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Comparison of the Foodchain Transport Models of WASH-1400 and MARC Using the Accident Consequence Model UFOMOD

C. Steinhauer
Institut für Neutronenphysik und Reaktortechnik
Projekt Nukleare Sicherheit

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE

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C. Steinhauer

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Vergleich der Nahrungskettentransportmodelle von WASH-1400 und MARC mit dem Unfallfolgenmodell UFOMOD

Kurzfassung

Im Rahmen des Vertrages mit der Europäischen Gemeinschaft "Methods for Assessing the Radiological Impact of Accidents" (CEC-MARIA) wurden mit dem Rechenprogramm UFOMOD vergleichende Unfallfolgenrechnungen durchgeführt, bei denen das bisher implementierte Nahrungskettentransportmodell der WASH-1400-Studie durch das dynamische Transportmodell des Unfallfolgenmodells MARC ersetzt wurde. Die Rechnungen erfolgten anhand der Freisetzungskategorie FK2 der "Deutschen Risikostudie Kernkraftwerke" mit meteorologischen Daten aus vier verschiedene Regionen der Bundesrepublik Deutschland. Die Untersuchung jahreszeitlicher Variationen erfolgte mit den MARC-Daten für vier repräsentative Freisetzungszeitpunkte, dabei lag eine auf englische Verhältnisse zugeschnittene Agrarpraxis zugrunde.

Dieser Bericht stellt die Unterschiede dar, die sich bei den potentiellen Ingestionsdosen, den von Verzehrverboten betroffenen Flächen und den Spätschäden durch die Verwendung beider Modelle und den Einfluß saisonaler Effekte ergeben.

Abstract

Within the frame of the contract with the European Community "Methods for Assessing the Radiological Impact of Accidents" (CEC-MARIA) comparative accident consequence assessments were performed with the computer code UFOMOD, replacing the currently implemented foodchain transport model of the WASH-1400 study by the dynamic transport model of the MARC-methodology. The calculations were based on the release category FK2 of the German Risk Study with meteorological data representing four different regions of the Federal Republic of Germany. The study of seasonal variations was carried out with the MARC- data for four representative times of deposition with an agricultural practice adopted in the UK.

In this report the differences are presented which are observed in the potential doses due to ingestion, the areas affected by food-bans and the late health effects when using both models and taking the influence of seasonal effects into account.

Contents

1. Introduction

Risk studies performed in the past have shown that the radioactive contamination of agricultural land can lead to a significant exposure of the population due to ingestion of food and to the necessity of introducing countermeasures to reduce this exposure /1-4/. It is therefore necessary, that the transport of activity to man via the foodchain is adequately modelled in accident consequence assessments.

In the accident consequence model UFOMOD /5/ of the GERMAN RISK STUDY /6/ the foodchain model currently in use is that of the US Reactor Safety Study WASH-1400 /7/. This, being a relatively easy-to-use equilibrium model of the multiplicative type, has the disadvantage that the results obtained represent some form of averaging over the year when the deposition occurs; this can have a large influence on the countermeasures required and on the health effects in the population /8/.

Several more sophisticated models have been developed after WASH-1400 to describe the transfer of radionuclides through the terrestrial foodchains, which include the possibility of depositions at varying times of the year. Among others the NRPB-model FOODMARC (UK) /9,10/ and the GSF-model ECOSYS (FRG) /11/ represent the type of dynamic models, which describe the processes of transfer through the terrestrial environments to food by series of interconnected compartments. The model ECOSYS was designed to represent the agricultural practice in the Federal Republic of Germany and is intended to replace the WASH-1400-foodchain transport model in a future improved version of UFOMOD. A limited comparison of MARC and ECOSYS has been performed by NRPB and GSF in 1982 and 1984 /12/. In addition it has been planned to extend this comparison by means of an accident consequence assessment using the computer-code UFOMOD as a part of the CEC-contract on "Methods for Assessing the Radiological Impact of Accidents" (CEC-MARIA).

Since the ECOSYS-model has currently been under development and the data were not available at KfK so far, this comparison will be subject to a future study.

To study the usefulness and the influence of a dynamical model in an accident consequence assessment, a comparison was performed using the data of the foodchain transport models of WASH-1400 and MARC in UFOMOD (Version B4). The results of this comparison are discussed in Chap.5. In Chap.2 and 3 a short review of both transport models and the foodchain-consequence-part of UFOMOD is given, and in Chap.4 the data used in the comparison are described.

2. Basic features of the foodchain transport models

2.1 WASH-1400

The WASH-1400 foodchain model was developed as a part of the U.S. Reactor Safety Study for assessing the consequences of LWR accidents and is thus based on American agricultural practice and consumptionary habits. It is widely used and represents the type of models called "multiplicative", which use a number of factors - normally derived from observations under equilibrium conditions - to relate levels of radioactivity in the various components of the foodchain to man.

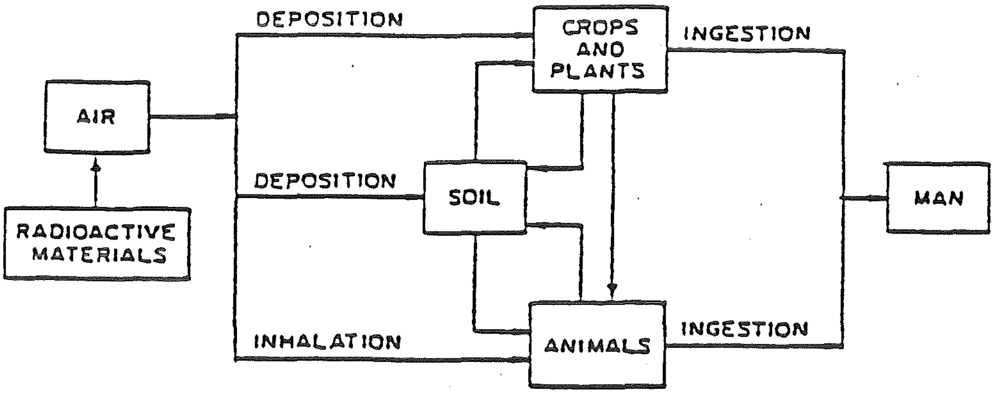
Two processes leading to a contamination of vegetation are considered, namely direct deposition with subsequent weathering, and root uptake, and only isotopes of iodine, strontium and caesium are taken into account. The transfer of these nuclides to man via the milk-pathway is modelled explicitely, and also the transfer of strontium via green vegetables by direct deposition. For iodine it is assumed that milk is the only possible source of exposure by ingestion. The transfer of isotopes of strontium and caesium to man via all other agricultural products is calculated by applying scaling factors to the milk values. These factors are derived from observations of the behaviour of nuclear weapons fallout and describe the relative contributions of milk and other products to the total intake of activity by man. A summary of the model and the parameters is given in Appendix A.

Due to the modelling described above the results obtained apply strictly only to situations where the deposition is relatively uniform throughout the year, and one has to proceed with caution in using them to assess the impact of accidental releases, which can occur at different times of the year at distinct growth periods of the vegetation. Also the time dependence in the model is very limited, allowing only a crude estimate of the length of time during which countermeasures may eventually be required.

2.2 FOODMARC

The foodchain model FOODMARC was developed by NRPB as a part of an overall methodology for evaluating the radiological consequences of accidental releases /13/. Being originally designed for continuous routine releases, the model was further developed for application to accidental releases occuring at any time of the year /14/.

In the model, the physical processes of the transfer of radionuclides through terrestrial foodchains are described by first order kinetics between compartments representing the different parts of the foodchain. The principles of this approach are illustrated in the figure below:

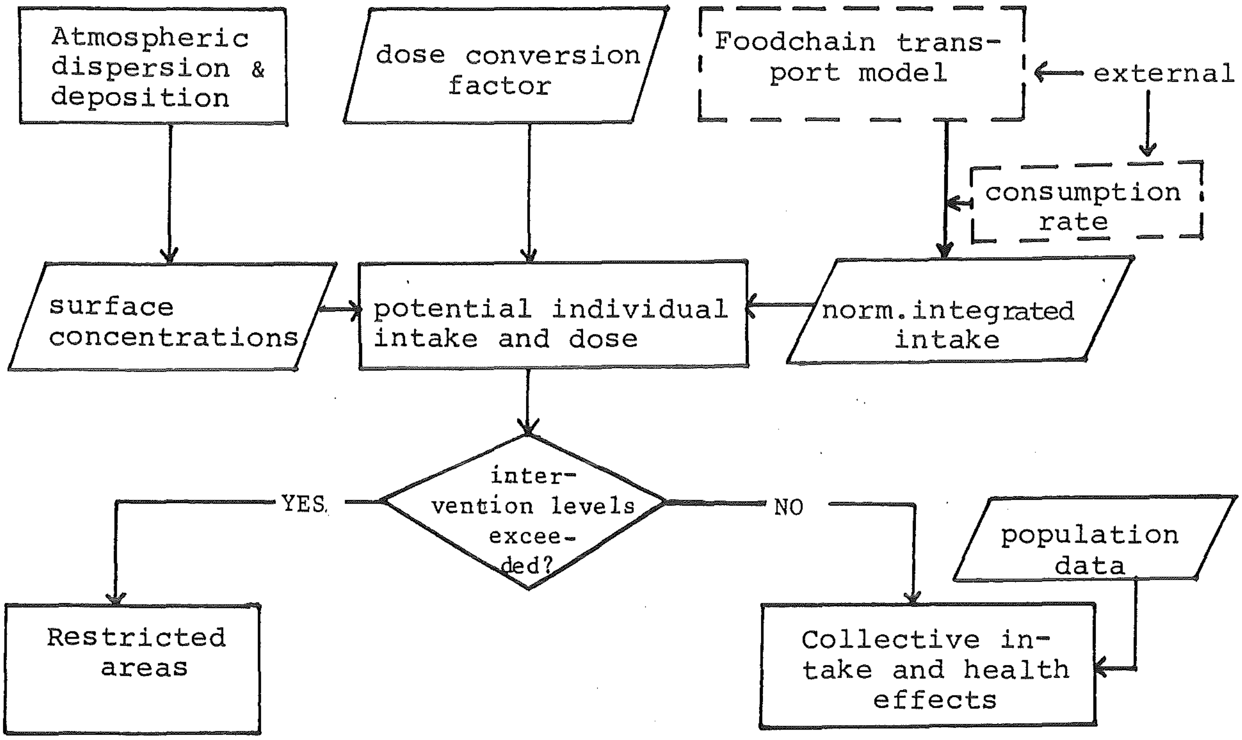


The major processes which affect the transfer of radionuclides within terrestrial foodchains are the following: When material is deposited on the ground a fraction is intercepted by and initially retained on the foliage of plants. This surface deposit can be removed from the foliage by a variety of processes which are generally referred to as weathering losses and which lead to material being transferred to the soil. Some of the material on the plant's surface may be absorbed in the plant's tissues and translocated from one part of a plant to another, for example, from the foliage to the fruit or grain. The radioactive material in the soil can be transferred to the plant by resuspension processes and through absorption via the root system, part may become fixed to some component of the soil material and part may migrate downwards out of the plant's rooting zone. Radioactive material is taken in y grazing animals due to ingestion of forage and soil as well as by inhalation and subsequently transferred to animal tissues and milk. Finally, man acquires radioactive materials by the ingestion of various types of agricultural produce. These transfer processes and how they are modelled are described elsewhere. /9,10,15/.

The main foods considered in the model are green vegetables, grain products, milk and meat from cattle, and meat from sheep. Offals from cattle and sheep can also be included and a limited model exists for root crops. A large variety of nuclides can be included although the degree of detail in modelling is greatest for isotopes of caesium, strontium and iodine.

3. Foodchain - consequence - model of UFOMOD

To evaluate the health effects resulting from ingestion of contaminated food, the actual intake of activity by people after an accidental release must be determined. How this is done in UFOMOD is illustrated by the following flowchart diagramm:



In the atmospheric dispersion and deposition submodel the surface concentrations are calculated. These are input to the late health effects submodel, of which the foodchain pathway forms a part. In a first step the potential individual intake is calculated by multiplication of the surface concentration and the normalized integrated intake, that is, the activity incorporated by an individual consuming a particular food over a certain time following unit deposition. In estimating the individual intake, the assumption is made that all food consumed is produced locally. From the intake the dose can be obtained with dose factors to convert the ingested activity into dose[1].

