-model, but there is a sub-model that is used for fruit vegetables: it is assumed that fruit are produced throughout the year (market garden scenario). The model and parameters for the fruit vegetable class have been chosen, as this class covers a wide variety of plants, from vegetables such as tomatoes and beans, to strawberries.

I–6.1. MODEL DESCRIPTION

The equations driven from the ASTRAL model are the following:

- For foliar contamination (1st harvest following contamination) :

$$C_{fol}\,\text{(at harvest)}=\left(D_{dry}.TF_{dry}+D_{wet}.TF_{wet}\right).e^{-(\lambda_{bw}+\lambda_r).\Delta t}$$

- For root uptake (soil contamination scenario, or for harvests following the 1st year for a foliar contamination scenario):

$$C_{root}\,\text{(at harvest)}=D.TF_{root}.e^{-(\varphi+\lambda_r).\Delta t}$$

where :

C	is the concentration for a given radionuclide at harvest time, due to foliar transfer or root uptake (Bq.kg^{-1} fresh weight);
D	is the total deposition over ground and plants (Bq.m^{-2});
D_{dry}	is the dry deposition over ground and plants (Bq.m^{-2});
D_{wet}	is the wet deposition over ground and plants (Bq.m^{-2});
TF	is the transfer factor in dry or wet deposition conditions for the foliar transfer, and the root transfer factor for the root uptake (m^2.kg^{-1} fresh weight);
λ_{bw}	is the decay rate due to both growth dilution and weathering (d^{-1});
λ_r	is the radiological decay rate (d^{-1});
Δt	is the time harvest-deposition (d); and
φ	is the rate of decay of activity available in the ground (d^{-1}).

ANNEX II

MODEL–MODEL INTERCOMPARISON SCENARIOS

II–1. MODEL–MODEL INTERCOMPARISON STUDY – ACUTE SOURCE TERM

II–1.1. SOURCE TERM

Release: Acute

Deposition time: See Section 4

Contaminants: Cs-137 and Sr-90 (both as sub-micron diameter particulates); I-129 as methyliodide (vapour)

Deposition: 1 kBq m^{-2} total deposition to ground (soil plus plant)

II–1.2. METEOROLOGICAL CONDITIONS

The meteorological conditions are the same as for the continuous source term.

II–1.3. ENVIRONMENTAL CONDITIONS

Soil type: Temperate loam

II–1.4. FRUIT

II–1.4.1. Strawberries

Ploughing (20 cm depth) and planting first occured on 1 October 1990. Plants are replaced every two years on 1 October. Ploughing occurs between replacements.

Spacing between rows: 0.75 m
Spacing between plants in rows: 0.50 m
Height: 15 cm
Land surface area covered by plant: 69%
Yield of fruit (fresh weight): 500 g per plant (1.30 kg m^{-2})
(Assume that there is only one harvest per year, and that this is the yield of fruit being harvested)

Biomass dry weight as a percentage to various plant parts:

Fruit:	13.4
Leaf:	36.2
Crown:	25.4
Root:	18.7

Date of Deposition:
15 May 1991 (during flowering time)
30 June 1991 (24 hours before harvesting)

II–1.4.2. Blackcurrant

No ploughing.
10 % pruning each year on 1 December
Prunings are removed (not recycled)

Spacing between rows: 1.5 m
Spacing between plants in rows: 1.5 m
Height: 1 metre
Land surface area covered by plant: 50% increasing to 75% at harvest
Yield of fruit (fresh weight): 5 kg per bush per season (2.22 kg m^{-2} per season)
General: Leaves are present before flowers develop. Flowers are produced in early spring.

Biomass dry weight as a percentage to various plant parts:
Fruit: 40
Leaf: 35
Wood: 15
Root: 10

Date of Deposition:
1. 30 March 1991 (during flowering time)
2. 15 June 1991 (30 days before harvest)
3. 14 July 1991 (24 hours before harvesting)

II–1.4.3. Apples

No ploughing.
10 % pruning each year on 1 December
Prunings are removed (not recycled)

Spacing between rows: 3.0 m
Spacing between plants in rows: 2.0 m
Height: 2 metres
Land surface area covered by plant: 50%
Yield of fruit (fresh weight): 20 kg per season (3.33 kgm^{-2})

Biomass dry weight as a percentage to various plant parts:
Leaf: 10.0
Fruit: 62.5
Wood: 22.5
Root: 5.0

Date of Deposition:
1. 15 May 1991 (during flowering time)
2. 7 July 1991 (seven weeks after flowering)
3. 30 September 1991 (24 hours before harvesting).

II–1.4.4. Endpoints

For each radionuclide and each deposition time:

Concentration in edible fruit (Bq kg^{-1} fresh weight) at the following dates:

Apples:	At annual intervals from1 October 1991 to 1 October 2000
Strawberries:	At annual intervals from 1 July 1992 to 1 July 2000
Blackcurrant:	At annual intervals from 15 July 1991 to 15 July 2000

If possible, results on the following intermediate stages should also be submitted:

Total Bq m^{-2} in soil and total Bq m^{-2} in the plant (for each radionuclide, each fruit and each deposition time).

II–2. MODEL–MODEL INTERCOMPARISON STUDY – CONTINUOUS SOURCE TERM

II–2.1. SOURCE TERM

Release: Continuous

Contaminants: Cs-137 and Sr-90 (both as sub-micron diameter particulates) I-129 as methyliodide (vapour)

Deposition: 1 kBq m^{-2} per year uniform deposition to ground (soil plus plant)

Start of release: 1 April 1991

II–2.2. METEOROLOGICAL CONDITIONS

The meteorological conditions are the standard conditions at the Horticultural Research Institute at East Malling, United Kingdom.

Month	Air temperature			Rainfall	Sunshine	Soil Temp		Mean daily wind run
	Average minimum (^{o}C)	Average maximum	Average mean	Average (mm)	Average (h)	10 cm (^{o}C)	20 cm (^{o}C)	km
January	6.7	1.1	3.9	61.8	51.6	3.2	3.9	227.4
February	7.0	1.0	4.0	44.3	69.5	3	3.7	225
March	9.8	2.4	6.1	45.2	113.9	5	5.3	239.2
April	12.6	4.0	8.3	42.8	148.5	8.2	8	225.3
May	16.5	6.7	11.6	48.1	201.0	13.1	12.2	199.7
June	19.6	9.7	14.7	47.3	204.8	16.8	15.9	179.3
July	21.6	11.8	16.7	50.6	200.9	19.1	18.3	166.6
August	21.4	11.5	16.5	55.1	195.6	18.1	17.8	158
September	18.9	9.5	14.2	58.4	151.4	14.3	14.5	158
October	15.1	6.8	11.0	63.9	114.4	10	10.7	162.9
November	10.2	3.6	6.9	68.9	69.3	6.1	7	191.1
December	7.9	2.2	5.1	64.7	46.5	4.1	4.8	215.5
Yearly totals				651.1	1567.4			

II–2.3. ENVIRONMENTAL CONDITIONS

Soil type: Temperate loam

II–2.4. FRUIT

II–2.4.1. Strawberries

Ploughing (20 cm depth) and planting first occurred on 1 October 1990. Plants are replaced every two years. Ploughing occurs between replacements.

Spacing between rows: 0.75 m
Spacing between plants in rows: 0.50 m
Height: 15 cm
Land surface area covered by plant: 69%
Yield of fruit (fresh weight): 500 g (1.3 kg m^{-2})

Yield of plant (% dry matter):

Fruit:	13.4
Leaf:	36.2
Crown:	25.4
Root:	18.7

Harvesting:
First harvest: 1 July 1991
Thereafter each year on 1 July.
(Assume that there is only one harvest per year, and that a total of 1.3 kg m^{-2} of fruit is harvested during this one harvest)

II–2.4.2. Blackcurrant

No ploughing.
10 % pruning each year on 1 December
Prunings are removed (not recycled)

Spacing between rows: 1.5 m
Spacing between plants in rows: 1.5 m
Height: 1 metre
Land surface area covered by plant: 50% increasing to 75% at harvest
Yield of fruit (fresh weight): 5 kg per bush per season (2.22 kg/m^2)
General: Leaves are present before flowers develop. Flowers are produced in early spring.

Yield of plant (% dry matter):

Fruit:	40
Leaf:	35
Wood:	15
Root:	10

Harvesting:
First harvest: 15 July 1991
Thereafter each year on 15 July.

II–2.4.3. Apples

No ploughing.
10 % pruning each year on 1 December
Prunings are removed (not recycled)

Spacing between rows: 3.0 m
Spacing between plants in rows: 2.0 m
Height: 2 metres
Land surface area covered by plant: 50%
Yield of fruit (fresh weight): 20 kg per season (3.33 kg/m^2)

Carbohydrate distribution (biomass dry weight as a percentage to various plant parts):

Leaf:	10.0
Fruit:	62.5
Wood:	22.5
Root:	5.0

Harvesting:
First harvest: 1 October 1991
Thereafter each year on 1 October.

II–2.5. ENDPOINTS

1. Acitivity concentration of Cs-137, Sr-90 and I-129 in fresh weight of edible fruit at the dates specified in the attached Excell spreadsheet.

   Unit: Bq kg^{-1} fresh weight.

   Specify whether processing and pruning has been taken into account.

2. Total Bq m^{-2} in soil and total Bq m^{-2} in the plant at the dates specified in the attached Excell spreadsheet.

II–3. MODEL–DATA INTERCOMPARISON STUDY

II–3.1. INTRODUCTION

The scenario is based on work undertaken by Franca Carini (UCSC, Piacenza). They investigated the transfer of ^{134}Cs and ^{85}Sr to strawberry plants after a spike release. Strawberry plants were grown in pots filled with peat substrate and placed under a ventilated tunnel in a field. The purpose of the tunnel was to prevent the loss of radioactivity by rain and, simultaneously, to allow natural ventilation under the tunnel. The plants were contaminated with ^{134}Cs and ^{85}Sr by wet deposition. Leaf–to–fruit and soil–to–fruit pathways were examined. Leaf contamination was effected at two phenological stages, anthesis and ripening. Soil contamination was effected at anthesis.

The following sections contain further information on the method and amount of contamination, interception and plant spacing and yield. Modellers are required to predict the activity concentration of ^{134}Cs and ^{85}Sr in the fruit and leaves (see Tables II–5a and II–5b).

II–3.2. GENERAL INFORMATION

Source term: Release: Spike source. Wet deposition
Plants: Strawberry plants in pots under a tunnel
Soil type: peat
Field arrangement (see Figure II–1):
Space between rows: 110 cm and 35 cm
Space between plants in rows: 35 cm
Plant density: 5.19 plants m^{-2}

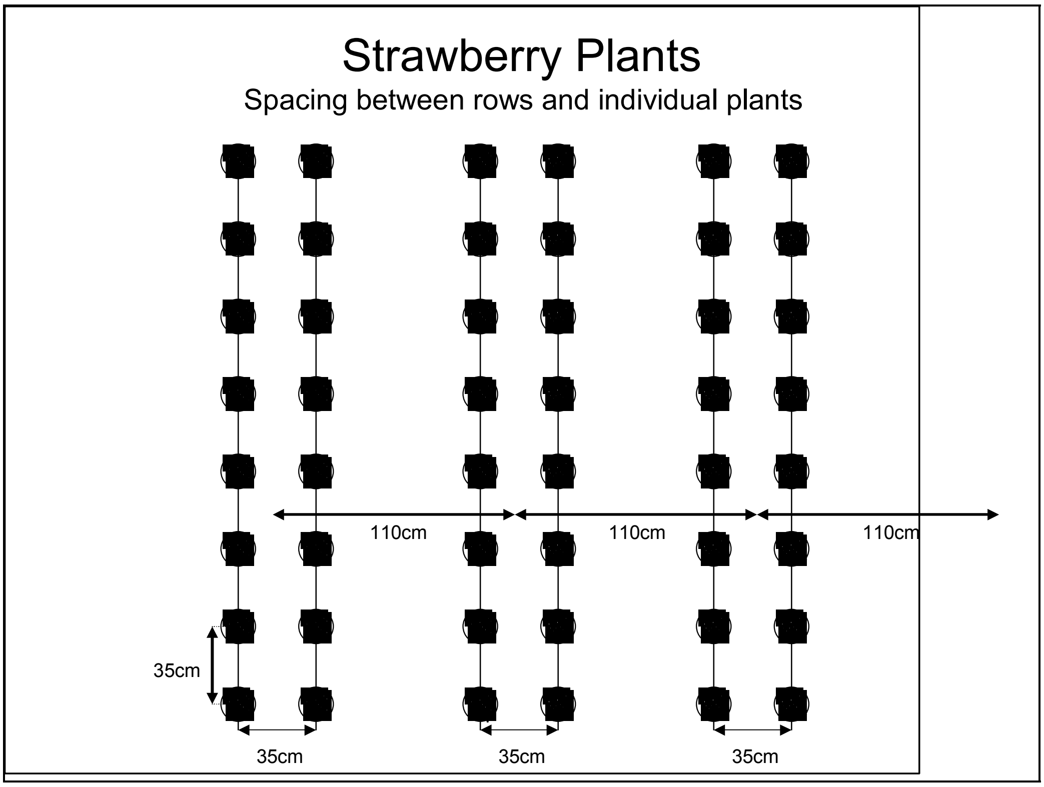

FIG. II–1. Spacing between rows and individual plants.

II–3.3. MATERIALS AND METHODS

II–3.3.1. Transplanting and agricultural practices

June bearer strawberry plants, cultivar MISS, were received from the farm “Martorano 5” in Cesena at the end of July. 120 of them were transplanted 30th July 1997 into 18 × 18 cm pots, filled with fair peat mixed with 15% Agriperlite. Pots were placed under a tunnel (2.5 × 12.0 × 2.0 m) covered with PVC up to 1 m in height from the ground. This device was meant to prevent the loss of radioactivity by rain and, simultaneously, to allow natural ventilation under the tunnel. Pots were arranged in rows of 30 plants each, simulating the arrangement in the open field. Plants were irrigated as required by an automatic drop system and regularly fertilized and treated with pesticides for disease control.

II–3.3.2. Radiocontamination

Strawberry plants were contaminated by application of ^{134}Cs and ^{85}Sr to the soil and leaves. Amersham (UK) supplied the radionuclides ^{134}Cs and ^{85}Sr:

- ^{134}Cs was in the form of caesium chloride, ^{134}CsCl, in aqueous solution. The mother solution had a specific activity of 104 MBq/mg of Cs.
- ^{85}Sr was in the form of strontium chloride, $^{85}SrCl_2$, in aqueous solution. The mother solution had a specific activity of 45 MBq/µg of Sr.

The experimental design foresaw one soil contamination and two foliar contaminations at two different growing stages, with both radionuclides. The supplier of radionuclides had technical problems and was unable to guarantee the arrival of ^{85}Sr in time for treatments. This compelled us to carry out the first foliar contamination with only ^{134}Cs. Therefore, treatments were performed as follows.

II–3.3.3. Soil contamination

Soil contamination was effected on 27 April 1998. Plants were at the anthesis stage, had well developed leaves, flowers and a few small green fruits. The soil of each pot was moistened over all its surface with 150 mL of an aqueous solution containing the following radionuclide concentrations:

^{134}Cs:	147.5	kBq/ plant
^{85}Sr:	327.21	kBq/ plant

and the following stable element concentrations:

Cs:	1.41	µg Cs/plant
Sr:	0.019	µg Sr/plant

The reference date for the activities of ^{134}Cs and ^{85}Sr administered to the soil was 27 April 1998. Twelve plants were contaminated, identified by initials R_1, …, R_{12}. After treatment the soil surface was covered with a layer of expanded clay to separate the leaves from the soil and prevent their direct contamination.

II–3.3.4. Foliar contamination

Foliar contamination was carried out when the strawberry plants were at two different phenological stages: anthesis and ripening.

II–3.3.4.1. First foliar contamination

The first foliar contamination was effected on 22 April 1998. Plants were at the anthesis stage, had well developed leaves, flowers and a few green fruitlets.

II–3.3.4.1.1. Sprinkling

The contamination was only effected with ^{134}Cs, by sprinkling the above ground part of each plant with 1 mL of an aqueous solution containing the following concentrations of radioactive and stable element per plant:

^{134}Cs:	155.12	kBq/ plant
Cs:	1.48	µg Cs/plant

The reference date for these activities was 22 April 1998.

Sprinkling was carried out by placing the pot on the bottom of a plexiglas box measuring 50 × 50 × 60 cm, and introducing the sprinkler at its top, about 20 cm over the foliar apparatus.

16 plants were contaminated. They were identified by initials:

- $A1_1$, …, $A1_9$: plants to be picked at ripening;
- $I1_1$, …, $I1_4$: plants to be picked immediately for the measurement of interception (see point: 3.3.2.1.2);
- L_1, … L_3: plants to be picked one month after contamination to evaluate loss (see point 3.4.).

The soil was covered with a plastic sheet before treatment to avoid its direct contamination. After treatment, the plastic sheet was removed and the soil surface, as for soil treatment, was covered with a layer of expanded clay to separate leaves from the soil.

II–3.3.4.1.2. Intercepted activity

The intercepted activity was estimated by sprinkling 4 plants, $I1_1$, …, $I1_4$, in the same above mentioned way. The above ground part was harvested as soon as dry and separated into leaves and green fruits, albeit small, to measure direct contamination. The mean wet weight of leaves and fruits in g/plant and the corresponding dry matter content at 60°C are reported in Table II–3. Intercepted activity for ^{134}Cs was determined by gamma spectrometry separately on the green fruits and on the remaining whole fresh mass and calculated as a sum for the whole above ground part. The latter was:

^{134}Cs: 57.210 ± 1.487 kBq/plant

The activity was corrected to the reference date of 22 April 1998 and is expressed as mean and standard error of four plants. The radioactivity intercepted by leaves and fruits, expressed as a percentage of the total sprayed radioactivity is reported in Table II–4.

II–3.3.4.1.3. Leaf area

Above mentioned plants, $I1_1$, …, $I1_4$, were used to determine the actual area of the leaves. After collection, each fresh leaf was cut from its stalk, laid out on a sheet and photocopied onto a transparency. Detection of the area of the leaves was performed by means of a surface integrator LAM (Leaf Area Meter) LI-COR, model LI 3000. Mean and standard error of the leaf areas expressed in cm^2/plant are reported in Table II–3.

II–3.3.4.2. Second foliar contamination

The second foliar contamination was effected on 18 May 1998. Plants were at ripening stage, bearing green and red fruits and very few flowers.

II–3.3.4.2.1. Sprinkling

The treatment was effected using the same methods as the first one (point 3.3.2.1.1.) using a solution with the following concentrations of radioactive and stable elements:

^{134}Cs:	171.63	kBq/plant
^{85}Sr:	149.63	kBq/plant
Cs:	1.7	µg Cs/plant
Sr:	0.011	µg Sr/plant

The reference date for the ^{134}Cs and ^{85}Sr activities was 18 May 1998.

13 plants were contaminated. They were identified by initials:

- $A2_1$, …, $A2_9$: plants to be picked at ripening;
- $I2_1$, …, $I2_4$: plants to be picked immediately for the measurement of interception (see point 3.3.2.2.2.).

II–3.3.4.2.2. Intercepted activity and leaf area

The calculation of intercepted activity and measurement of leaf area at the second growing stage were effected using the same methods as for the first treatment. The above ground part was harvested when dry and separated into leaves and green+red fruits to measure direct contamination. The mean wet weight of leaves and fruits in g/plant, the corresponding dry matter content at 60°C and the leaf area in cm^2/plant are reported in Table II–3. Intercepted activity was determined by gamma spectrometry separately on fruits and on the remaining whole fresh mass and calculated as a sum for the whole above ground part. The latter was:

^{134}Cs:	52.037 ± 3.004	kBq/plant
^{85}Sr:	47.079 ± 2.343	kBq/plant

The activity was corrected to the reference date of 18 May 1998 and is expressed as mean and standard error of four plants. The radioactivity intercepted by leaves and fruits, expressed as a percentage of the total sprayed radioactivity is reported in Table II–4.

II–3.3.5. Harvest

II–3.3.5.1. Fruit

Fruits were picked plant by plant when ripe, weighed as collected and frozen. They were grouped into two harvests:

— 1st harvest:	20 May 1998
— 2nd harvest	2 June 1998

Average yields were expressed in g wet weight/plant, and standard errors of 9 replicates for foliar contaminations and 12 replicates for soil contamination. Each sample was defrosted and homogenized before being analysed by direct gamma spectrometry. The harvest of each plant was analysed separately as a single replicate. The dry matter content was obtained drying fruits at 60°C until constant weight, after gamma measurement.

II–3.3.5.2. Leaves, crowns and roots

At the end of the fruit season, the whole plant was harvested. For technical reasons it was possible to pick samples only approximately one month after the last fruit harvest. After separation of fruits, the above ground part was divided into leaves and crowns, weighed as collected and dried in a fan oven at 60° C until constant weight. The root apparatus was rinsed carefully to free it from soil, weighed after rinsing and dried at 60° C until constant weight. Samples of leaves, crowns and roots were kept separate and weighed individually plant by plant. Each dried sample was minced and homogenized before being analysed by direct gamma spectrometry.