In the current version of UFOMOD, the values for the normalized integrated intake are taken from the WASH-1400 study. There they are given for a member of the critical group as "Concentration Factors" for milk and other products integrated to infinity for a contamination by direct deposition and root uptake. For the comparative calculations, these Concentration Factors were replaced by values derived from MARC (Chap. 4.2)

The collective intake is also estimated under the assumption of local food production by combining the spatial distribution of the individual intake with the spatial distribution of the population. This method has the advantage to provide information about the spatial distribution of the intake and with this on individual risk, but these values and the collective risk give only a rough estimate, because no agricultural production or food distribution patterns are taken into account. The subsequent evaluation of the health effects is described elsewhere /17/.

To keep the exposure of the population from ingestion within acceptable limits, intervention levels have been defined to decide on interdictions to consume the contaminated food. In UFOMOD, these intervention levels refer to the doses accumulated in the total body, red bone marrow and the thyroid. The intervention levels currently implemented are:

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1) The potential individual doses are calculated with dose factors taken from FOODMARC for the doses accumulated over 50 years by an adult individual after a single intake of activity /16/.

Organ	Milk	Other Products
total body	$3.3\cdot10^{-2}$ Sv	$2.0\cdot10^{-2}$ Sv
red bone marrow	$3.3\cdot10^{-2}$ Sv	$2.0\cdot10^{-2}$ Sv
thyroid	0.1 Sv	-

The intervention levels are compared separately with the doses resulting from ingestion of milk and other products contaminated by direct deposition. If any one of the levels is exceeded, they are compared in addition with the doses resulting from intake of the corresponding food-category contaminated by root uptake. This is modelled within 540 km distance to the site, beyond this limit no restrictions are imposed.

The modelling approach of UFOMOD described above is based on the American Reactor Safety Study. Because the WASH-1400 Concentration Factors represent the total amount of activity transferred by direct deposition and root uptake, the countermeasures model is very crude and detailed information about the length of time the food-bans may need to be applied cannot be derived. This is especially a disadvantage for restrictions of food contaminated by root uptake, which is a long term process and might affect agricultural practice many years after the accident.

A more sophisticated model for the estimation of restricted areas and collective intake is implemented in the accident consequence code system MARC /18/. Although in MARC the countermeasures model is also based on the assumption of local production of the food consumed, the inherent time dependence of the foodchain transport model allows a detailed analysis of the duration of the required countermeasures. The collective intake is estimated using the actual spatial distribution of agricultural production and assuming that all contaminated food outside the restricted area is consumed by the whole population. This method gives a reasonable overall estimate of the collective intake, but the information about individual intake ranges is lost, unless food-distribution patterns are included.

4. Data used in the comparison

4.1 General data

The comparative calculations were performed on the basis of release category FK2 of the GERMAN RISK STUDY /6/. This release category represents a core meltdown in a PWR with a large leak in containment (Ø = 30 cm) and was chosen as the worst case category for the development of future models and input parameters. The inventory and release characteristics are collected in Tab.1 and Tab.2. The probabilistic assessment was done with 115 weather sequences each for four meteriological regions representing the Upper Rhine valley, North German low land, South German high land and valley conditions other than the Rhine valley.

In Tab. 3 the foodchain-related data which provide input to UFOMOD are given. The nuclides considered were those most relevant for the ingestion pathway in the case of a PWR release, namely isotopes of strontium, caesium, and iodine.

To study the influence of seasonality, depositions in February, April, June and August were assumed for the data of MARC, because risk-assessments with MARC have shown, that these months are adequate representations for accidents occuring in winter, spring, early and late summer /8/.

The foodproducts were chosen according to German consumption habits /19/, where milk, beef, grain and green vegetables are among the most relevant foods. Pork and potatoes, which are also an important part of the average German diet, could not be included in the comparison, the former, because it is not modelled in MARC, and the latter because the model for root crops was under development.

The agricultural practice adopted for each group of foods is based on practices common in the United Kingdom: Green vegetables are assumed to be produced and consumed continuously throughout the year, whereas grain is assumed to be planted in spring, harvested at the end of August and eaten uniformly throughout the following year. Beef and dairy cattle are assumed to graze pasture from mid-April to the end of October. For the rest of the year they are fed on locally grown hay or silage which was harvested between May and mid-September.

4.2. Normalized integrated intake

The results of the MARC foodchain transport model are given as differential and integrated activity concentrations for the different food products.[1] For the comparison these had to be reduced to a form similar to the WASH-1400 Concentration Factors for milk and other products for direct deposition and root uptake required by the current countermeasures model of UFOMOD. Since direct deposition can affect only the first vegetation cycle after the accident and root uptake is a long term process, the Concentration Factors were approximated by intakes I in the first year and the subsequent year calculated in the following way:

$$I_{milk}\ (\Delta t) = \dot{V}_m \cdot C_m^{Int}\ (\Delta t)$$

$$I_{oth.prod.}\ (\Delta t) = \sum_p \dot{V}_p \cdot C_p^{Int}\ (\Delta t)$$

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[1] The transfer parameters used to produce the MARC results are summarized in Appendix B. After the comparison was completed the cow model for iodine has been revised, but these changes have no significant effects on the results discussed in this report.

where m stands for milk, p for beef, grain and green vegetables, $\dot{V}$ are consumption rates explained later, and C^{Int} are the activitiy concentrations from MARC integrated for the first year and the subsequent year, respectively, taking account of the agricultural practice for each product (Appendix B).

These intake values approximate the time dependence of the Concentration Factors suggested implicitely by the distinction of direct deposition and root uptake, but they do not necessarily correspond to the above transfer processes because of the agricultural practice considered in the model. For instance, for long-lived nuclides the first year's activity concentration in grain and the intake is only due to root uptake for a deposition in February, while for a deposition in summer the effect of direct deposition onto the grain may partly show up in the second year's intake due to the consumption of the rest of the first year's harvest.

The integrated intakes derived from MARC are shown in Fig.1 and 2 together with the WASH-1400 values (see also Tab.4) for assumed depositions at 1st of February, April, June and August. All values for milk were calculated here with the WASH-1400 assumptions of a milk consumption rate of 0.7 $l \cdot d^{-1}$ and an average delay between production and consumption of 3 days and are therefore directly comparable. The MARC values for "other products" were obtained using the consumption rates for the adult member of the critical group in the UK (/4/ and Tab.3). In WASH-1400 they are derived without using consumption rates but apply also to a critical individual.

For the intake in the first year after the accident (Fig.1) the WASH-1400 values are slightly lower than the August data computed from MARC for almost all nuclides in milk. Although the values for "other products" are derived in a very different way by the two models, they still show the same overall behaviour as the milk values. The deviations of the WASH-1400 data from the August data of MARC are more marked for "other products" than for milk, but this might be entirely due to the different consumption rates.

A different pattern is observed in the subsequent years (Fig.2), where for both products and all times of deposition the MARC data for caesium are significantly higher, for the long-lived strontium isotope Sr-90 about equal and for the short-lived Sr-89 much lower than the WASH-1400 data. This can partly be explained by the different way the intake values were obtained mentioned earlier, but additionally indicates differences in the time-dependence of root-uptake between the two models.

The MARC data are shown for all the different food products in Fig. 3 and 4 (Sr-90, Cs-134 and Cs-137) and in Tab.5 (all nuclides), the milk values now also being calculated with the UK-consumption rate for an adult member of the critical group1).

In the first year (Fig.3), grain clearly dominates the intake of activity if the deposition is in August, falling down by several orders of magnitude to a minimum for a deposition in winter. This is due to the fact that direct deposition and translocation can only lead to a substantial contamination of the grain if the deposition occurs in the growth period of the plant, and that root uptake in the first year is unimportant compared to these two processes. The variation with season is not so pronounced for the long lived isotopes considered here in milk and beef, because the effect of seasonality is somewhat diminished by feeding cattle in

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1) No delay times between production and consumption were taken into account. The introduction of such delays would reduce the intake values for very short-lived nuclides, such as I-131 and I-133, but they were generally omitted in the calculations.

winter with hay or silage harvested during summer when the contamination level was still high. For nuclides with short half lives the differences are bigger because of the radioactive decay during the storage time of the fodder, as it can be seen for iodine in Tab. 5. For caesium, the values for milk and meat are almost equal, whereas strontium in meat is about one order of magnitude lower than in milk, reflecting the fact that strontium is a bone seeking element. Green vegetables, which are assumed to be produced and consumed throughout the year, contribute significantly to the intake only for a deposition early in the year, when they become an important source of iodine, because the iodine levels in all other products are very low due to radioactive decay. Ruthenium, which is also included in Tab. 5, gives a moderate or neglegible contribution to the intake, dependent on the product considered.

The intake in the subsequent years (Fig.4) shows still some variation with the time of deposition, reflecting that the effects of direct deposition can influence also the intake in the second year after a release, due to the agricultural practice. For Sr-90, the effect virtually vanishes and the total intakes from the subsequent years are greater than from the first year for most foods, demonstrating the importance of root uptake for this isotope. From Tab. 6, however, it can be seen that for the two long-lived isotopes considered here the major part of the intake from the subsequent years comes from the first 50 years after the assumed deposition.

5. Results

The integrated intake values discussed in the last section were made input to UFOMOD to study the influences on the accident consequences following an FK2 release. The potential individual doses are discussed in Chap. 5.1 particularly with respect to the various food products available from MARC. The areas affected by countermeasures and the late health effects are discussed in Chap. 5.2 and 5.3, respectively.

5.1 Potential individual dose

In Fig. 5 the expectation values of the potential individual dose due to ingestion for the organs red bone marrow and thyroid are shown at 100 km distance from the site under the centerline of the plume. Since the organ doses are proportional to the intakes, the same overall behaviour is observed as in Fig. 1 and 2. The doses computed with the WASH-1400 intakes are within a factor of 2 of the same value as the summer doses with the MARC-intakes for food consumption in the first year, but lower in the following years.

In Tab. 8-10[1] both the contributions of foodstuffs and nuclides to all the organ doses are given for depositions at 1st February and 1st August. Since in the release considered the fraction of actinides is very low, isotopes of caesium and strontium are most important for the ingestion dose of all organs except the

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[1] In Tables 8-10 the organs are identified by GK = whole body (Ganzkörper), KM = red bone marrow (Knochenmark), LG = lung (Lunge), KD = testes (Keimdrüsen), KN = bone surface (Knochenoberfläche) and SD = thyroid (Schilddrüse)

thyroid, for which isotopes of iodine are known to be of greatest relevance. For the release considered here, the thyroid dose in the first year results almost exclusively from the exposure to the short-lived isotope I-131. In the subsequent years, when this isotope is decayed, caesium becomes significant, but leads to a dose level about two orders of magnitude lower than in the first year.

In Tab. 7 the contributions of foodstuffs to the red bone marrow- and thyroid-doses are summarized. Besides for the thyroid dose in the first year the contributions from milk and other products calculated with the WASH-1400 intake data represent some average of the results obtained with the MARC data for February and August, but the MARC data show, that the contributions of the individual food products are quite different for the two months: in February, milk, beef and green vegetables are the significant sources of exposure, whereas in August grain is clearly dominant. For the thyroid dose in the first year, WASH-1400 overestimates the milk pathway and consequently underestimates the influence of the other products, especially for a release in February. These results reflect the different agricultural practices assumed in both models: In WASH-1400 cattle are assumed to graze outdoors permanently whereas in MARC they are kept indoors in winter and start to feed on contaminated pasture later in the year, when - if the deposition occurs in winter - field losses and radioactive decay have decreased the activity levels in pasture grass. On the other hand, green vegetables are assumed in MARC to be produced also in winter and become an important source of activity especially for the short-lived isotopes of iodine.

5.2 Restricted areas

The complementary cumulative frequency distributions (CCFD) of the areas affected by restrictions of milk and other products are shown in Fig. 6 and 7 (intake in first year) and Fig. 8 and 9 (intake in subsequent years), respectively. These distributions were calculated by UFOMOD using the WASH-1400 data and the MARC - intake data for depositions in February and August. Tab. 11 - 14 give characteristic values of these distributions together with values obtained for depositions in April and June.

In the first year, the results obtained with the WASH-1400 data agree quite well with those obtained with the MARC-data for a deposition in August over the whole range of observed consequences. For depositions in the other months, smaller areas are estimated. In the subsequent years, larger areas are predicted in comparison to the WASH-1400 data for all times of deposition when using the MARC - data. These findings are expected from the variations of the potential individual doses discussed earlier. However, the slopes of the curves do not reflect the larger deviations between both models observed in the potential doses. This is an effect of the cutoff of the countermeasures at 540 km in UFOMOD. For the relatively large release considered here, the dose levels may still exceed the intervention levels beyond this distance, so that the implementation of different foodchain models would lead to a significant effect only beyond this limiting radius where the doses become sufficiently low.