TABLE II–1. DEPOSITION

Contaminated compartment	Above ground plant part	Above ground plant part		Soil	
Phenological stage	anthesis	ripening		anthesis	
Code	1st foliar	2nd foliar		soil	
Date of deposition	22th April 1998	18th May 1998		27th April 1998	
Radionuclide	^{134}Cs	^{134}Cs	^{85}Sr	^{134}Cs	^{85}Sr
Sprayed activity (kBq m^{-2})	805.1	890.8	776.6	–	–
Intercepted activity (% of the sprayed activity) (See Table II–4 for details)	36.9 ± 1.0	30.3 ± 1.8	31.5 ± 1.6	–	–
Deposited activity (kBq m^{-2})	–	–	–	765.5	1698.2

TABLE II–2. YIELD

		1st foliar		2nd foliar		soil	
Endpoint	Unit of measure	yield	dry matter (%)	yield	dry matter (%)	yield	dry matter (%)
Fruit, 1st harvest	kg ww · m^{-2}	1.169	6.2	1.109	6.4	1.088	6.7
Fruit, 2nd harvest	kg ww · m^{-2}	1.621	7.2	1.595	8.1	0.888	8.0
Leaf	kg dw · m^{-2}	0.594	36.2	0.614	36.9	0.515	39.5
Crown	kg dw · m^{-2}	0.219	25.4	0.227	21.1	0.201	25.2
Root	kg dw · m^{-2}	0.193	18.7	0.265	16.1	0.180	18.9

Data on deposition and yield have been calculated using the plant density of 5.19 plants·m^{-2}

TABLE II–3. FOLIAR CONTAMINATION. WET WEIGHT, DRY MATTER CONTENT AND LEAF AREA OF THE ABOVE GROUND PART OF STRAWBERRY AT THE TWO PHENOLOGICAL STAGES OF CONTAMINATION

Contamination	1st Foliar			2nd Foliar		
Plant component	Wet weight g/plant	Dry matter %	Leaf area cm^2/plant	Wet weight g/plant	Dry matter %	Leaf area cm^2/plant
Leaves	84.0 ± 4.7	24.7 ± 0.3	1745.7 ± 59.4	94.2 ± 9.1	26.8 ± 0.2	2239.5 ± 108.6
Fruits	10.8 ± 3.2	18.2 ± 3.4	–	391.3 ± 27.4	6.8 ± 0.4	–
Whole above ground part	94.8 ± 6.3	42.9 ± 3.2	–	485.5 ± 30.0	33.7 ± 0.5	–

TABLE II–4. FOLIAR CONTAMINATION. RADIOACTIVITY INTERCEPTED AT THE TWO PHENOLOGICAL STAGES EXPRESSED AS PERCENTAGE OF THE RADIOACTIVITY SPRAYED ON THE ABOVE GROUND PART OF THE PLANT

Contamination	1st Foliar	2nd Foliar	
Radionuclide	^{134}Cs	^{134}Cs	^{85}Sr
Plant component:			
Leaves	36.7 ± 0.9	29.2 ± 1.7	30.3 ± 1.5
Fruits	0.23 ± 0.07	1.16 ± 0.22	1.20 ± 0.24
Whole above ground part	36.9 ± 1.0	30.3 ± 1.8	31.5 ± 1.6

TABLE II–5a. ACTIVITY CONCENTRATION IN THE ENDPOINTS

^{134}Cs

		1st foliar		2nd foliar		soil	
Endpoint	Unit of measure	Activity Concentration	Date of harvest	Activity Concentration	Date of harvest	Activity Concentration	Date of harvest
Fruit, 1st harvest	Bq g^{-1} ww	(2.7±0.2)E+1	20/5/98	(2.5±0.9)E+0	20/5/98	(1.4±0.3)E+1	20/5/98
Fruit, 2nd harvest	Bq g^{-1} ww	(2.5±0.2)E+1	2/6/98	(1.2±0.1_E+1	2/6/98	(2.0±0.6)E+0	2/6/98
Leaf	Bq g^{-1} dw	(5.1±0.3)E+2	1/7/98	(6.9±0.5)E+2	14/7/98	(1.9±0.3)E+2	1/7/98

TABLE II–5b. ACTIVITY CONCENTRATION IN THE ENDPOINTS

^{85}Sr

		2nd foliar		soil	
Endpoint	Unit of measure	Activity Concentration	Date of harvest	Activity Concentration	Date of harvest
Fruit, 1st harvest	Bq g^{-1} ww	(1.7±0.6)E+0	20/5/1998	(1.1±0.5)E+0	20/5/1998
Fruit, 2nd harvest	Bq g^{-1} ww	(2.2±0.3)E+0	2/6/1998	(2.4±1.7)E+0	2/6/1998
Leaf	Bq g^{-1} dw	(4.4±0.3)E+2	14/7/1998	(1.2±0.1)E+2	1/7/1998

ANNEX III

THE RADFLUX DATABASE: DATA FOR FRUIT

Please see Section 5 for a discussion of the RADFLUX Database. The entries relating to fruit in the RADFLUX Database are listed below.

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Am	Apple tree	.		Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00062	TF(fw/dw)	.	.	.	4	Fruit: water content 84.4;
Am	Apple tree	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	2.2E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Apple tree	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	8E-06	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Apple tree	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	1.5E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Apple tree	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	1.3E-06	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Blackcurrant	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00023	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	7.8E-06	TF(fw/dw)	.	362	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 16-17*; Row number = 101001; dry% = 79; pH in CaCl2 = 4
Am	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	1.3E-05	TF(fw/dw)	.	87	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 17*; Row number = 101002; dry% = 79
Am	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	5.2E-05	TF(dw/dw)	.	173	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb30*; Row number = 101003; dry% = 79
Am	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	0.00012	TF(fw/dw)	.	33	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb31*; Row number = 101004; dry% = 79
Am	Gooseberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	6.5E-05	TF(fw/dw)	.		Bq kg^{-1}	11	Washed fruit
Am	Melon	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00072	TF(fw/dw)	.		Bq kg^{-1}	11	Washed fruit
Am	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	5E-06	TF(fw/dw)	.	290	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3; remark = house 26a*; Row number = 101023; dry% = 89
Am	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	1.7E-05	TF(fw/dw)	.	656	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3; remark = house 27b*; Row number = 101024; dry% = 95
Am	Peach tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.00044	TF(fw/dw)	.	.	.	4	Fruit: water content 89.1;
Am	Rhubarb	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	5.5E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Strawberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00005	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Strawberry	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	7.3E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Strawberry	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	0.00017	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Strawberry	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	6.8E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Am	Strawberry	Tem-perate	L	.	A	.	Sand	0.3		2.1	.	I,F	ST		0.00041	TF(fw/dw)		3.32	Bq kg^{-1} dw	14	Notes = CEC7.8 FER; Dry matter (%) = 7.49; ; irrig. (mm) = 260; ; pH (KCl) = 6.8; ; Contaminated : 0y 9m to harvest
Am	Watermelon	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.0003	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6
Ce	Apple tree	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00062	TF(fw/dw)	.	.	.	4	Fruit: water content 84.4
Ce	Peach tree	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00044	TF(fw/dw)	.	.	.	4	Fruit: water content 89.1

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Ce	Watermelon	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.0003	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6
Cm	Apple tree	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00062	TF(fw/dw)	.	.	.	4	Fruit: water content 84.4
Cm	Peach tree	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00044	TF(fw/dw)	.	.	.	4	Fruit: water content 89.1
Cm	Strawberry	Tem-perate	L	.	A	.	Sand	0.3		2.1	.	I,F	ST		0.00064	TF(fw/dw)	.	2.89	Bq kg^{-1} dw	14	Notes = CEC7.8 FER; Dry matter (%) = 7.49; ; irrig. (mm) = 260; ; pH (KCl) = 6.8; ; Contaminated ; 0y 9m to harvest
Cm	Watermelon	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.0003	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6
Co	Apple tree	.	P	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.0048	TF(fw/dw)	.	.	.	8	Fruit
Cs	Apple tree	.	P	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.0024	TF(fw/dw)	.	.	.	8	Fruit
Cs	Apple tree	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00086	TF(fw/dw)	.	.	.	11	Washed fruit
Cs	Apple tree	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.00094	TF(fw/dw)	.	.	.	11	Washed fruit
Cs	Apple tree	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	0.00185	TF(fw/dw)	.	.	.	11	Washed fruit
Cs	Apple tree	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	0.037	TF(fw/dw)	.	.	.	11	Washed fruit
Cs	Apple tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.019	TF(fw/dw)	.	.	.	20	Fruit: water content 84.4
Cs	Apple tree	.	F	Agricultural	F	.	Loamy sand	.	.	.	.	.	ST	PF	0.004	TF(fw/dw)	.	.	.	26	Fruit
Cs	Apples	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	PF	TBIO	310	d^{-1}	.	.	.	2	Spadedat soil code = NLCO; Characteristic half-life
Cs	Apples	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	ST	PI	0.002	TF	.	.	.	2	Spadedat soil code = NLCO; Soil-to-leaf transfer factor
Cs	Apples	.	.	.	C	.	Loamy	.	8	0.013	.	.	ST	PI	0.008	TF	.	.	.	2	Spadedat soil code = ALLO; Soil-to-leaf transfer factor
Cs	Apricots	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	PF	TBIO	280	d^{-1}	.	.	.	2	Spadedat soil code = NLCO; Characteristic half-life
Cs	Apricots	.	.	.	C	.	Loamy	.	8	0.013	.	.	PF	TBIO	310	d^{-1}	.	.	.	2	Spadedat soil code = ALLO; Characteristic half-life
Cs	Black currant	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.0033	TF(fw/dw)	.	.	.	11	Washed fruit
Cs	Breadfruit	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	1.4	TF(fw/dw)	.	.	.	17	Fruit: water content 80 (Mayall);
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	0.22	TF(fw/dw)	.	3944	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 16-17*; Row number = 110166; dry% = 75
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	0.66	TF(fw/dw)	.	2700	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb30*; Row number = 110167; dry% = 79
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	0.77	TF(fw/dw)	.	1378	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 17*; Row number = 110168; dry% = 75
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	1.1	TF(fw/dw)	.	2496	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 22*; Row number = 110169; dry% = 76