It is not yet possible in UFOMOD to examine the individual contributions of food products to the restrictions imposed collectively on "other products". However, the contributions of the food-products derived from the MARC data to the potential individual doses discussed in the last paragraph imply, that the restrictions will mainly affect the standing grain crop for a deposition in August, and beef and green vegetables for a release in February.

The amount of predicted restrictions can be large for both milk and other products, even if the release is assumed to take place in winter. However, due to the very crude countermeasures model currently implemented in UFOMOD, no detailed in formation can be derived about the actual length of time the food bans would need to be maintained. A full utilization of the time-dependence of the intake and the resulting effects on the countermeasures obtainable from a dynamic foodchain model requires intervention-levels based on, for instance, yearly intake rates rather than on total intake.

5.3 Late health effects

Fig. 10 depicts the CCFD of the number of late fatalities estimated by UFOMOD for an FK2 release, and Tab. 15 gives the corresponding characteristic values for releases in different months. The countermeasures imposed after such a relatively large release reduce the influence of season on the late health effects as it was also observed in another study /8/, so that the health consequences calculated with both the WASH-1400 and the MARC foodchain transport model show less differences than observed in the agricultural consequences for depositions at different times of the year.

However, a significant contribution arises from distances greater than 540 km (Tab. 16), where countermeasures are no longer modelled in UFOMOD, but the potential individual doses due to ingestion may still exceed the intervention levels. This contribution is calculated to be 58% with the WASH-1400 data, and varies with the MARC data between 23% for a release in February and 67% for a release in August.

The contribution of the ingestion pathway to the overall number of late health effects (Tab.16) derived with the data from both models is generally large, ranging from 40% to 65%. This is due to the fact that at far distances from the site a large number of individuals[1] accumulates very small radiation doses (below 0.05 SV), leading in connection with the linear dose-risk-relationship assumed in the calculations to a large number of late fatalities.

The current countermeasures model of UFOMOD does not give a reasonable estimate of the amount of food-bans actually required. This can be seen from Tab.17, where characteristic values of the CCFDs of the number of late fatalities are given for the case, that the intervention levels for long term intake were omitted in the calculations. The CCFDs do not change significantly when using both transport models. With the MARC-data, the differences are more pronounced, because the long term intakes are somewhat higher than for the WASH-1400 data. The expectation values show a slight increase in all cases, leading to an increase in the contribution of the ingestion pathway and a decrease in the contribution from beyond 540 km (Tab. 18).

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1) In UFOMOD, a constant population density of 240 individuals/ km^2 is assumed for distances between 80 km and 540 km, beyond 540 km the population density is taken to be 25 individuals/ km^2

6. Summary

In this report results have been presented of an accident consequence assessment performed with UFOMOD using data of the terrestrial foodchain transport models from the WASH-1400 study and from MARC. The analysis was based on release category FK2 of the German Risk Study and was carried out with four sets of meteorological data representing different regions of Germany. Seasonal variations were studied by means of the MARC data for depositions in February, April, June and August with an agricultural practice adopted in the UK. In order to perform the comparison, an adaption of the MARC data had been necessary to comply with the current UFOMOD code.

The potential individual doses due to ingestion, the areas affected by food-bans and the late health effects estimated with the data from both transport models have been compared. For all types of consequences considered, the results obtained with the WASH-14oo data correspond approximately to those obtained with the MARC data representing a deposition in August. In general, the consequences estimated for a release in August exceed those for depositions earlier in the year.

The potential individual doses due to ingestion show large variations with season both with respect to the values and the contributions of individual food products. Besides milk, grain products are the most important sources of exposure for a release in August, whereas for a release in February, beef and green vegetables give an important contributions. The contributions calculated with the WASH-1400 intake data, which are given only for the foods "milk" and "other products", represent some average over the year.

The seasonal variation in the areas affected by food restrictions is still considerable, but does not reflect the large differences seen in the potential doses. However, food bans were only applied within 540 km distance to the sites, where the ingestion doses may still exceed the intervention levels, so that a greater effect is expected if the analysis would be extended to larger distances.

The countermeasures imposed largely reduce the seasonal variations in the late health effects, so that the results obtained with both models agree within a factor of about 2 for all assumed times of deposition. The contribution of the ingestion pathway to the overall number of late fatalities is estimated to range from about 40% to about 65%, depending on the time of the release; however, a large fraction arises from distances beyond 540 km.

It was also demonstrated that the intervention-levels for food bans currently implemented in UFOMOD are over-restrictive; a less restrictive level leads only to a moderate increase in the late health effects.

TAB.1

Inventory of radionuclides

Nuklid	Halbwertszeit (Tage)	Kerninventar (Curie)
Co-58	7,1 E + 01	1,27 E + 06
Co-60	1,9 E + 03	9,63 E + 05
Kr-85m	1,8 E - 01	2,70 E + 07
Kr-85	3,9 E + 03	7,92 E + 05
Rb-86	1,9 E + 01	3,73 E + 04
Kr-87	5,3 E - 02	5,26 E + 07
Kr-88	1,2 E - 01	7,64 E + 07
Sr-89	5,2 E + 01	1,05 E + 08
Sr-90	1,1 E + 04	5,30 E + 06
Y-90	2,7 E + 00	5,72 E + 06
Sr-91	4,0 E - 01	1,28 E + 08
Y-91	5,9 E + 01	1,33 E + 08
Zr-95	6,5 E + 01	1,78 E + 08
Nb-95	3,5 E + 01	1,76 E + 08
Zr-97	7,1 E - 01	1,76 E + 08
Mo-99	2,8 E + 00	1,91 E + 08
Tc-99m	2,5 E - 01	1,66 E + 08
Ru-103	3,9 E + 01	1,37 E + 08
Ru-105	1,8 E - 01	9,79 E + 07
Rh-105	1,5 E + 00	6,59 E + 07
Ru-106	3,7 E + 02	3,96 E + 07
Sb-127	3,9 E + 00	7,93 E + 06
Te-127m	1,1 E + 02	1,51 E + 06
Te-127	3,9 E - 01	7,68 E + 06
Sb-129	1,8 E - 01	4,13 E + 07
Te-129m	3,4 E + 01	6,58 E + 06
Te-129	4,8 E - 02	3,91 E + 07
Te-131m	1,2 E + 00	1,56 E + 07
J-131	8,0 E + 00	1,04 E + 08
Te-132	3,2 E + 00	1,45 E + 08
J-132	9,6 E - 02	1,50 E + 08
J-133	8,7 E - 01	2,02 E + 08
Xe-133	5,3 E + 00	1,99 E + 08
J-134	3,7 E - 02	2,32 E + 08
Cs-134	7,5 E + 02	1,38 E + 07
J-135	2,8 E - 01	1,81 E + 08
Xe-135	3,8 E - 01	4,07 E + 07
Cs-136	1,3 E + 01	4,51 E + 06
Cs-137	1,1 E + 04	7,06 E + 06
Ba-140	1,3 E + 01	1,86 E + 08
La-140	1,7 E + 00	1,93 E + 08
Ce-141	3,2 E + 01	1,80 E + 08
Ce-143	1,4 E + 00	1,59 E + 08
Pr-143	1,4 E + 01	1,55 E + 08
Ce-144	2,8 E + 02	1,09 E + 08
Nd-147	1,1 E + 01	7,32 E + 07
Np-239	2,3 E + 00	2,14 E + 09
Pu-238	3,2 E + 04	1,27 E + 05
Pu-239	8,9 E + 06	2,89 E + 04
Pu-240	2,4 E + 06	3,22 E + 04
Pu-241	5,3 E + 03	6,04 E + 06
Am-241	1,5 E + 05	3,54 E + 03
Cm-242	1,6 E + 02	1,42 E + 06
Cm-244	6,6 E + 03	1,15 E + 05

Kerninventar - Abbrand: 10 000, 19 600, 33 500 MWd/t Uran

TAB.2

Release category and its characteristic parameters

Freisetzungskategorie (FK) Nr.	Beschreibung	Zeitpunkt der Freisetzung h	Dauer der Freisetzung h	Höhe der Freisetzung m	Freigesetzte Energie 10^6 KJ/h	Häufigkeit der Freisetzung 1/a
2	Kernschmelzen, großes Leck im Sicherheitsbehälter (Ø 300 mm)	1	3	10	15	$6 \cdot 10^{-7}$

Freigesetzter Anteil des Kerninventars							
Xe-Kr	J_{org}	J_2-Br	Cs-Rb	Te-Sb	Ba-Sr	Ru ²)	La ³)
1.0	$7.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-1}$	$2.9 \cdot 10^{-1}$	$1.9 \cdot 10^{-1}$	$3.2 \cdot 10^{-2}$	$1.7 \cdot 10^{-2}$	$2.6 \cdot 10^{-3}$

¹) Da die Freisetzung über einen längeren Zeitraum erfolgt, werden die freigesetzten Anteile für drei Zeitintervalle getrennt angegeben,

²) enthält Ru, Rh, Co, Mo, Tc

³) enthält Y, La, Zr, Nb, Ce, Pr, Nd, Np, Pu, Am, Cm

Table 3

Data used in the comparison

(a) Nuclides

Sr89	Sr90	Cs134	Cs137	I131	I133

(b) time of deposition

WASH 1400:	no seasonality
FOOD-MARC:	1st February, 1st April, 1st June, 1st August

(c) food-products and modelling of agricultural practice

WASH 1400	milk	cows outside throughout the year
	other products	no explicit agricultural practice
FOOD-MARC	milk beef	cows outside 17th April to 30th September Hay/silage harvested 1st May to 15th September until end of first winter cows permanently outside after first winter Age at slaughter 6y
	grain	growth from 1st May to 31st August for first two crops continuous harvesting for all following crops
	green vegetables	continuous harvesting

(d) consumption rates

WASH 1400	milk	255 ℓ·a^{-1} (average value for small child)	
	other products	no explicit consumption rates	
FOOD-MARC	milk	300 ℓ·a^{-1}	adult member of critical group
	beef	60 kg·a^{-1}	
	grain	130 kg·a^{-1}	
	green vegetables	80 kg·a^{-1}	

NUCLIDE	MILK	OTHER	DIR.DEP.
SR- 89	4.020E-01	3.970E-01	
SR- 90	5.880E-01	5.050E-01	
J -131	6.920E-01	0.0	
J -133	4.200E-03	0.0	
CS-134	4.220E+00	8.440E+00	
CS-136	1.420E+00	2.840E+00	
CS-137	4.220E+00	8.440E+00	

NUCLIDE	MILK	OTHER	ROOT UP.
SR- 89	6.800E-03	1.360E-02	
SR- 90	6.690E-01	1.340E+00	
J -131	0.0	0.0	
J -133	0.0	0.0	
CS-134	5.470E-02	1.640E-01	
CS-136	0.0	0.0	
CS-137	8.350E-02	2.510E-01	

TAB.4

Normalized integraded intake$(Bq/(Bq\cdot m^{-2}))$from WASH 1400

Depostion 1st of February

NUCLIDE	MILK	BEEF	GRAIN	GR.VEG.	1ST YEAR
SR- 89	2.005E-02	8.122E-04	1.468E-04	2.048E-01	
SR- 90	1.919E-01	8.066E-03	9.557E-03	2.909E-01	
RU-106	5.243E-05	5.291E-03	4.050E-03	2.347E-01	
J-131	3.144E-04	1.854E-05	0.0	1.003E-01	
J-133	0.0	0.0	0.0	1.564E-02	
CS-134	5.636E-01	3.573E-01	9.155E-04	2.979E-01	
CS-136	0.0	0.0	0.0	0.0	
CS-137	6.582E-01	4.204E-01	1.198E-03	3.048E-01	
					FOL. YRS
SR- 89	3.586E-04	1.545E-05	2.065E-05	4.423E-05	
SR- 90	8.213E-01	3.529E-02	7.285E-01	1.030E+00	
RU-106	2.530E-05	8.422E-03	1.581E-02	4.998E-04	
J-131	0.0	0.0	0.0	0.0	
J-133	0.0	0.0	0.0	0.0	
CS-134	2.797E-01	2.372E-01	7.287E-03	7.274E-03	
CS-136	0.0	0.0	0.0	0.0	
CS-137	5.505E-01	4.542E-01	9.607E-02	1.114E-01	