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	1.8	TF(fw/dw)	.	1063	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb31*; Row number = 110170; dry% = 77
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	2.3	TF(fw/dw)	.	1341	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 39*; Row number = 110171; dry% = 75
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	3.1	TF(fw/dw)	.	815	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb35*; Row number = 110172; dry% = 78
Cs	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	3.7	TF(fw/dw)	.	1252	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 35*; Row number = 110173; dry% = 75
Cs	Chestnut	.	.	.	.	.	.	0.2	.	.	.	.	ST	PF	<1.4	TF(fw/dw)	.	.	Bq kg^{-1}	19	Plant = Pods and seeds of beans, peas, nuts; Ca cr= ; K cr = ; ; remark = Italy, southern; Row number = 142020; dry% = ;
Cs	Chestnut	.	.	.	.	.	.	0.2	.	.	.	.	ST	PF	0.68	TF(fw/dw)	.	.	Bq kg^{-1}	19	Plant = Pods and seeds of beans, peas, nuts; Ca cr= ; K cr = ; ; remark = Italy, Latium; Row number = 142022; dry% = ;
Cs	Chestnut	.	.	.	.	.	.	0.2	.	.	.	.	ST	PF	0.7	TF(fw/dw)	.	.	Bq kg^{-1}	19	Plant = Pods and seeds of beans, peas, nuts; Ca cr= ; K cr = ; ; remark = Italy, Latium; Row number = 142023; dry% = ;
Cs	Coconut		F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	1.8	TF(fw/dw)	.	.	.	17	Fruit meat: water content 80 (Mayall);
Cs	Fig	.		.	.	.	Loam, Clay	0.2	.	.	.	.	ST	PF	0.026	TF(fw/dw)	.	Bartulla	Bq kg^{-1}	18	Plant = Miscellaneous; Ca cr= ; K cr = ;; remark = Bq/kg fresh/kg dry soil; Row number = 144014; dry% = ;
Cs	Fig	.		.	.	.	Loam	0.2	.	.	.	.	ST	PF	0.05	TF(fw/dw)	.	Tellafar	Bq kg^{-1}	18	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = Bq/kg fresh/kg dry soil; Row number = 144015; dry% = ;
Cs	Gooseberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00069	TF(fw/dw)	.		Bq kg^{-1}	11	Washed fruit
Cs	Grapefruit dregs	.	F	Agricultural	C	01/05/86	Clay, Loam	0.2		5.3	01/05/95	.	ST	PF	0.006	TF(fw/dw)	.	339	Bq kg^{-1}	29	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.41 ; remark = cec = 9.34 fert CF ; Row number = 112028; dry% = 12.6; pH in CaCl2 = 7.2
Cs	Grapefruit juice	.	F	Agricultural	C	01/05/86	Clay, Loam	0.2		5.3	01/05/95	.	ST	PF	0.032	TF(fw/dw)	.	339	Bq kg^{-1}	29	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.41 ; remark = cec = 9.34 fert CF ; Row number = 112029; dry% = 6.5; pH in CaCl2 = 4.4
Cs	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PF	0.001	TF(fw/dw)	.	.	.	5	Peel; 6y study
Cs	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PL	0.035	TF(fw/dw)	.	.	.	5	Leaves; 6 y study
Cs	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PA	0.006	TF(fw/dw)	.	.	.	5	Shoots; 6 y study
Cs	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PO	0.02	TF(fw/dw)	.	.	.	5	Grape-stalks; 6 y study

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PO	0.001	TF(fw/dw)	.	.	.	5	Peel; 6 y study
Cs	Grape vine	.	P	Agricultural	E		Sandy loam	.	.	.	.	.	ST	PF	0.08	TF(fw/dw)	.	.	.	6	Berries: water content 77.2;
Cs	Guava	.	.	.	.	.	.	0.2	.	.	.	.	ST	PT	0.01	TF(fw/dw)	.	.	Bq kg^{-1}	24	Plant = Miscellaneous; Ca cr= ; K cr = ;; remark = Indonesia to Philipines; Row number = 142041; dry% =
Cs	Hazelnut fresh	.	.	.	.	.	.	0.2	.	.	.	.	ST	PT	9	TF(fw/dw)	.	.	Bq kg^{-1}	19	Plant = Pods and seeds of beans, peas, nuts; Ca cr= ; K cr = ; ; remark = Italy, Latium; Row number = 142024; dry% =
Cs	Kiwi fruit	.	P	Agricultural	C	01/05/86	Loam, Clay	0.2	.	3.8	01/12/96	.	ST	PF	0.026	TF(fw/dw)	.	322	Bq kg^{-1}	29	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1 ; remark = Kex +pH estimated; Row number = 112030; dry% = 20; pH in CaCl2 = 4.4
Cs	Lemon	.	F	Agricultural	F	01/12/59	Clay	0.2	.	.	.	.	ST	PF	0.0083	TF(fw/dw)	.		Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 138004; dry% = ; pH in CaCl2 = 7
Cs	Lime	.	F	Agricultural	F	01/12/62	Loam, Sand	0.2	6.4	5.7	01/01/96	.	ST	PT	< 0.19	TF(fw/dw)	.	1.46	Bq kg^{-1}	30	Plant = Miscellaneous; Ca cr= 31; K cr = 9.49; Ex-K = 0.12; Ex-Ca = 2.23 31 9.49; remark = Fer; Row number = 113016; dry% = 90.5
Cs	Mandarin fruit	.	F	Agricultural	C	01/05/86	Clay, Loam	0.2	.	5.3	01/05/95	.	ST	PT	0.035	TF(fw/dw)	.	339	Bq kg^{-1}	29	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.41 ; remark = cec = 9.34 fert CF ; Row number = 112031; dry% = 6.9; pH in CaCl2 = 4.5
Cs	Mandarin skin	.	F	Agricultural	C	01/05/86	Clay, Loam	0.2	.	5.3	01/05/95	.	ST	PT	0.009	TF(fw/dw)	.	339	Bq kg^{-1}	29	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.41 ; remark = cec = 9.34 fert CF ; Row number = 112032; dry% = 24.5; pH in CaCl2 = 4.4
Cs	Mango	.	.	.	.	.	.	0.2	.	.	.	.	ST	PF	0.02	TF(fw/dw)	.	.	Bq kg^{-1}	24	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = India to Thailand; Row number = 142042;
Cs	Mango	.	F	Agricultural	F	01/12/62	Loam, Sand	0.2	6.9	6	01/01/96	.	ST	PF	< 0.24	TF(fw/dw)	.	1.84	Bq kg^{-1}	30	Plant = Miscellaneous; Ca cr= 6.8; K cr = 0.238; Ex-K = 0.12; Ex-Ca = 4.48 6.8 0.238; remark = Fer; Row number = 113017; dry% = 71
Cs	Mango peeled fruit	.	F	Agricultural	F	01/12/59	Clay	0.2	.	.	.	.	ST	PF	0.012	TF(fw/dw)	.		Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°.

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
																					Average annual mean 24.7°; Row number = 138005; dry% = ; pH in CaCl2 = 7
Cs	Mayer lemon	.	F	Agricultural	F	01/12/62	Loam, Clay	0.2	6.5	8.5	01/01/96		ST	PT	< 0.33	TF(fw/dw)	.	1.54	Bq kg^{-1}	30	Plant = Miscellaneous; Ca cr= 13.9; K cr = 5.02; Ex-K = 0.38; Ex-Ca = 1.7 13.9 5.02; remark = Fer; Row number = 113018; dry% = 90.8
Cs	Melon	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00041	TF(fw/dw)	.			11	Washed fruit
Cs	Olive fruit	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PF	0.0011	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= 15; K cr = ; Ex-K = 0.72 15 ; remark = contaminat 9 month; Row number = 111090; dry% = 54; pH in CaCl2 = 7.5
Cs	Olive fruit	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PF	0.0022	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111091; dry% = 56; pH in CaCl2 = 7.5
Cs	Olive fruit	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PF	0.0029	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111092; dry% = 47; pH in CaCl2 = 7.5
Cs	Olive fruit	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/94	I	ST	PF	0.003	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= 13.5; K cr = ; Ex-K = 0.22 13.5 ; remark = contaminat 7 month; Row number = 111126; dry% = ;
Cs	Olive fruit	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PF	0.025	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111127; dry% = 60
Cs	Olive fruit	.	P	.	E	01/04/994	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PF	0.0244	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111128; dry% = 41
Cs	Olive new branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PS	0.0016	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 8; K cr = ; Ex-K = 0.72 8 ; remark = contaminat 9 month; Row number = 111074; dry% = 43
Cs	Olive new branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/05/95	I	ST	PS	0.0012	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 15 month; Row number = 111075; dry% = ; pH in CaCl2 = 7.5
Cs	Olive new branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PS	0.0012	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111076; dry% = 54; pH in CaCl2 = 7.5
Cs	Olive new	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PS	0.0024	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ;

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
	branch																				Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111077; dry% = 47; pH in CaCl2 = 7.5
Cs	Olive new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/94	I	ST	PS	0.0105	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 18.6; K cr = ; Ex-K = 0.22 18.6 ; remark = contaminat 7 month; Row number = 111111; dry% = ; pH in CaCl2 = 7.5
Cs	Olive new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/05/95	I	ST	PS	0.0178	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 13 month; Row number = 111112; dry% = ;
Cs	Olive new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PS	0.028	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111113; dry% = 49
Cs	Olive new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PS	0.0243	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111114; dry% = 41
Cs	Olive new leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PS	0.002	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 14; K cr = ; Ex-K = 0.72 14 ; remark = contaminat 9 month; Row number = 111078; dry% = 38; pH in CaCl2 = 7.5
Cs	Olive new leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/05/95	I	ST	PS	0.0016	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 15 month; Row number = 111079; dry% = ; pH in CaCl2 = 7.5
Cs	Olive new leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PS	0.002	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111080; dry% = 47; pH in CaCl2 = 7.5
Cs	Olive new leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PS	0.0019	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111081; dry% = 47; pH in CaCl2 = 7.5
Cs	Olive new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/94	I	ST	PS	0.0125	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 15.9; K cr = ; Ex-K = 0.22 15.9 ; remark = contaminat 7 month; Row number = 111115; dry% = ;
Cs	Olive new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/05/95	I	ST	PS	0.0223	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 13 month; Row number = 111116; dry% = ;
Cs	Olive new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PS	0.034	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111117; dry% = 41