Deposition 1st of April

NUCLIDE	MILK	BEEF	GRAIN	GR.VEG.	1ST YEAR
SR- 89	1.221E-01	4.950E-03	5.473E-04	2.048E-01	
SR- 90	4.964E-01	2.094E-02	1.333E-02	2.909E-01	
RU-106	2.107E-04	2.357E-02	6.320E-03	2.347E-01	
J-131	2.113E-01	1.246E-02	0.0	1.003E-01	
J-133	2.076E-07	8.891E-09	0.0	1.564E-02	
CS-134	2.549E+00	1.645E+00	1.345E-03	2.979E-01	
CS-136	0.0	0.0	0.0	0.0	
CS-137	2.906E+00	1.889E+00	1.671E-03	3.048E-01	
					FOL. YRS
SR- 89	4.764E-04	2.122E-05	3.336E-05	4.423E-05	
SR- 90	9.057E-01	3.905E-02	7.305E-01	1.030E+00	
RU-106	2.437E-05	1.783E-02	1.725E-02	4.998E-04	
J-131	0.0	0.0	0.0	0.0	
J-133	0.0	0.0	0.0	0.0	
CS-134	3.343E-01	3.889E-01	7.576E-03	7.274E-03	
CS-136	0.0	0.0	0.0	0.0	
CS-137	6.223E-01	6.654E-01	9.632E-02	1.114E-01	

TAB.5

Normalized integrated intake(Bq/(Bq·m^{-2}))derived from FOOD-MARC

Deposition 1st of June

NUCLIDE	MILK	BEEF	GRAIN	GR.VEG.	1ST YEAR
SR- 89	2.206E-01	8.942E-03	5.840E-03	2.048E-01	
SR- 90	7.871E-01	3.350E-02	7.731E-02	2.909E-01	
RU-106	3.793E-04	4.458E-02	1.180E-02	2.347E-01	
J-131	1.243E+00	7.330E-02	3.597E-05	1.003E-01	
J-133	1.047E-01	4.482E-03	0.0	1.564E-02	
CS-134	4.810E+00	3.259E+00	1.624E+00	2.979E-01	
CS-136	0.0	0.0	0.0	0.0	
CS-137	5.470E+00	3.773E+00	1.965E+00	3.048E-01	
					FOL. YRS
SR- 89	4.565E-04	1.963E-05	1.043E-04	4.423E-05	
SR- 90	9.435E-01	4.052E-02	7.342E-01	1.030E+00	
RU-106	1.756E-05	2.503E-02	1.462E-02	4.998E-04	
J-131	0.0	0.0	0.0	0.0	
J-133	0.0	0.0	0.0	0.0	
CS-134	1.911E-01	2.721E-01	4.547E-01	7.274E-03	
CS-136	0.0	0.0	0.0	0.0	
CS-137	4.226E-01	4.986E-01	7.285E-01	1.114E-01	

Deposition 1st of August

NUCLIDE	MILK	BEEF	GRAIN	GR.VEG.	1ST YEAR
SR- 89	2.342E-01	9.494E-03	2.478E-01	2.048E-01	
SR- 90	7.533E-01	3.207E-02	1.727E+00	2.909E-01	
RU-106	3.871E-04	5.017E-02	7.011E-02	2.347E-01	
J-131	1.243E+00	7.331E-02	3.209E-02	1.003E-01	
J-133	1.046E-01	4.482E-03	1.970E-12	1.564E-02	
CS-134	4.852E+00	3.383E+00	1.031E+01	2.979E-01	
CS-136	0.0	0.0	0.0	0.0	
CS-137	5.369E+00	3.833E+00	1.215E+01	3.048E-01	
					FOL. YRS
SR- 89	4.137E-04	1.778E-05	8.526E-04	4.423E-05	
SR- 90	9.052E-01	3.887E-02	8.374E-01	1.030E+00	
RU-106	1.755E-05	2.077E-02	1.769E-02	4.998E-04	
J-131	0.0	0.0	0.0	0.0	
J-133	0.0	0.0	0.0	0.0	
CS-134	1.450E-01	1.442E-01	7.844E-01	7.274E-03	
CS-136	0.0	0.0	0.0	0.0	
CS-137	3.571E-01	3.169E-01	1.162E+00	1.114E-01	

TAB. 5 cont' d

Normalized integrated intake(Bq/(Bq·m^{-2}))derived from FOOD-MARC

Food-product	Isotope	Deposition at 1st of..	$\frac{\text{Intake 2y-50y}}{\text{Intake 2y-infinity}}$
Milk	Sr90	Aug.	0.98
		Feb.	0.98
	Cs137	Aug.	1.00
		Feb.	1.00
Beef	Sr90	Aug.	0.98
		Feb.	0.98
	Cs137	Aug.	1.00
		Feb.	1.00
Grain	Sr90	Aug.	0.83
		Feb.	0.79
	Cs137	Aug.	0.98
		Feb.	0.78
Green veg.	Sr90	-	0.79
	Cs137	-	0.77
"other products"	Sr90	Aug.	0.81
		Feb.	0.80
	Cs137	Aug.	0.97
		Feb.	0.93

TAB.6: Contributions to intake beyond 50 years derived from FOOD-MARC

food	WASH 1400 (dir. deposition)	MARC (febr.) (intake in first year)	MARC (aug.) (intake in first year)	WASH 1400 (root uptake)	MARC (febr.) (intake from year 2 to infinity)	MARC (aug.) (intake from year 2 to infinity)
milk	34 %	45 %	26 %	31 %	40 %	22 %
other prod.	66 %	55 %	74 %	69 %	60 %	78 %
beef	-	26 %	17 %	-	20 %	9 %
grain	-	0 %	55 %	-	17 %	53 %
green veg.	-	29 %	2 %	-	23 %	16 %
	Red bone marrow			Red bone marrow		
milk	98 %	2 %	84 %	25 %	49%	15 %
other prod.	2 %	98 %	16 %	75 %	51 %	85 %
beef	-	0 %	5 %	-	41 %	14 %
grain	-	0 %	4 %	-	5 %	68 %
green veg.	-	98 %	7 %	-	5 %	3 %
	thyroid			thyroid		

Tab. 7 Contribution of food products to expectation value of potential dose by ingestion with intake data from different foodchain models (FK2, distance 100 km, under centerline of plume)

NUCLIDES	GK	KM	LG	KD	KN	SD	direct deposition
SR- 89	0.1%	0.6%	0.1%	0.0%	0.9%	0.0%	
SR- 90	0.2%	2.5%	0.0%	0.0%	5.5%	0.0%	
J -131	2.2%	0.5%	0.6%	0.2%	0.5%	96.4%	
J -133	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	
CS-134	70.3%	71.4%	71.4%	72.4%	66.9%	2.5%	
CS-137	27.2%	25.0%	27.9%	27.3%	26.2%	0.9%	
DOSE (cSv)	1.474E+02	1.626E+02	1.455E+02	1.603E+02	1.552E+02	4.392E+03	
MILK	34.8%	34.3%	33.7%	33.5%	34.9%	97.7%	
OTHER	65.2%	65.7%	66.3%	66.5%	65.1%	2.3%	
SR- 89	0.1%	0.3%	0.0%	0.0%	0.5%	0.0%	MILK
SR- 90	0.1%	1.3%	0.0%	0.0%	3.0%	0.0%	
J -131	2.2%	0.5%	0.6%	0.2%	0.5%	96.4%	
J -133	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	
CS-134	23.4%	23.8%	23.8%	24.1%	22.3%	0.8%	
CS-137	9.1%	8.3%	9.3%	9.1%	8.7%	0.3%	
SR- 89	0.0%	0.3%	0.0%	0.0%	0.5%	0.0%	OTHER
SR- 90	0.1%	1.1%	0.0%	0.0%	2.5%	0.0%	
J -131	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
J -133	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
CS-134	46.9%	47.6%	47.6%	48.3%	44.6%	1.7%	
CS-137	18.2%	16.7%	18.6%	18.2%	17.5%	0.6%	

Table 8 <u>Contributions to expectation value of potential dose by ingestion with intake data from WASH 1400 (FK2, distance 100 km, under centerline of plume)</u>

NUCLIDES	GK	KM	LG	KD	KN	SD	ROOT UPTAKE
SR- 89	0.1%	0.2%	0.1%	0.1%	0.2%	0.1%	
SR- 90	12.5%	70.5%	1.8%	1.7%	84.4%	1.8%	
J -131	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
J -133	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
CS-134	54.9%	19.1%	61.4%	62.3%	9.6%	62.7%	
CS-137	32.5%	10.2%	36.7%	36.0%	5.8%	35.5%	
DOSE (cSv)	3.262E+00	1.052E+01	2.923E+00	3.217E+00	1.861E+01	3.028E+00	
MILK	26.0%	30.9%	25.2%	25.1%	32.0%	25.2%	
OTHER	74.0%	69.1%	74.9%	74.9%	68.0%	74.9%	
SR- 89	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	MILK
SR- 90	4.2%	23.5%	0.6%	0.6%	28.1%	0.6%	
J -131	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
J -133	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
CS-134	13.7%	4.8%	15.4%	15.6%	2.4%	15.7%	
CS-137	8.1%	2.5%	9.2%	9.0%	1.4%	8.9%	
SR- 89	0.1%	0.2%	0.0%	0.0%	0.1%	0.0%	OTHER
SR- 90	8.3%	47.0%	1.2%	1.1%	56.3%	1.2%	
J -131	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
J -133	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
CS-134	41.2%	14.3%	46.0%	46.8%	7.2%	47.0%	
CS-137	24.4%	7.7%	27.6%	27.0%	4.3%	26.6%	

Table 8 (cont.) Contributions to expectation value of potential dose by ingestion with intake data from WASH 1400 (FK2, distance 100 km, under centerline of plume)

```
REPR. DISTANCE (KM) IS        100.

FOOD ACCUMULATION TIME IS 1ST YEAR


NUCLIDES        GK         KM         LG         KD         KN         SD
--------       ----       ----       ----       ----       ----       ----

 SR- 89        0.3%       1.6%       0.1%       0.1%       2.2%       0.0%
 SR- 90        0.7%      10.3%       0.1%       0.1%      20.7%       0.0%
 J -131        3.1%       0.6%       0.9%       0.3%       0.5%      93.9%
 J -133        0.2%       0.1%       0.1%       0.1%       0.1%       3.9%
 CS-134       66.5%      62.5%      68.4%      69.6%      53.0%       1.6%
 CS-137       29.2%      24.9%      30.4%      29.8%      23.5%       0.7%

DOSE (cSv)  1.502E+01  1.789E+01  1.463E+01  1.606E+01  1.888E+01  6.560E+02


 MILK         44.9%      44.8%      46.1%      46.4%      43.8%       1.4%
 BEEF         28.4%      26.0%      29.3%      29.4%      23.0%       0.7%
 GRAIN         0.1%       0.3%       0.1%       0.1%       0.5%       0.0%
 GR.VEG.      26.6%      28.9%      24.5%      24.1%      32.8%      98.0%


 SR- 89        0.0%       0.1%       0.0%       0.0%       0.2%       0.0%      MILK
 SR- 90        0.3%       4.0%       0.0%       0.0%       7.9%       0.0%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.3%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134       30.7%      28.9%      31.6%      32.2%      24.5%       0.7%
 CS-137       13.9%      11.8%      14.4%      14.2%      11.2%       0.3%


 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%      BEEF
 SR- 90        0.0%       0.2%       0.0%       0.0%       0.3%       0.0%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134       19.5%      18.3%      20.0%      20.4%      15.5%       0.5%
 CS-137        8.9%       7.5%       9.2%       9.0%       7.1%       0.2%


 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%      GRAIN
 SR- 90        0.0%       0.2%       0.0%       0.0%       0.4%       0.0%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134        0.0%       0.0%       0.1%       0.1%       0.0%       0.0%
 CS-137        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%


 SR- 89        0.3%       1.5%       0.1%       0.1%       2.0%       0.0%      GR.VEG.
 SR- 90        0.4%       6.0%       0.1%       0.0%      12.0%       0.0%
 J -131        3.1%       0.6%       0.9%       0.3%       0.5%      93.6%
 J -133        0.2%       0.1%       0.1%       0.1%       0.1%       3.9%
 CS-134       16.2%      15.3%      16.7%      17.0%      12.9%       0.4%
 CS-137        6.4%       5.5%       6.7%       6.6%       5.2%       0.1%
```