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Olive new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PS	0.0251	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111118; dry% = 41
Cs	Olive oil	.	P	.	E	01/02/94	Clay, Loam	0.2		2.4	01/11/96	I	ST	PF	n.d.	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111089; dry% = 47; pH in CaCl2 = 7.5
Cs	Olive oil	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PF	n.d.	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111125; dry% = 41
Cs	Olive old branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PS	0.0008	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 9; K cr = ; Ex-K = 0.72 9 ; remark = contaminat 9 month; Row number = 111082; dry% = 52; pH in CaCl2 = 7.5
Cs	Olive old branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PS	0.0013	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111083; dry% = 56; pH in CaCl2 = 7.5
Cs	Olive old branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PS	0.0017	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111084; dry% = 47; pH in CaCl2 = 7.5
Cs	Olive old branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/94	I	ST	PS	0.0048	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 7.9; K cr = ; Ex-K = 0.22 7.9 ; remark = contaminat 7 month; Row number = 111119; dry% = ;
Cs	Olive old branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PS	0.018	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111120; dry% = 53
Cs	Olive old branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PS	0.0147	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111121; dry% = 41
Cs	Olive tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.0014	TF(fw/dw)	.	.	.	27	Fruit: water content 53;
Cs	Olive tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PF	0.01	TF(fw/dw)	.	.	.	27	Fruit: water content 59;
Cs	Olive tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.0014	TF(fw/dw)	.	.	.	27	Fruit: water content 53;
Cs	Olive tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PL	0.00089	TF(fw/dw)	.	.	.	27	New leaves: water content 53;
Cs	Olive tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PL	0.0011	TF(fw/dw)	.	.	.	27	Old leaves: water content 53;
Cs	Olive tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PS	0.0011	TF(fw/dw)	.	.	.	27	New branches: water content 53;
Cs	Olive tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PS	0.0008	TF(fw/dw)	.	.	.	27	Old branches: water content 53;
Cs	Olive tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PF	0.01	TF(fw/dw)	.	.	.	27	Fruit: water content 59;
Cs	Olive tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PL	0.01	TF(fw/dw)	.	.	.	27	New leaves: water content 59;
Cs	Olive tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PL	0.01	TF(fw/dw)	.	.	.	27	Old leaves: water content 59;

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Olive tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PS	0.01	TF(fw/dw)	.	.	.	27	New branches: water content 59;
Cs	Olive tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PS	0.006	TF(fw/dw)	.	.	.	27	Old branches: water content 59;
Cs	Olive wood	.	P	.	E	01/02/94	Clay loam	0.2		2.4	01/11/94	I	ST	PS	0.0007	TF(fw/dw)	.		Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 4; K cr = ; Ex-K = 0.72 4 ; remark = contaminat 9 month; Row number = 111088; dry% = 55; pH in CaCl2 = 7.5
Cs	Olives	.		.	C	.	Loamy	.	8	0.013	.	.	PF	TBIOL	300	d-1	.	.	.	2	Spadedat soil code = ALLO; Soil-to-leaf transfer factor
Cs	Olives old leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PS	0.0009	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 14; K cr = ; Ex-K = 0.72 14 ; remark = contaminat 9 month; Row number = 111085; dry% = 44; pH in CaCl2 = 7.5
Cs	Olives old leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PS	0.008	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111086; dry% = 50; pH in CaCl2 = 7.5
Cs	Olives old leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PS	0.0024	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111087; dry% = 47; pH in CaCl2 = 7.5
Cs	Olives old leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/94	I	ST	PS	0.0052	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 14; K cr = ; Ex-K = 0.22 14 ; remark = contaminat 7 month; Row number = 111122; dry% = ;
Cs	Olives old leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PS	0.014	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111123; dry% = 45
Cs	Olives old leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PS	0.0244	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111124; dry% = 41
Cs	Orange branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PS	0.0009	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 5; K cr = ; Ex-K = 0.72 5 ; remark = contaminat 9 month; Row number = 111094; dry% = 43; pH in CaCl2 = 7.5
Cs	Orange edible part	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PF	0.0006	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= 13; K cr = ; Ex-K = 0.72 13 ; remark = contaminat 9 month; Row number = 111107; dry% = 51; pH in CaCl2 = 7.5
Cs	Orange edible part	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PF	0.0014	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111108; dry% = 26; pH in CaCl2 = 7.5

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Orange edible part	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PF	0.0026	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111109; dry% = 34; pH in CaCl2 = 7.5
Cs	Orange edible part	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PF	0.1105	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111141; dry% = 32
Cs	Orange leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PL	0.0011	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 11; K cr = ; Ex-K = 0.72 11 ; remark = contaminat 9 month; Row number = 111095; dry% = 37; pH in CaCl2 = 7.5
Cs	Orange new branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/05/95	I	ST	PS	0.0015	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 15 month; Row number = 111096; dry% = ; pH in CaCl2 = 7.5
Cs	Orange new branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PS	0.0015	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111100; dry% = 46; pH in CaCl2 = 7.5
Cs	Orange new branch	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PS	0.0024	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111101; dry% = 34; pH in CaCl2 = 7.5
Cs	Orange new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/94	I	ST	PS	0.014	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 5.5; K cr = ; Ex-K = 0.22 5.5 ; remark = contaminat 7 month; Row number = 111134; dry% = ;
Cs	Orange new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/05/95	I	ST	PS	0.0192	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 13 month; Row number = 111135; dry% = ;
Cs	Orange new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PS	0.032	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111136; dry% = 38
Cs	Orange new branch	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PS	0.0543	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111137; dry% = 32
Cs	Orange new leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/05/95	I	ST	PL	0.0013	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 15 month; Row number = 111097; dry% = ; pH in CaCl2 = 7.5
Cs	Orange new leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PL	0.0014	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111098; dry% = 34; pH in CaCl2 = 7.5

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Orange new leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PL	0.0016	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111099; dry% = 34; pH in CaCl2 = 7.5
Cs	Orange new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/94	I	ST	PL	0.0125	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= 13.2; K cr = ; Ex-K = 0.22 13.2 ; remark = contaminat 7 month; Row number = 111130; dry% = ;
Cs	Orange new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/05/95	I	ST	PL	0.0153	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 13 month; Row number = 111131; dry% =;
Cs	Orange new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PL	0.047	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111132; dry% = 32
Cs	Orange new leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PL	0.0575	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111133; dry% = 32
Cs	Orange old leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PL	0.0011	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111102; dry% = 43; pH in CaCl2 = 7.5
Cs	Orange old leaves	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PL	0.0019	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111103; dry% = 34; pH in CaCl2 = 7.5
Cs	Orange old leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/10/95	I	ST	PL	0.02	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 18 month; Row number = 111138; dry% = 39
Cs	Orange old leaves	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PL	0.0609	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Stems and shoots; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111139; dry% = 32
Cs	Orange skin	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/94	I	ST	PF	0.0007	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= 8; K cr = ; Ex-K = 0.72 8 ; remark = contaminat 9 month; Row number = 111104; dry% = 57; pH in CaCl2 = 7.5
Cs	Orange skin	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/10/95	I	ST	PF	0.0013	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 20 month; Row number = 111105; dry% = 34; pH in CaCl2 = 7.5
Cs	Orange skin	.	P	.	E	01/02/94	Clay, Loam	0.2	.	2.4	01/11/96	I	ST	PF	0.0023	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.72 ; remark = contaminat 33 month; Row number = 111106; dry% = 34; pH in CaCl2 = 7.5

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Orange skin	.	P	.	E	01/04/94	Sand, Loam	0.2	5.6	1.1	01/11/96	I	ST	PF	0.0789	TF(fw/dw)	.	.	Bq kg^{-1}	28	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.22 ; remark = contaminat 31 month; Row number = 111140; dry% = 32
Cs	Orange tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.00088	TF(fw/dw)	.	.	.	27	Fruit: edible: water content 66;
Cs	Orange tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.00078	TF(fw/dw)	.	.	.	27	Fruit: skin: water content 66;
Cs	Orange tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PF	0.035	TF(fw/dw)	.	.	.	27	Fruit: edible: water content 68;
Cs	Orange tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PF	0.025	TF(fw/dw)	.	.	.	27	Fruit: skin: water content 68;
Cs	Orange tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	.	0.00088	TF(fw/dw)	.	.	.	27	Fruit: edible: water content 66;
Cs	Orange tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	.	0.00078	TF(fw/dw)	.	.	.	27	Fruit: skin: water content 66;
Cs	Orange tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PL	0.00054	TF(fw/dw)	.	.	.	27	New leaves: water content 66;
Cs	Orange tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PL	0.00065	TF(fw/dw)	.	.	.	27	Old leaves: water content 66;
Cs	Orange tree	.	P	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PS	0.00082	TF(fw/dw)	.	.	.	27	New branches: water content 66;
Cs	Orange tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PF	0.035	TF(fw/dw)	.	.	.	27	Fruit: edible: water content 68;
Cs	Orange tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PO	0.025	TF(fw/dw)	.	.	.	27	Fruit: skin: water content 68;
Cs	Orange tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PL	0.018	TF(fw/dw)	.	.	.	27	New leaves: water content 68;
Cs	Orange tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PL	0.019	TF(fw/dw)	.	.	.	27	Old leaves: water content 68;
Cs	Orange tree	.	P	Agricultural	E	.	Sandy loam	.	.	.	.	.	ST	PS	0.017	TF(fw/dw)	.	.	.	27	New branches: water content 68;
Cs	Pandanus	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	1.6	TF(fw/dw)	.	.	.	17	Fruit: water content 80 (Mayall);
Cs	Papaya	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	1.6	TF(fw/dw)	.	.	.	17	Fruit: water content 80 (Mayall);
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	1	TF(fw/dw)	.	5022	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 24*; Row number = 110344; dry% = 88
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	1.1	TF(fw/dw)	.	10296	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 24b*; Row number = 110345; dry% = 90
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	1.1	TF(fw/dw)	.	842	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = aic plot; Row number = 110346; dry% = 97
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	1.4	TF(fw/dw)	.	3304	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 26*; Row number = 110347; dry% = 90
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	1.4	TF(fw/dw)	.	3440	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 27b*; Row number = 110348; dry% = 92
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	1.5	TF(fw/dw)	.	6711	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 24d*; Row number = 110349; dry% = 93

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	1.6	TF(fw/dw)	.	1859	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb30*; Row number = 110350; dry% = 91
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	2.2	TF(fw/dw)	.	9185	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 24a*; Row number = 110351; dry% = 91
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	2.4	TF(fw/dw)	.	3440	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 27a; Row number = 110352; dry% = 92
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	4.8	TF(fw/dw)	.	3304	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 26a*; Row number = 110353; dry% = 91
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/12/82	.	ST	PT	4.9	TF(fw/dw)	.	2904	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 17d*; Row number = 110354; dry% = 88
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	5.4	TF(fw/dw)	.	1719	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 28*; Row number = 110355; dry% = 88
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/04/94	.	ST	PT	12	TF(fw/dw)	.	3252	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls1tree2; Row number = 110356; dry% = 87
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	15	TF(fw/dw)	.	3748	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 35a; Row number = 110357; dry% = 88
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/04/94	.	ST	PT	16	TF(fw/dw)	.	3252	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls1tree3; Row number = 110358; dry% = 89
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/04/94	.	ST	PT	16	TF(fw/dw)	.	3252	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls1tree8; Row number = 110359; dry% = 90
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	17	TF(fw/dw)	.	1323	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls6tree6; Row number = 110360; dry% = 88
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/04/94	.	ST	PT	21	TF(fw/dw)	.	3252	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls1tree4; Row number = 110361; dry% = 90
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	21	TF(fw/dw)	.	1323	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls6tree7; Row number = 110362; dry% = 89
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	22	TF(fw/dw)	.	1323	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls6tree8; Row number = 110363; dry% = 87

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	22	TF(fw/dw)	.	1323	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls6tree8; Row number = 110364; dry% = 87
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	31	TF(fw/dw)	.	3541	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 35*; Row number = 110365; dry% = 89
Cs	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/04/94	.	ST	PT	31	TF(fw/dw)	.	1323	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = mls6tree2; Row number = 110366; dry% = 89
Cs	Papaya peeled fruit	.	F	Agricultural	F	01/12/59	Clay	.	.	.	.	.	ST	PF	0.031	TF(fw/dw)	.		Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 138006; dry% = ; pH in CaCl2 = 7
Cs	Pawpaw	.	F	Agricultural	F	01/12/62	Loam, Sand	0.2	7.6	5.7	01/01/96		ST	PT	1.15	TF(fw/dw)	.	1.09	Bq kg^{-1}	30	Plant = Miscellaneous; Ca cr= 25.2; K cr = 2.3; Ex-K = 0.12; Ex-Ca = 5.93 25.2 2.3; remark = Fer; Row number = 113019; dry% = 91.5
Cs	Peach tree	.		Agricultural		.		.	.	.	.	.	ST	PF	0.0131	TF(fw/dw)	.		Bq kg^{-1}	4	Fruit: water content 89.1;
Cs	Peach tree	.	F	Agricultural	F	.	Loamy sand	.	.	.	.	.	ST	PF	0.009	TF(fw/dw)	.	.	.	26	Fruit
Cs	Peaches	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	PF	TBIOL	310	d^{-1}	.	.	.	2	Spadedat soil code = NLCO; Soil-to-leaf transfer factor
Cs	Peaches	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	ST	PI	0.0018	TF	.	.	.	2	Spadedat soil code = NLCO; Concentration ratio,, Mediterranean pasture
Cs	Pear tree	.	F	Agricultural	F	.	Loam	.			.	.	ST	PF	0.006	TF(fw/dw)	.	.	.	26	Fruit
Cs	Pears	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	PF	TBIOL	250	d^{-1}	.	.	.	2	Spadedat soil code = NLCO; Characteristic half-life
Cs	Pears	.	.	.	C	.	Loamy	.	8	0.013	.	.	PF	TBIOL	240	d^{-1}	.	.	.	2	Spadedat soil code = ALLO; Characteristic half-life
Cs	Platano peeled fruit	.	F	Agricultural	F	01/12/59	Clay	.	.	.	.	.	ST	PF	0.03	TF(fw/dw)	.	.	Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 138008; dry% = ; pH in CaCl2 = 7
Cs	Pome granate	.	.	.	.	.	Loam, Clay	0.2	.	.	.	.	ST	PT	0.003	TF(fw/dw)	.	Bartulla	Bq kg^{-1}	18	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = Bq/kg fresh/kg dry soil; Row

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
																					number = 144013;
Cs	Rambutan	.	F	Agricultural	F	01/12/62	Loam, Sand	0.2	6.4	4.8	01/01/96	.	ST	PT	0.687	TF(fw/dw)	.	1.02	Bq kg^{-1}	30	Plant = Miscellaneous; Ca cr= 8.24; K cr = 1.98; Ex-K = 0.1; Ex-Ca = 1.94 8.24 1.98; remark = Fer; Row number = 113020; dry% = 87.6
Cs	Raspberry	.	F	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.0057	TF(fw/dw)	.	.	.	10	Fruit: water content 84.2;
Cs	Raspberry	.	F	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.00333	TF(fw/dw)	.	.	.	10	Fruit: water content 84.2;
Cs	Red currant	.	F	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.0018	TF(fw/dw)	.	.	.	10	Fruit: water content 84.7;
Cs	Red currant	.	F	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.00098	TF(fw/dw)	.	.	.	10	Fruit: water content 84.7;
Cs	Rhubarb	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00053	TF(fw/dw)	.	.	.	11	Washed fruit
Cs	Ruby grapefruit	.	F	Agricultural	F	01/12/62	Loam, Clay	0.2	7.1	9.6	01/01/96	.	ST	PF	< 0.069	TF(fw/dw)	.	2.07	Bq kg^{-1}	30	Plant = Miscellaneous; Ca cr= 18.3; K cr = 1.77; Ex-K = 0.36; Ex-Ca = 3.26 18.3 1.77; remark = Fer; Row number = 113021; dry% = 89.9
Cs	Strawberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00094	TF(fw/dw)	.	.	.	11	Washed fruit;
Cs	Strawberry	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.0009	TF(fw/dw)	.	.	.	11	Washed fruit;
Cs	Strawberry	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	0.0042	TF(fw/dw)	.	.	.	11	Washed fruit;
Cs	Strawberry	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	0.0064	TF(fw/dw)	.	.	.	11	Washed fruit;
Cs	Strawberry	.	F	Agricultural	C	01/05/86	Clay, Loam	0.2		5.3	01/05/95	.	ST	PT	0.006	TF(fw/dw)	.	339	Bq kg^{-1}	29	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.41 ; remark = cec = 9.34 fert CF ; Row number = 112040; dry% =; pH in CaCl2 = 7.2
Cs	Strawberry wild	.	F	Agricultural	C	01/05/86	Clay, Loam	0.2		5.3	01/05/95	.	ST	PT	0.006	TF(fw/dw)	.	339	Bq kg^{-1}	29	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.41 ; remark = cec = 9.34 fert CF ; Row number = 112035; dry% =; pH in CaCl2 = 7.2
Cs	Sweet cherries	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	PF	TBIOL	240	d-1	.	.	.	2	Spadedat soil code = NLCO; Characteristic half-life
Cs	Sweet cherries	.	.	.	C	.	Loamy	.	8	0.013	.	.	PF	TBIOL	250	d-1	.	.	.	2	Spadedat soil code = ALLO; Characteristic half-life
Cs	Sweet cherries	.	.	.	C	.	Clayey	.	6.9	0.011	.	.	ST	PI	0.0018	TF	.	.	.	2	Spadedat soil code = NLCO; Soil-to-leaf transfer factor
Cs	Sweet cherries	.	.	.	C	.	Loamy	.	8	0.013	.	.	ST	PI	0.072	TF	.	.	.	2	Spadedat soil code = ALLO; Concentration ratio
Cs	walnut fresh	.	.		.	.	.	0.2	.	.	.	.	ST	PT	16	TF(fw/dw)	.		Bq kg^{-1}	19	Plant = Pods and seeds of beans, peas, nuts; Ca cr= ; K cr = ; ; remark = Italy, Latium; Row number = 142021; dry% =
Cs	Watermelon	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.00888	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6;
Cs	Watermelon	.	F	Agricultural	E	.	Semi-arid	.	.	.	.	.	ST	PF	0.0006	TF(fw/dw)	.	.	.	22	Fruit: water content 94;

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/96	W,I	ST	PF	0.0029	TF(fw/dw)	.	4112	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116099; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/95	W,I	ST	PF	0.006	TF(fw/dw)	.	4774	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116100; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/96	W,I	ST	PF	0.006	TF(fw/dw)	.	4919	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116101; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/95	I	ST	PF	0.008	TF(fw/dw)	.	5590	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116102; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/95	I	ST	PF	0.008	TF(fw/dw)	.	8588	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116103; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/95	W,I	ST	PF	0.01	TF(fw/dw)	.	4611	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116104; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/95	I	ST	PF	0.012	TF(fw/dw)	.	4436	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116105; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/95	I	ST	PF	0.012	TF(fw/dw)	.	6357	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116106; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/95	W,I	ST	PF	0.02	TF(fw/dw)	.	4408	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116107; dry% = ; pH in CaCl2 = 7.5
Cs	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/96	W,I	ST	PF	0.026	TF(fw/dw)	.	4610	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 116108; dry% = ; pH in CaCl2 = 7.5
I	Apple tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.0312	TF(fw/dw)	.	.	.	4	Fruit: water content 84.4;
I	Apple tree	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	0.00041	TF(fw/dw)	.	.	.	16	Fruit;