Table 9 Contributions to expectation value of potential dose by ingestion with intake data derived from FOOD-MARC for a deposition on 1st February (FK2, distance 100 km, under centerline of plume)

```
REPR. DISTANCE (KM) IS        100.

FOOD ACCUMULATION TIME IS FOL. YRS


NUCLIDES        GK          KM          LG          KD          KN          SD
--------       ----        ----        ----        ----        ----        ----

 SR- 89        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 SR- 90        6.1%       52.4%        0.8%        0.8%       71.3%        0.8%
 J -131        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 J -133        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 CS-134       49.9%       26.5%       52.4%       53.4%       15.2%       53.8%
 CS-137       44.1%       21.1%       46.8%       45.9%       13.6%       45.4%

DOSE (cSv)  8.724E+00   1.842E+01   8.320E+00   9.133E+00   2.868E+01   8.577E+00

 MILK         48.2%       40.0%       49.1%       49.2%       36.6%       49.2%
 BEEF         38.9%       20.4%       40.9%       41.0%       12.8%       41.0%
 GRAIN         5.9%       16.6%        4.7%        4.6%       21.1%        4.6%
 GR.VEG.       7.1%       23.0%        5.3%        5.2%       29.5%        5.2%

 SR- 89        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%     MILK
 SR- 90        1.9%       16.5%        0.3%        0.2%       22.4%        0.3%
 J -131        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 J -133        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 CS-134       26.3%       13.9%       27.6%       28.1%        8.0%       28.3%
 CS-137       20.0%        9.6%       21.2%       20.8%        6.2%       20.6%

 SR- 89        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%     BEEF
 SR- 90        0.1%        0.7%        0.0%        0.0%        1.0%        0.0%
 J -131        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 J -133        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 CS-134       22.3%       11.8%       23.4%       23.8%        6.8%       24.0%
 CS-137       16.5%        7.9%       17.5%       17.2%        5.1%       17.0%

 SR- 89        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%     GRAIN
 SR- 90        1.7%       14.6%        0.2%        0.2%       19.9%        0.2%
 J -131        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 J -133        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 CS-134        0.7%        0.4%        0.7%        0.7%        0.2%        0.7%
 CS-137        3.5%        1.7%        3.7%        3.6%        1.1%        3.6%

 SR- 89        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%     GR.VEG.
 SR- 90        2.4%       20.6%        0.3%        0.3%       28.1%        0.3%
 J -131        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 J -133        0.0%        0.0%        0.0%        0.0%        0.0%        0.0%
 CS-134        0.7%        0.4%        0.7%        0.7%        0.2%        0.7%
 CS-137        4.0%        1.9%        4.3%        4.2%        1.2%        4.2%
```

Table 9 (cont.) Contributions to expectation value of potential dose by ingestion with intake data derived from FOOD-MARC for a deposition on 1st February

(FK2, distance 100 km, under centerline of plume)

```
REPR. DISTANCE (KM) IS        100.

FOOD ACCUMULATION TIME IS 1ST YEAR


NUCLIDES        GK         KM         LG         KD         KN         SD
--------       ----       ----       ----       ----       ----       ----

 SR- 89        0.1%       0.4%       0.0%       0.0%       0.5%       0.0%
 SR- 90        0.2%       4.1%       0.0%       0.0%       8.8%       0.0%
 J -131        2.9%       0.6%       0.8%       0.3%       0.6%      95.4%
 J -133        0.1%       0.0%       0.0%       0.0%       0.0%       2.2%
 CS-134       66.9%      67.7%      68.4%      69.5%      62.1%       1.8%
 CS-137       29.8%      27.2%      30.7%      30.1%      27.9%       0.7%

DOSE (cSv)  2.307E+02  2.552E+02  2.262E+02  2.485E+02  2.488E+02  9.297E+03

 MILK         27.3%      26.0%      26.0%      25.6%      26.0%      84.3%
 BEEF         17.4%      17.1%      17.8%      17.8%      16.2%       5.4%
 GRAIN        53.5%      55.0%      54.7%      55.0%      55.3%       3.5%
 GR.VEG.       1.7%       2.0%       1.6%       1.6%       2.5%       6.9%

 SR- 89        0.0%       0.1%       0.0%       0.0%       0.2%       0.0%      MILK
 SR- 90        0.1%       1.1%       0.0%       0.0%       2.4%       0.0%
 J -131        2.5%       0.5%       0.7%       0.2%       0.5%      81.8%
 J -133        0.1%       0.0%       0.0%       0.0%       0.0%       1.8%
 CS-134       17.2%      17.4%      17.6%      17.9%      16.0%       0.5%
 CS-137        7.4%       6.8%       7.6%       7.5%       6.9%       0.2%

 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%      BEEF
 SR- 90        0.0%       0.0%       0.0%       0.0%       0.1%       0.0%
 J -131        0.1%       0.0%       0.0%       0.0%       0.0%       4.8%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.1%
 CS-134       12.0%      12.2%      12.3%      12.5%      11.2%       0.3%
 CS-137        5.3%       4.8%       5.4%       5.3%       4.9%       0.1%

 SR- 89        0.0%       0.1%       0.0%       0.0%       0.2%       0.0%      GRAIN
 SR- 90        0.2%       2.5%       0.0%       0.0%       5.4%       0.0%
 J -131        0.1%       0.0%       0.0%       0.0%       0.0%       2.1%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134       36.6%      37.0%      37.4%      38.0%      34.0%       1.0%
 CS-137       16.7%      15.3%      17.2%      16.9%      15.7%       0.4%

 SR- 89        0.0%       0.1%       0.0%       0.0%       0.1%       0.0%      GR.VEG.
 SR- 90        0.0%       0.4%       0.0%       0.0%       0.9%       0.0%
 J -131        0.2%       0.0%       0.1%       0.0%       0.0%       6.6%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.3%
 CS-134        1.1%       1.1%       1.1%       1.1%       1.0%       0.0%
 CS-137        0.4%       0.4%       0.4%       0.4%       0.4%       0.0%
```

Table 10 Contributions to expectation value of potential dose by ingestion with intake data derived from FOOD-MARC for a deposition on 1st August (FK2, distance 100 km, under centerline of plume)

```
REPR. DISTANCE (KM) IS        100.

FOOD ACCUMULATION TIME IS FOL. YRS


NUCLIDES        GK         KM         LG         KD         KN         SD
---------      ----       ----       ----       ----       ----       ----

 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 SR- 90        3.6%      39.1%       0.5%       0.4%      59.3%       0.5%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134       56.8%      37.4%      58.4%      59.3%      23.9%      59.7%
 CS-137       39.6%      23.6%      41.2%      40.3%      16.9%      39.8%

DOSE (cSv)  1.560E+01  2.653E+01  1.520E+01  1.672E+01  3.708E+01  1.572E+01

 MILK         16.0%      21.9%      15.5%      15.5%      25.4%      15.5%
 BEEF         14.1%       9.4%      14.5%      14.5%       6.8%      14.4%
 GRAIN        65.9%      52.8%      67.1%      67.2%      45.1%      67.2%
 GR.VEG.       4.0%      15.9%       2.9%       2.9%      22.8%       2.9%

 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%      MILK
 SR- 90        1.2%      12.6%       0.2%       0.1%      19.1%       0.2%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134        7.6%       5.0%       7.8%       8.0%       3.2%       8.0%
 CS-137        7.3%       4.3%       7.5%       7.4%       3.1%       7.3%

 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%      BEEF
 SR- 90        0.1%       0.5%       0.0%       0.0%       0.8%       0.0%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134        7.6%       5.0%       7.8%       7.9%       3.2%       8.0%
 CS-137        6.4%       3.8%       6.7%       6.6%       2.7%       6.5%

 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%      GRAIN
 SR- 90        1.1%      11.7%       0.1%       0.1%      17.7%       0.1%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134       41.2%      27.1%      42.4%      43.0%      17.4%      43.4%
 CS-137       23.6%      14.1%      24.6%      24.0%      10.1%      23.7%

 SR- 89        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%      GR.VEG.
 SR- 90        1.3%      14.3%       0.2%       0.2%      21.7%       0.2%
 J -131        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 J -133        0.0%       0.0%       0.0%       0.0%       0.0%       0.0%
 CS-134        0.4%       0.3%       0.4%       0.4%       0.2%       0.4%
 CS-137        2.3%       1.3%       2.4%       2.3%       1.0%       2.3%
```

Table 10 (cont.) Contributions to expectation value of potential dose by ingestion with intake data derived from FOOD-MARC for a deposition on 1st August
(FK2, distance 100 km, under centerline of plume)

Tab. 11

Characteristic values of the CCFDs of restricted areas for milk in first year from UFOMOD with input from different foodchain models

Restricted area, A, for milk in first year						
Foodchain model	Expectation value,E	Value at p^{th} percentile			% Probability	
		p=50	p=95	p=99	P/A=0)	P(A>E)
WASH 1400	$5.8\cdot10^4$	$6.1\cdot10^4$	$7.3\cdot10^4$	$8.0\cdot10^4$	0	53
FOODMARC						
-August	$6.0\cdot10^4$	$6.1\cdot10^4$	$7.5\cdot10^4$	$8.4\cdot10^4$	0	62
-June	$6.0\cdot10^4$	$6.1\cdot10^4$	$7.5\cdot10^4$	$8.4\cdot10^4$	0	62
-April	$4.8\cdot10^4$	$4.9\cdot10^4$	$6.2\cdot10^5$	$6.9\cdot10^4$	0	51
-February	$5.0\cdot10^3$	$2.6\cdot10^3$	$1.7\cdot10^4$	$2.5\cdot10^4$	0	34

Tab. 12

Characteristic values of the CCFDs of the restricted areas for other products in first year from UFOMOD with input from different foodchain models

Restricted area, A, for other products in first year						
Foodchain model	Expectation value,E	Value at p^{th} percentile			% Probability	
		p=50	p=95	p=99	P(A=0)	P(A>E)
WASH 1400	$4.2\cdot10^4$	$4.2\cdot10^4$	$6.0\cdot10^4$	$6.2\cdot10^4$	0	50
FOODMARC						
-August	$4.8\cdot10^4$	$4.8\cdot10^4$	$6.2\cdot10^4$	$6.9\cdot10^4$	0	47
-June	$3.6\cdot10^4$	$3.7\cdot10^4$	$5.5\cdot10^4$	$6.1\cdot10^4$	0	47
-April	$2.2\cdot10^4$	$2.2\cdot10^4$	$4.3\cdot10^4$	$4.8\cdot10^4$	0	49
-February	$1.0\cdot10^4$	$7.4\cdot10^3$	$2.9\cdot10^4$	$3.6\cdot10^4$	0	40

Tab. 13

Characteristic values of the CCFDs of the restricted areas for milk in the subsequent years from UFOMOD with input from different foodchain models

Restricted area, A, for milk in subsequent years						
Foodchain model	Expectation value,E	Value at p^{th} percentile			% Probability	
		p=50	p=95	p=99	P(A=0)	P(A>E)
WASH 1400	$1.6 \cdot 10^3$	$4.5 \cdot 10^3$	$6.7 \cdot 10^3$	$1.2 \cdot 10^4$	0	29
FOODMARC						
-August	$3.4 \cdot 10^3$	$1.6 \cdot 10^3$	$1.3 \cdot 10^4$	$1.8 \cdot 10^4$	0	32
-June	$4.1 \cdot 10^3$	$1.9 \cdot 10^3$	$1.4 \cdot 10^4$	$2.5 \cdot 10^4$	0	32
-April	$5.3 \cdot 10^3$	$2.8 \cdot 10^3$	$1.8 \cdot 10^4$	$2.5 \cdot 10^4$	0	35
-February	$4.5 \cdot 10^3$	$2.3 \cdot 10^3$	$1.5 \cdot 10^4$	$2.5 \cdot 10^4$	0	34

Tab. 14

Characteristic values of the CCFDs of the restricted areas for other products in the subsequent year from UFOMOD with input from different foodchain model

Restricted area, A, for other products in subsequent years						
Foodchain model	Expectation value,E	Value at p^{th} percentile			% Probability	
		p=50	p=95	p=99	P(A=0)	P(A>E)
WASH 1400	$7.6 \cdot 10^3$	$5.0 \cdot 10^3$	$2.4 \cdot 10^4$	$2.9 \cdot 10^4$	0	38
FOODMARC						
-August	$1.9 \cdot 10^4$	$1.7 \cdot 10^4$	$4.1 \cdot 10^4$	$4.6 \cdot 10^4$	0	44
-June	$1.7 \cdot 10^4$	$1.4 \cdot 10^4$	$3.9 \cdot 10^4$	$4.4 \cdot 10^4$	0	43
-April	$1.3 \cdot 10^4$	$1.1 \cdot 10^4$	$3.4 \cdot 10^4$	$4.1 \cdot 10^4$	0	43
-February	$1.0 \cdot 10^4$	$7.4 \cdot 10^3$	$2.9 \cdot 10^4$	$3.6 \cdot 10^4$	0	40

Tab. 15

Characteristic values of the CCFDs of the number of late health effects from UFOMOD with input from different foodchain models

Number of Late health effects, N						
Foodchain model	Expectation value,E	Value at p th percentile			% Probability	
		p=50	p=95	p=99	P(N=0)	P(N>E)
WASH 1400	$2.1\cdot 10^4$	$2.2\cdot 10^4$	$2.6\cdot 10^4$	$3.0\cdot 10^4$	0	59
FOODMARC						
-August	$2.8\cdot 10^4$	$3.0\cdot 10^4$	$3.5\cdot 10^4$	$3.7\cdot 10^4$	0	62
-June	$2.2\cdot 10^4$	$2.3\cdot 10^4$	$2.8\cdot 10^4$	$3.1\cdot 10^4$	0	58
-April	$1.7\cdot 10^4$	$1.7\cdot 10^4$	$2.2\cdot 10^4$	$2.6\cdot 10^4$	0	46
-February	$1.5\cdot 10^4$	$1.6\cdot 10^4$	$2.2\cdot 10^4$	$2.6\cdot 10^4$	0	47

Tab. 16

Contribution of ingestion pathway to late health effects from UFOMOD with input from different foodchain models

Foodchain model	Contribution to late health effects (%)	Contribution from beyond 540 km (%)
WASH 1400	54	58
FOODMARC		
-August	66	67
-June	57	57
-April	43	38
-February	38	23

Tab. 17

Characteristic values of the CCFDs of the number of late effects from UFOMOD with input from different foodchain models and reduced intervention Levels for food-bans

Number of late health effects, N						
Foodchain model	Expectation value, E	Value at the pth percentile			% Probability	
		p=50	p=95	p=99	P(N=0)	P(N>E)
WASH 1400	$2.2 \cdot 10^4$	$2.2 \cdot 10^4$	$2.8 \cdot 10^4$	$3.2 \cdot 10^4$	0	47
FOODMARC						
-August	$3.3 \cdot 10^4$	$3.3 \cdot 10^4$	$4.0 \cdot 10^4$	$4.7 \cdot 10^4$	0	49
-June	$2.6 \cdot 10^4$	$2.6 \cdot 10^4$	$3.4 \cdot 10^4$	$4.1 \cdot 10^4$	0	40
-April	$2.0 \cdot 10^4$	$1.9 \cdot 10^4$	$2.9 \cdot 10^4$	$3.6 \cdot 10^4$	0	37
-February	$1.8 \cdot 10^4$	$1.7 \cdot 10^4$	$2.7 \cdot 10^4$	$3.3 \cdot 10^4$	0	41

Tab. 18

Contribution of ingestion pathway to late health effects from UFOMOD with input from different foodchain models and reduced intervention levels for food-bans

Foodchain model	Contribution to late health effects (%)	Contribution from beyond 540 km (%)
WASH 1400	56	56
FOOCHMARC		
-August	70	60
-June	62	49
-April	51	32
-February	45	20

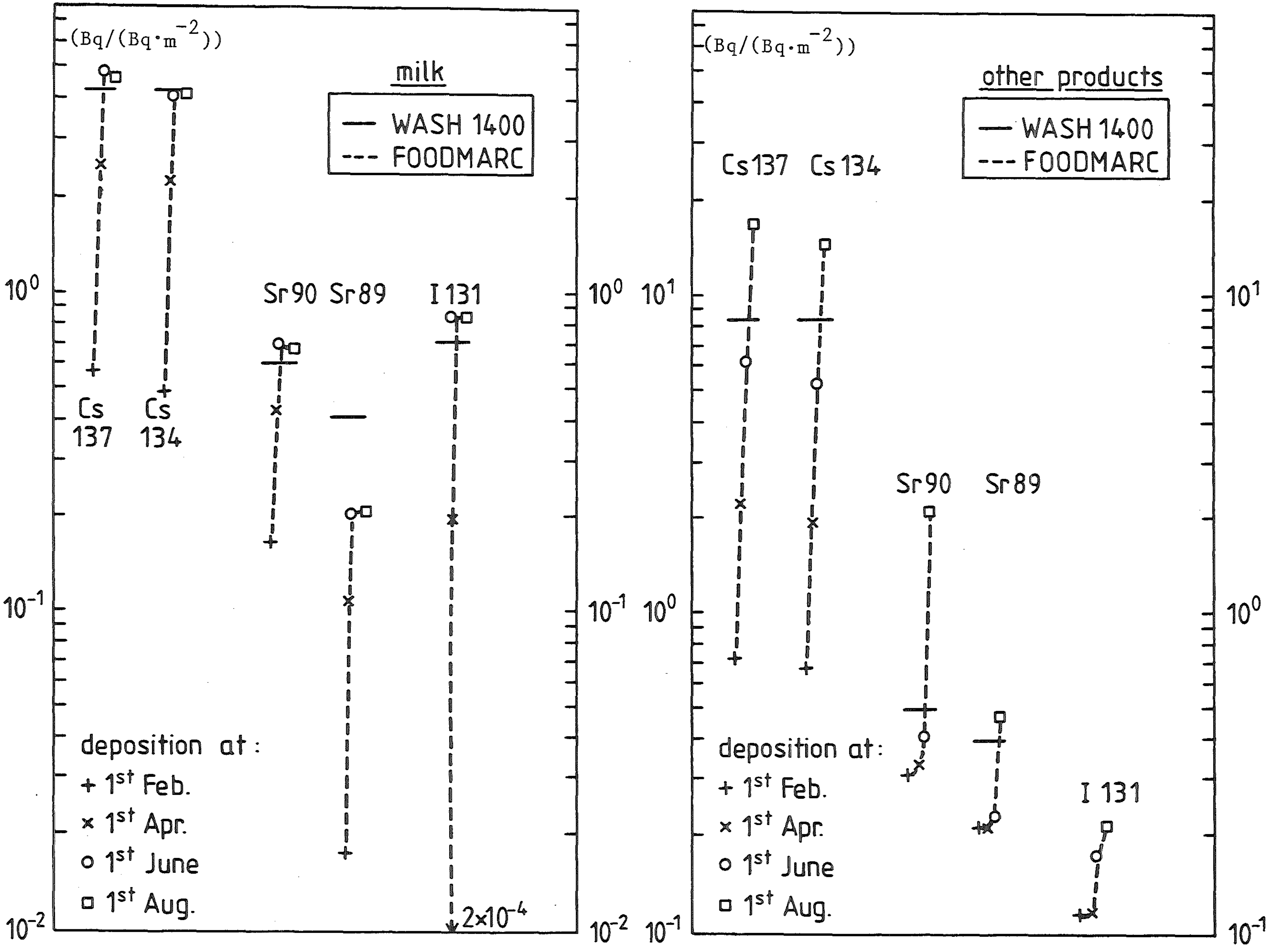


Fig: 1 Normalized intake (first year) derived from WASH-1400 and MARC foodchain-models for depositions in different months.

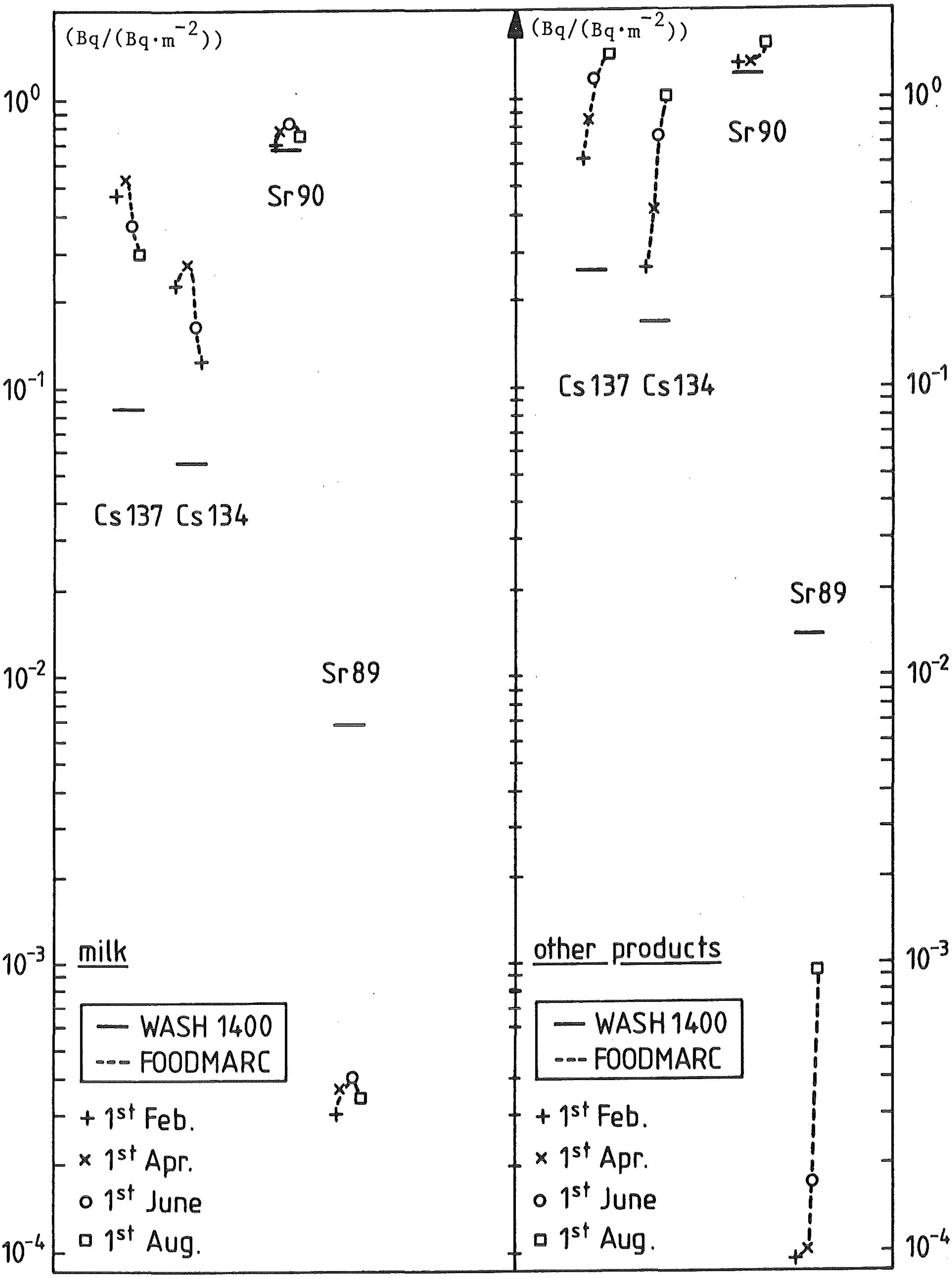


Fig. 2: Normalized intake (year 2 onwards) derived from WASH-1400 and MARC foodchain-models for depositions in different months.

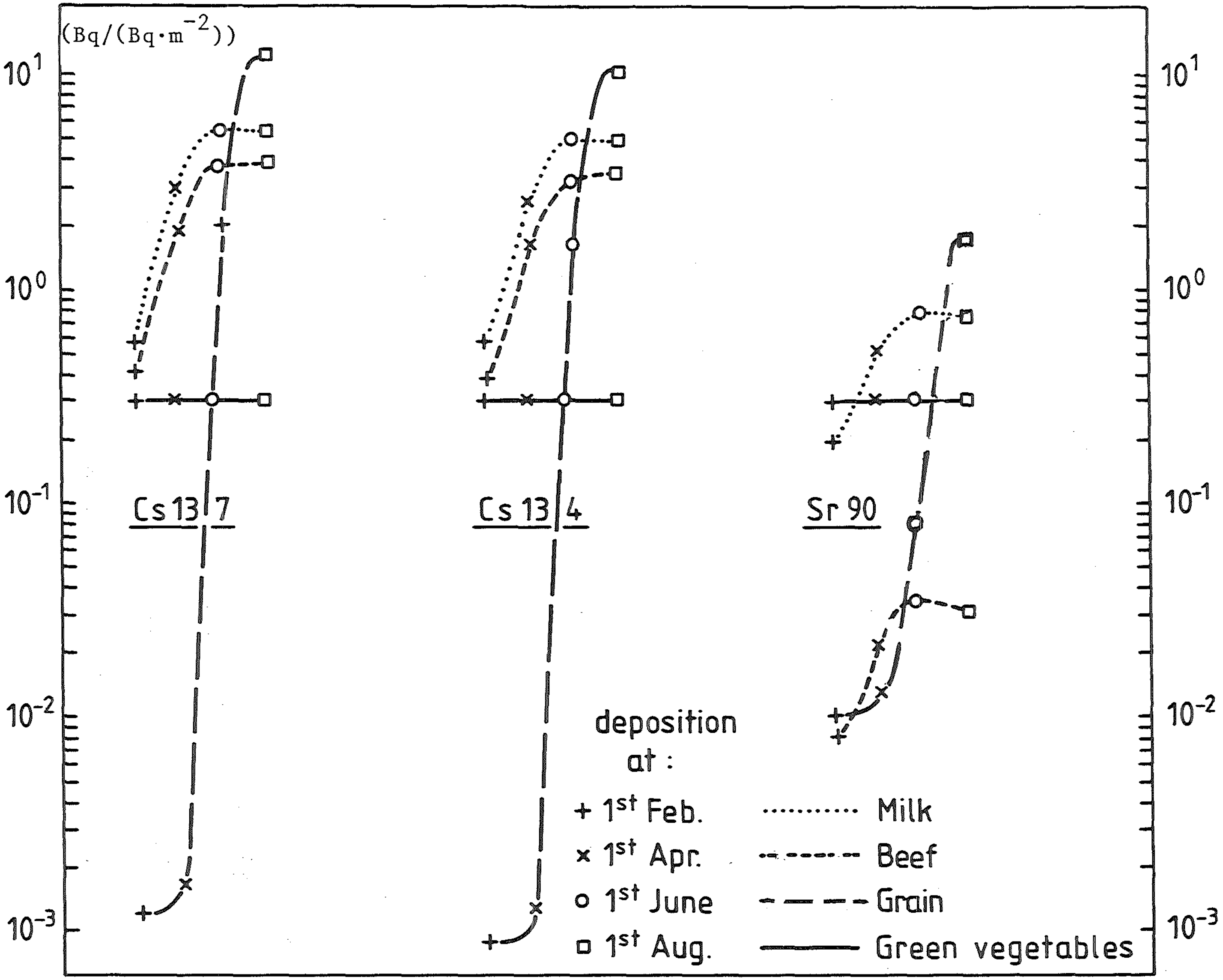


Fig.3: Normalized intake (first year) derived from FOODMARC for different foodstuffs.