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
I	Apricot tree	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	0.006	TF(fw/dw)	.	.	.	16	Fruit;
I	Apricot tree	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	0.012	TF(fw/dw)	.	.	.	16	Peeled fruit;
I	Peach tree	.	.	Agricultural		.	.	.	.	.	.	.	ST	PF	0.0109	TF(fw/dw)	.	.	.	4	Fruit: water content 89.1;
I	Watermelon	.	.	Agricultural		.	.	.	.	.	.	.	ST	PF	0.0148	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6;
Mn	Apple tree	.	P	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	n.d.	TF(fw/dw)	.	.	.	8	Fruit;
Na	Apple tree	.	P	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.024	TF(fw/dw)	.	.	.	8	Fruit;
Np	Strawberry	Temperate	L	.	A	.	Sand	0.3		2.1	.	I,F	ST	.	0.015	TF(fw/dw)	.	1.19	Bq kg^{-1} dw	14	Notes = CEC7.8 FER; Dry matter (%) = 7.49; ; irrig. (mm) = 260; ; pH (KCl) = 6.8; ; Contaminated ; 0y 9m to harvest
Pb	Blueberry	Prairie, northern	L	.	A	.	Loam	0.2	4.9	0.8	.	W	ST	PL	0.09	TF(fw/dw)	sd = 3.7	.	.	15	Notes = CEC5.8 CO3-0.7 d-1.50; Dry matter (%) = 50; Crop part = LF; ; Dystric cambisol; ; ; Contaminated 87; 0y 4m to harvest; Plant type = BLUEBERR;
Pb	Blueberry	Prairie, northern	L	.	A	.	Clay	0.2	5.5	64	.	W	ST	PL	0.016	TF(fw/dw)	sd = 3.7	.	.	15	Notes = CEC116. CO3-1.1 d-0.20; Dry matter (%) = 50; Crop part = LF; ; Dystric cambisol; ; ; Contaminated 87; 0y 4m to harvest; Plant type = BLUEBERR;
Pu	Apple tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.00023	TF(fw/dw)	.	.	.	4	Fruit: water content 84.4;
Pu	Apple tree	.	F	Agricultural		.	.	.	.	.	.	.	ST	PF	0.021	TF(fw/dw)	.	.	.	7	Cored fruit; Cumbria
Pu	Apple tree	.	F	Agricultural		.	.	.	.	.	.	.	ST	PF	0.0036	TF(fw/dw)	.	.	.	7	Cored fruit; Cumbria
Pu	Apple tree	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	2.8E-05	TF(fw/dw)	.	.	.	11	Washed fruit;
Pu	Apple tree	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	8E-06	TF(fw/dw)	.	.	.	11	Washed fruit;
Pu	Apple tree	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	1.5E-05	TF(fw/dw)	.	.	.	11	Washed fruit;
Pu	Apple tree	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	1.3E-06	TF(fw/dw)	.	.	.	11	Washed fruit;
Pu	Apple tree	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	0.00092	TF(fw/dw)	.	.	.	23	Fruit;
Pu	Black currant	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00027	TF(fw/dw)	.	.	.	11	Washed fruit;
Pu	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	5.2E-06	TF(fw/dw)	.	748	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3; remark = house 39*; Row number = 121001; dry% = 79; pH in CaCl2 = 4
Pu	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	6.4E-06	TF(fw/dw)	.	770	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 16-17*; Row number = 121002; dry% = 79
Pu	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	3.3E-05	TF(fw/dw)	.	394	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb30*; Row number = 121003; dry% = 79
Pu	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	3.3E-05	TF(fw/dw)	.	57	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb31*; Row number = 121004; dry% = 79
Pu	Breadfruit	Pacific	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/78	.	ST	PT	3.8E-05	TF(fw/dw)	.	168	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
		Atolls																			K = 0.04; Ex-Ca = 6.3 ; remark = house 17*; Row number = 121005; dry% = 79
Pu	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	5.6E-05	TF(fw/dw)	.	208	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 35*; Row number = 121006; dry% = 79
Pu	Coconut	Pacific Atolls	F	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.0002	TF(fw/dw)	.	.	.	1	Fruit meat: water content 80 (Mayall); Eniwetok
Pu	Damson	.	F	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.0053	TF(fw/dw)	.	.	.	7	Stewed fruit; Cumbria
Pu	Damson	.	F	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00068	TF(fw/dw)	.	.	.	7	Stewed fruit; Cumbria
Pu	Damson	.	F	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.03	TF(fw/dw)	.	.	.	7	Stewed fruit; Cumbria
Pu	Gooseberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	6.4E-05	TF(fw/dw)	.	.	.	11	Washed fruit;
Pu	Melon	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.00083	TF(fw/dw)	.	.	.	11	Washed fruit;
Pu	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	6.3E-07	TF(fw/dw)	.	1970	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 27b*; Row number = 121038; dry% = 95
Pu	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	1.5E-06	TF(fw/dw)	.	618	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 26a*; Row number = 121039; dry% = 89
Pu	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	4.8E-05	TF(fw/dw)	.	2178	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 24d*; Row number = 121040; dry% = 93
Pu	Peach tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.00016	TF(fw/dw)	.	.	.	4	Fruit: water content 89.1;
Pu	Rhubarb	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	3.6E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Pu	Strawberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	6.8E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Pu	Strawberry	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	8.8E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Pu	Strawberry	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	0.00016	TF(fw/dw)	.	.	.	11	Washed fruit
Pu	Strawberry	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	7.3E-05	TF(fw/dw)	.	.	.	11	Washed fruit
Pu	Strawberry	Temperate	L		A	.	Sand	0.3		2.1	.	I,F	ST	.	5.3E-05	TF(fw/dw)	.	5.78	Bq kg^{-1} dw	14	Notes = CEC7.8 FER; Dry matter (%) = 7.49; ; irrig. (mm) = 260; ; pH (KCl) = 6.8; ; Contaminated ; 0y 9m to harvest
Pu	Strawberry	Temperate	L		A	.	Sand	0.3		2.1	.	I,F	ST	.	5.3E-05	TF(fw/dw)	.	5.78	Bq kg^{-1} dw	14	Notes = CEC7.8 FER; Dry matter (%) = 7.49; ; irrig. (mm) = 260; ; pH (KCl) = 6.8; ; Contaminated ; 0y 9m to harvest
Pu	Strawberry	Temperate	L		A	.	Sand	0.3		2.1	.	I,F	ST	.	5.3E-05	TF(fw/dw)	.	5.78	Bq kg^{-1} dw	14	Notes = CEC7.8 FER; Dry matter (%) = 7.49; ; irrig. (mm) = 260; ; pH (KCl) = 6.8; ; Contaminated ; 0y 9m to harvest
Pu	Strawberry	.		Agricultural		.	.	.	.	.	.	.	ST	PF	2.7E-05	TF(fw/dw)	.	.	.	21	Fruit: water content 89.9 (Table 7.1)
Pu	Strawberry	.	F	Agricultural	F	.	.	.	.	.	.	.	ST	PF	0.00074	TF(fw/dw)	.	.	.	23	Fruit: water content 89.9 (Table 7.1)
Pu	Watermelon	.		Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00011	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6;

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Ra	Glinus oppositifolius	.	.		.	.	.	.	.	.	01/01/83	.	ST	PT	3	TF(fw/dw)	.	3	Bq kg^{-1}	31	Plant = ; Ca cr= ; K cr = ; ; remark = ; Row number = 140060;
Ru	Apple tree	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00156	TF(fw/dw)	.	.	.	4	Fruit: water content 84.4;
Ru	Peach tree	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00109	TF(fw/dw)	.	.	.	4	Fruit: water content 89.1;
Ru	Watermelon	.	.	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.00074	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6;
Sr	Apple	Temperate	F	.	E	.	Sand	0.2	.	4	.	.	ST	PF	0.11	TF(fw/dw)	.	.	.	13	Dry matter (%) = 11; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Apple	Temperate	F	.	E	.	Sand	0.2	.	4	.	.	ST	PF	0.11	TF(fw/dw)	.	.	.	13	Dry matter (%) = 11; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Apple tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.0312	TF(fw/dw)	.	.	.	4	Fruit: water content 84.4;
Sr	Apple tree	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.012	TF(fw/dw)	.	.	.	11	Washed fruit
Sr	Apple tree	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.012	TF(fw/dw)	.	.	.	11	Washed fruit
Sr	Apple tree	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	0.025	TF(fw/dw)	.	.	.	11	Washed fruit
Sr	Apple tree	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	0.0012	TF(fw/dw)	.	.	.	11	Washed fruit
Sr	Apple tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.032	TF(fw/dw)	.	.	.	20	Fruit
Sr	Apple tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.011	TF(fw/dw)	.	.	.	20	Fruit
Sr	Black currant	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.11	TF(fw/dw)	.	.	.	11	Washed fruit
Sr	Black currant	Temperate	F	.	E	.	Sand	0.2	.	4	.	.	ST	.	0.15	TF(fw/dw)	.	.	.	13	Dry matter (%) = 18; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Black currant	Temperate	F	.	E	.	Sand	0.2	.	4	.	.	ST	.	0.23	TF(fw/dw)	.	.	.	13	Dry matter (%) = 19; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Breadfruit	Pacific Atolls	F	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.16	TF(fw/dw)	.	.	.	17	Fruit: water content 80 (Mayall); Eniwetok
Sr	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	0.018	TF(fw/dw)	.	3541	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb30*; Row number = 129052; dry% = 73
Sr	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	0.14	TF(fw/dw)	.	1563	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 17*; Row number = 129053; dry% = 75
Sr	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	0.024	TF(fw/dw)	.	6200	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 16-17*; Row number = 129054; dry% = 75
Sr	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	0.29	TF(fw/dw)	.	1459	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 35*; Row number = 129055; dry% = 75

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Sr	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	0.24	TF(fw/dw)	.	1096	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 22*; Row number = 129056; dry% = 75
Sr	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/08/77	.	ST	PT	0.13	TF(fw/dw)	.	6370	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 39*; Row number = 129057; dry% = 75
Sr	Breadfruit	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	.	.	ST	PT	0.034	TF(fw/dw)	.	620	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = treeb31*; Row number = 129058; dry% = 71
Sr	Coconut	Pacific Atolls	F	Agricultural		.	.	.	.	.	.	.	ST	PF	0.006	TF(fw/dw)	.		Bq kg^{-1}	17	Fruit: water content 80 (Mayall); Eniwetok
Sr	Currant	.	F	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.026	TF(fw/dw)	.	.	.	9	Fruit: water content 84.7;
Sr	Currant	.	F	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.017	TF(fw/dw)	.	.	.	10	Fruit: water content 84.7;
Sr	Gooseberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.042	TF(fw/dw)	.	.	.	11	Washed fruit;
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PF	0.014	TF(fw/dw)	.	.	.	5	Pulp; 6y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PF	0.034	TF(fw/dw)	.	.	.	5	Peel; 6y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PF	0.021	TF(fw/dw)	.	.	.	5	Juice; 6y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PL	0.97	TF(fw/dw)	.	.	.	5	Leaves; 6 y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PS	0.52	TF(fw/dw)	.	.	.	5	Shoots; 6 y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PO	0.07	TF(fw/dw)	.	.	.	5	Grape-stalks; 6 y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PO	0.014	TF(fw/dw)	.	.	.	5	Pulp; 6 y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PO	0.034	TF(fw/dw)	.	.	.	5	Peel; 6 y study
Sr	Grape vine	.	F	Agricultural	E	.	.	.	.	.	.	.	ST	PO	0.021	TF(fw/dw)	.	.	.	5	Juice; 6 y study
Sr	Grape vine	.	P	Agricultural	E	.	Loamy sand	.	.	.	.	.	ST	PF	0.066	TF(fw/dw)	.	.	.	6	Berries: water content 77.2;
Sr	Guava	.	F	Agricultural	F	01/12/59	Clay	0.2	.	.	.	.	ST	PF	0.028	TF(fw/dw)	.	.	Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 139013; dry% = ; pH in CaCl2 = 7
Sr	Lemon	.	F	Agricultural	F	01/12/59	Clay	0.2	.	.	.	.	ST	PF	0.19	TF(fw/dw)	.	.	Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°. Climate: Sub-