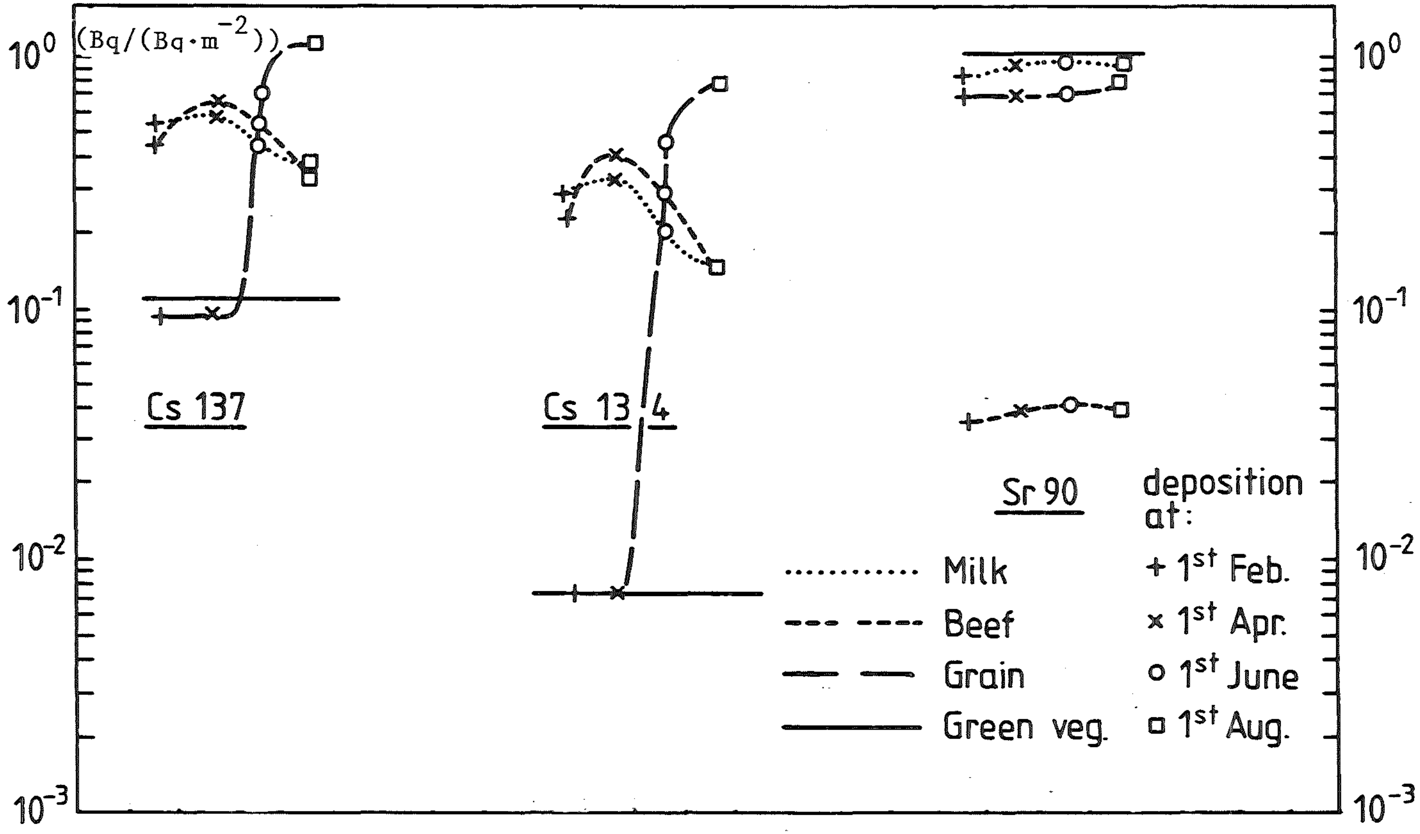


Fig.4: Normalized intake (year 2 onwards) derived from FOODMARC for different foodstuffs.

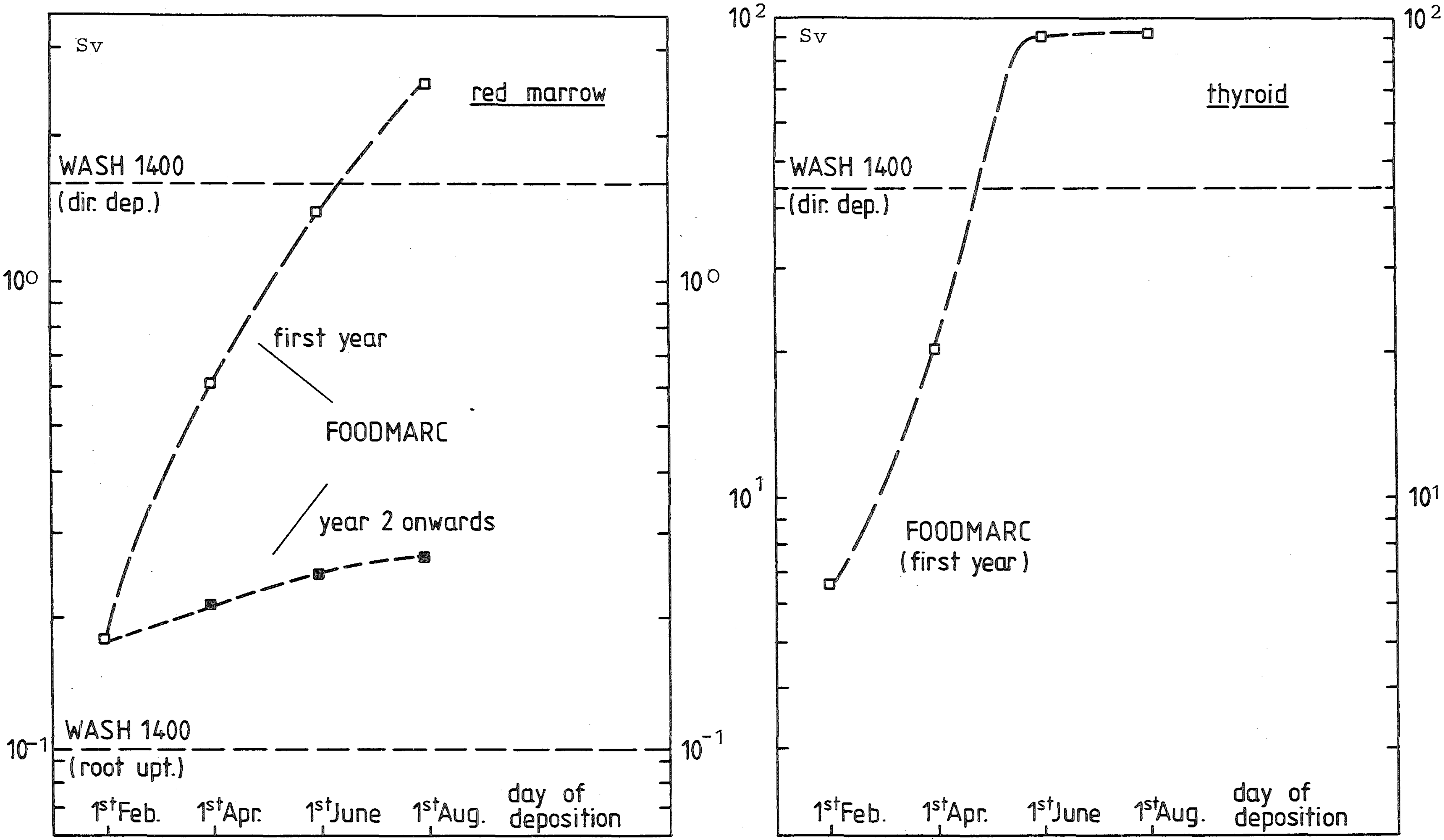


Fig.5 : Expectation value of potential dose due to ingestion calculated with different foodchain-data (FK2, under centerline of plume in 100 km distance).

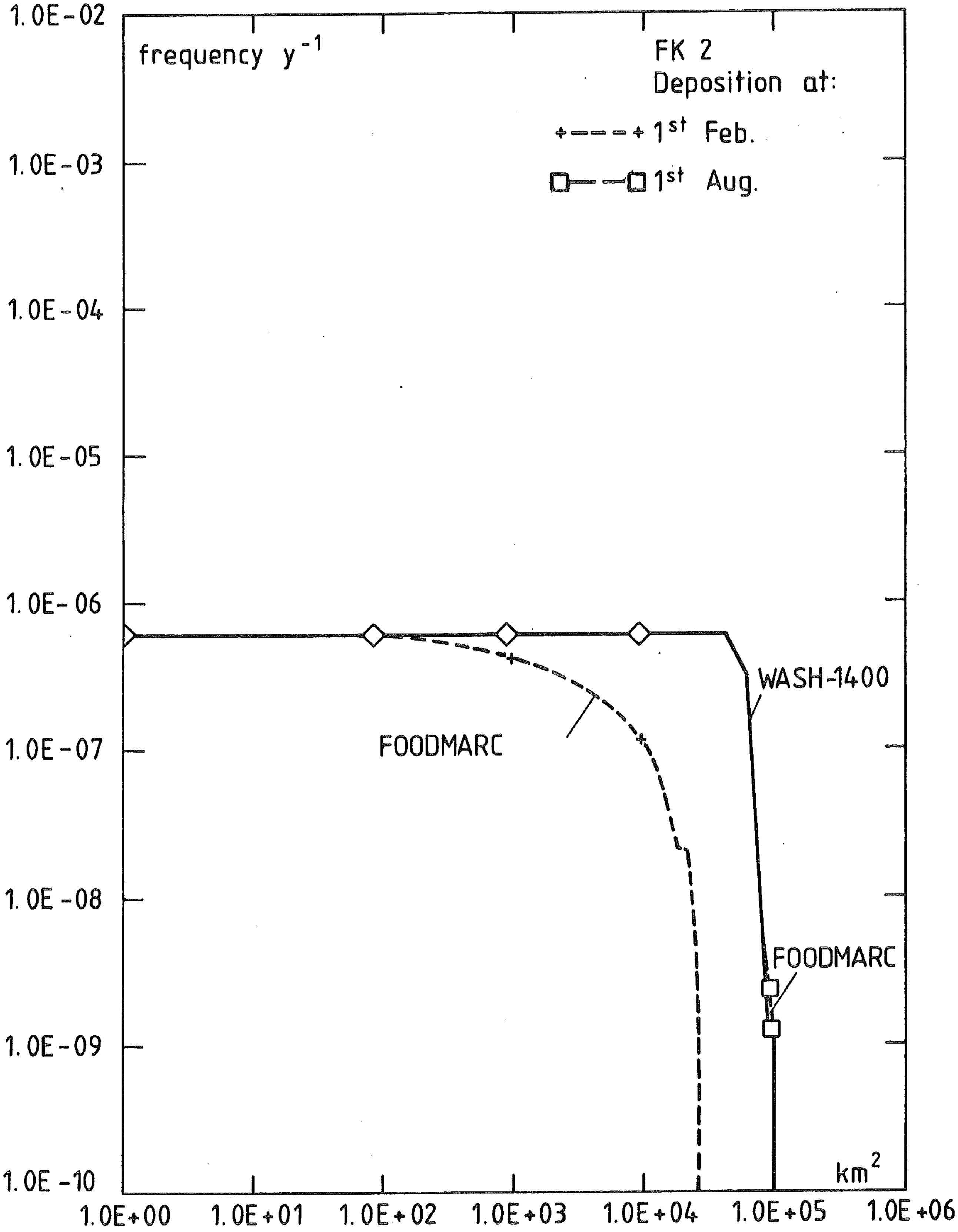


Fig.6: CCFDs of restricted areas (milk 1st year) from UFOMOD with input from different foodchain-models.