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
																					tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 139014; dry% = ; pH in CaCl2 = 7
Sr	Mango peeled fruit	.	F	Agricultural	F	01/12/59	Clay	0.2	.	.	.	.	ST	PF	0.011	TF(fw/dw)	.	.	Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 139015; dry% = ; pH in CaCl2 = 7
Sr	Melon	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.02	TF(fw/dw)	.	.		11	Washed fruit
Sr	Orange peeled fruit		F	Agricultural	F	01/12/59	Clay	0.2	.	.	.	.	ST	PF	0.17	TF(fw/dw)	.	.	Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 139017; dry% = ; pH in CaCl2 = 7
Sr	Pandanus	Pacific Atolls	F	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.1	TF(fw/dw)	.	.	.	17	Fruit: water content 80 (Mayall); Eniwetok
Sr	Papaya	Pacific Atolls	F	Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.08	TF(fw/dw)	.	.	.	17	Fruit: water content 80 (Mayall); Eniwetok
Sr	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	0.19	TF(fw/dw)	.	6267	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 24d*; Row number = 129059; dry% = 93
Sr	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/05/78	.	ST	PT	0.11	TF(fw/dw)	.	3867	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 26a*; Row number = 129060; dry% = 89
Sr	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	0.41	TF(fw/dw)	.	293	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 27a*; Row number = 129061; dry% = 92

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Sr	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	0.15	TF(fw/dw)	.	9185	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 27b*; Row number = 129062; dry% = 95
Sr	Papaya	Pacific Atolls	F	Agricultural	F	01/03/54	Calcareous	0.2	8.1	5.3	01/11/78	.	ST	PT	0.44	TF(fw/dw)	.	1193	Bq kg^{-1}	25	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 0.04; Ex-Ca = 6.3 ; remark = house 28*; Row number = 129063; dry% = 93
Sr	Papaya peeled fruit	.	F	Agricultural	F	01/12/59	Clay	.	.	.	.	.	ST	PF	0.027	TF(fw/dw)	.	.	Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 139018; dry% = ; pH in CaCl2 = 7
Sr	Peach tree	.		Agricultural		.	.	.	.	.	.	.	ST	PF	0.0218	TF(fw/dw)	.	.	.	4	Fruit: water content 89.1;
Sr	Peach tree	.	F	Agricultural	F	.	Loamy sand	.	.	.	.	.	ST	PF	0.07	TF(fw/dw)	.	.	.	26	Fruit
Sr	Peaches	Temperate	F		E	.	Sand	0.2		4	.	.	ST	PF	0.14	TF(fw/dw)	.	.	.	13	; Dry matter (%) = 6.8; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Pear	Temperate	F		E	.	Sand	0.2		4	.	.	ST	PF	0.12	TF(fw/dw)	.	.	.	13	; Dry matter (%) = 13; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Pear	Temperate	F		E	.	Sand	0.2		4	.	.	ST	PF	0.15	TF(fw/dw)	.	.	.	13	Dry matter (%) = 7.6; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Pear tree		F	Agricultural	F	.	Loamy clay	.	.	.	.	.	ST	PF	0.04	TF(fw/dw)	.	.	.	26	Fruit
Sr	Platano peeled fruit	.	F	Agricultural	F	01/12/59	Clay	.	.	.	.	.	ST	PF	0.053	TF(fw/dw)	.	.	Bq kg^{-1}	3	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = South-center part of Cuba. Latitude North 22°3'-22°21' Longitude west 80°21'-8/~-54. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°. Climate: Sub-tropical.. Temp.: max. annual mean 30.4°, min. annual mean 19.9°. Average annual mean 24.7°; Row number = 139020; dry% = ; pH in CaCl2 = 7
Sr	Raspberry	.	F	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.055	TF(fw/dw)	.	.	.	9	Fruit: water content 84.2;
Sr	Raspberry	.	F	Agricultural	E	.	Clay loam	.	.	.	.	.	ST	PF	0.081	TF(fw/dw)	.	.	.	9	Fruit: water content 84.2;

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Sr	Red currant	Tem-perate	F		E	.	Sand	0.2		4	.	.	ST	PF	0.09	TF(fw/dw)	.	.	.	13	Dry matter (%) = 13; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Rhubarb	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.02	TF(fw/dw)	.	.	.	11	Washed fruit;
Sr	Strawberry	.	F	Agricultural	O	.	.	.	.	.	.	.	ST	PF	0.022	TF(fw/dw)	.	.	.	11	Washed fruit;
Sr	Strawberry	.	L	Agricultural	E	.	Loam	.	.	.	.	.	ST	PF	0.1	TF(fw/dw)	.	.	.	11	Washed fruit;
Sr	Strawberry	.	L	Agricultural	E	.	Sand	.	.	.	.	.	ST	PF	0.21	TF(fw/dw)	.	.	.	11	Washed fruit;
Sr	Strawberry	.	L	Agricultural	E	.	Peat	.	.	.	.	.	ST	PF	0.012	TF(fw/dw)	.	.	.	11	Washed fruit;
Sr	Strawberry	Tem-perate	F		E	.	Sand	0.2		4	.	.	ST	.	0.32	TF(fw/dw)	.	.	.	13	; Dry matter (%) = 7.6; ; ; Calcaric fluvisol; pH (KCl) = 5.5; ; Contaminated ; 0y 0m to harvest
Sr	Watermelon	.		Agricultural	.	.	.	.	.	.	.	.	ST	PF	0.0148	TF(fw/dw)	.	.	.	4	Fruit: water content 92.6;
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/94	W,I	ST	PF	0.085	TF(fw/dw)	.	15844	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132083; dry% = ; pH in CaCl2 = 7.5
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/94	W,I	ST	PF	0.088	TF(fw/dw)	.	15707	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132084; dry% = ; pH in CaCl2 = 7.5
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/94	W,I	ST	PF	0.115	TF(fw/dw)	.	20842	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132085; dry% = ; pH in CaCl2 = 7.5
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/95	W,I	ST	PF	0.15	TF(fw/dw)	.	14227	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132086; dry% = ; pH in CaCl2 = 7.5
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/95	W,I	ST	PF	0.07	TF(fw/dw)	.	21799	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132087; dry% = ; pH in CaCl2 = 7.5
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/08/95	W,I	ST	PF	0.04	TF(fw/dw)	.	32059	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132088; dry% = ; pH in CaCl2 = 7.5
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/96	W,I	ST	PF	0.029	TF(fw/dw)	.	14754	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132089; dry% = ; pH in CaCl2 = 7.5

Element	Plant type	Location	Study type	Ecosystem	Radionuclide source	Contamination started	Soil type	Soil depth	Soil pH	Soil organic C	Crop harvested	Physical treatments	Parameter from	Parameter to	Parameter value	Parameter units	Stats parameter	Conc 1	Conc 1 units	Reference	Comments
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/96	W,I	ST	PF	0.048	TF(fw/dw)	.	19071	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132090; dry% = ; pH in CaCl2 = 7.5
Sr	Water melon flesh	.	F	.	E	01/01/94	Loam, Clay	0.2	.	1	01/09/96	W,I	ST	PF	0.11	TF(fw/dw)	.	21331	Bq kg^{-1}	32	Plant = Miscellaneous; Ca cr= ; K cr = ; Ex-K = 1.6; Ex-Ca = 15 ; remark = ; Row number = 132091; dry% = ; pH in CaCl2 = 7.5
Th	Blueberry	Prairie, northern	L	.	A	.	Sand	0.2	4.9	0.8	.	W	ST	PL	0.07	TF(fw/dw)	sd = 3.3	8	Bq kg^{-1} dw soil	15	Notes = CEC5.8 CO3-0.7 d-1.50; Dry matter (%) = 50; Crop part = LF; ; Dystric cambisol; ; ; Contaminated 87; 0y 4m to harvest; Plant type = BLUEBERR;
Th	Blueberry	Prairie, northern	L	.	A	.	Loam	0.2	5.5	64	.	W	ST	PL	0.0024	TF(fw/dw)	sd = 3.3	8	Bq kg^{-1} dw soil	15	Notes = CEC116. CO3-1.1 d-0.20; Dry matter (%) = 50; Crop part = LF; ; Dystric cambisol; ; ; Contaminated 87; 0y 4m to harvest; Plant type = BLUEBERR;
U	Blueberry	Prairie, northern	L	.	A	.	Sand	0.2	4.9	0.8	.	W	ST	PL	0.11	TF(fw/dw)	sd = 1.8	.	.	15	Notes = CEC5.8 CO3-0.7 d-1.50; Dry matter (%) = 50; Crop part = LF; ; Dystric cambisol; ; ; Contaminated 87; 0y 4m to harvest; Plant type = BLUEBER;
U	Blueberry	Prairie, northern	L	.	A	.	Sand	0.2	5.5	64	.	W	ST	PL	0.0028	TF(fw/dw)	sd = 1.8	.	.	15	Notes = CEC116. CO3-1.1 d-0.20; Dry matter (%) = 50; Crop part = LF; ; Dystric cambisol; ; ; Contaminated 87; 0y 4m to harvest; Plant type = BLUEBER;
U	Fruits	.	.	.	.	.	.	0.2	.	.	01/01/77		ST	PF	0.01075	TF(fw/dw)	.	.	Bq kg^{-1}	12	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = ; Row number = 143044; dry% = ;
U	Water melon	.	.	.	.	.	.	0.2	.	.	.	.	ST	PT	0.05	TF(fw/dw)	.	.	Bq kg^{-1}	12	Plant = Miscellaneous; Ca cr= ; K cr = ; ; remark = ; Row number = 143050; dry% = ;
Zn	Apple tree	.	P	Agricultural	E		Loam						ST	PF	n.d.	TF(fw/dw)	.	.	.	8	Fruit

Codes:

Study type: F = Field, L = Lysimeter and P = Pot

Radionuclide source: A = Accidental event, C = Chernobyl fallout, E = Experimental contamination, F = Weapons testing and O = Others

Parameter to and from: ST = Soil Total, PF = Plant Fruit, PA = Plant shoots, PI = Plant Internal, PL = Plant Leaf, PO = Plant Other, PS = Plant Stem and PT = Plant Total.

Parameter units: TF (dw/dw) = Transfer Factor (Bq kg-1 dry weight plant/Bq kg-1 dry weight soil), TF (fresh weight/dry weight) and d-1 = rate constant.

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Meetings

BIOMASS Plenary and Working Group Meetings, Vienna, Austria: 20–24 October 1997

BIOMASS Fruits WG Spring 1998 Meeting, London, United Kingdom: 15–18 April 1998

BIOMASS Research Co-ordination, Plenary and Working Group Meetings,
Vienna, Austria: 5–9 October 1998

BIOMASS Fruits WG Spring 1999 Meeting, Athens, Greece: 10–13 May 1999

BIOMASS Research Co-ordination, Plenary and Working Group Meetings,
Vienna, Austria: 6–10 October 1999

BIOMASS Fruits WG Spring 2000, Madrid, Spain: 26–28 April 2000

BIOMASS Research Co-ordination, Plenary and Working Group Meetings,
Vienna, Austria: 7–9 November 2000