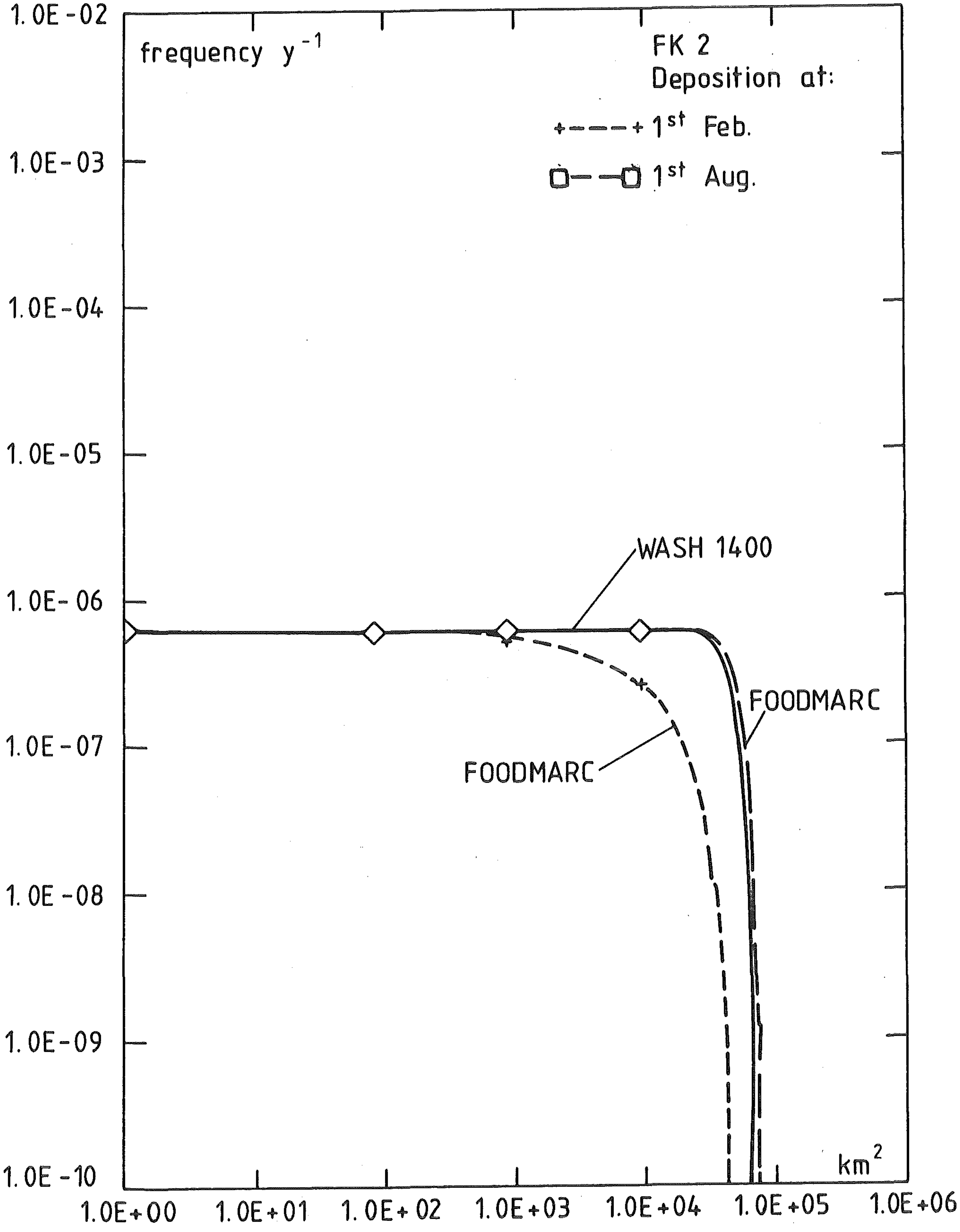


Fig.7: CCFDs of restricted areas (other products 1st year) from UFOMOD with input from different foodchain-models.

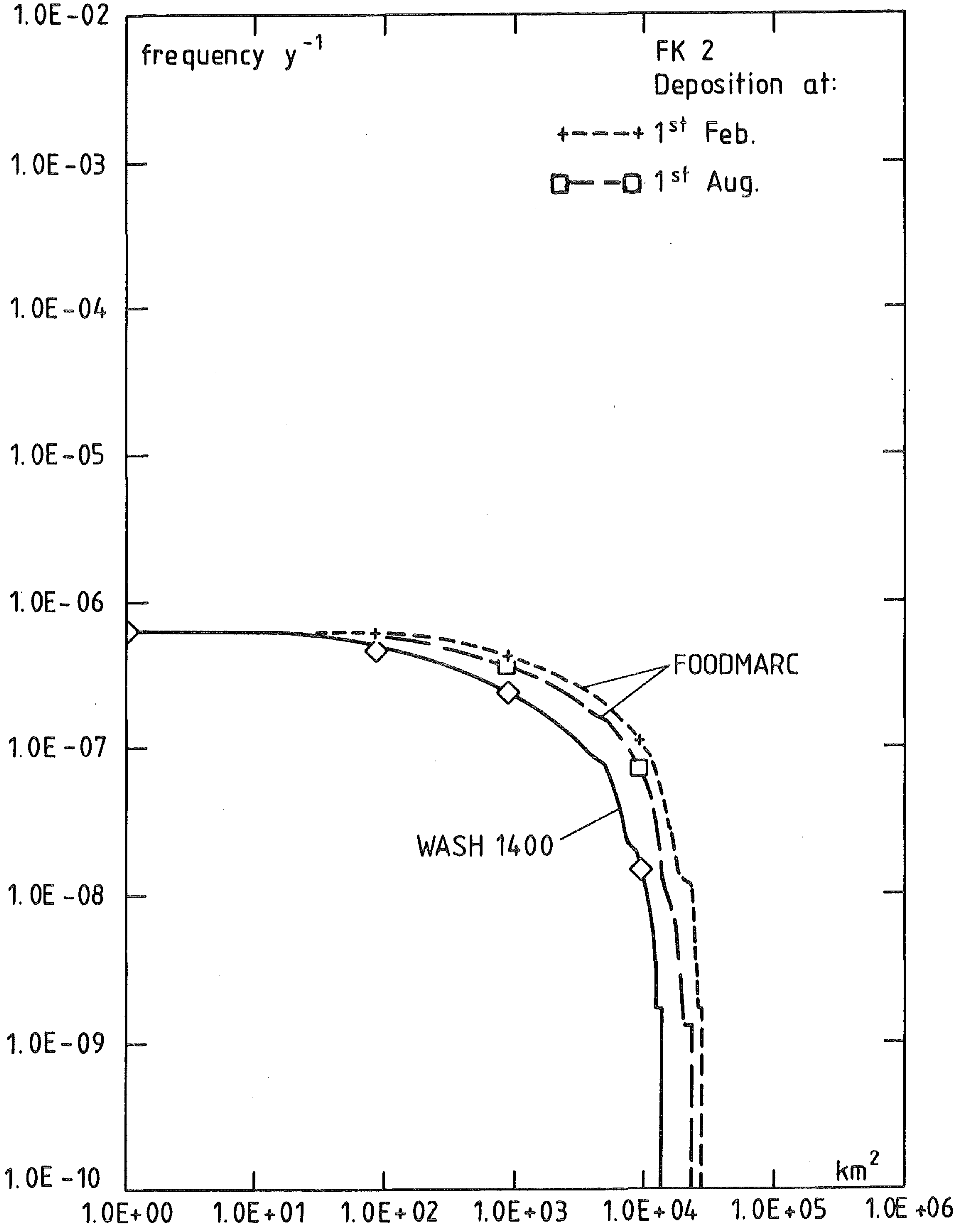


Fig.8: CCFDs of the restricted areas (milk year 2 onwards) from UFOMOD with input from different foodchain-models.

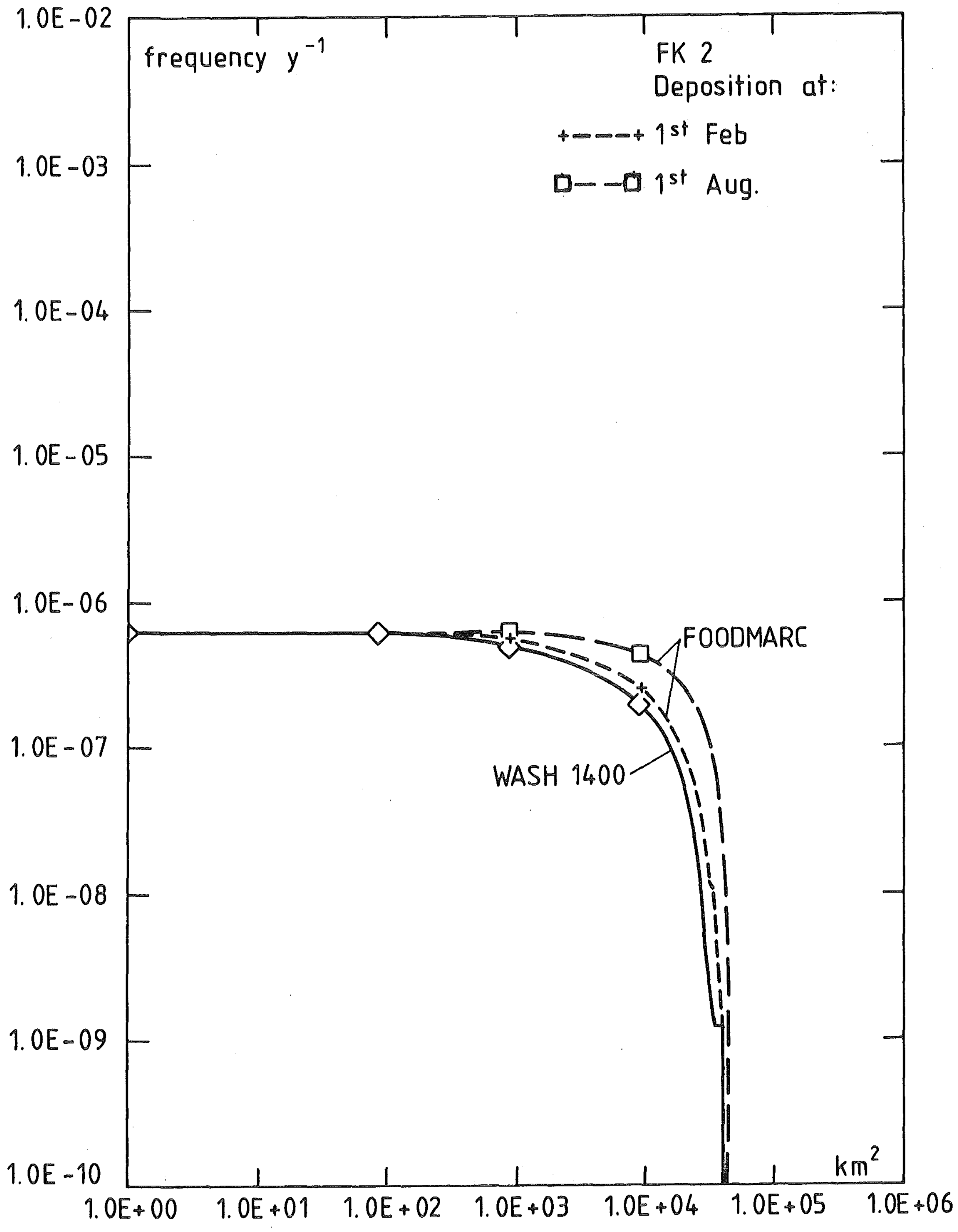


Fig.9: CCFDs of the restricted areas (other products year 2 onwards) from UFOMOD with input from different foodchain-models.

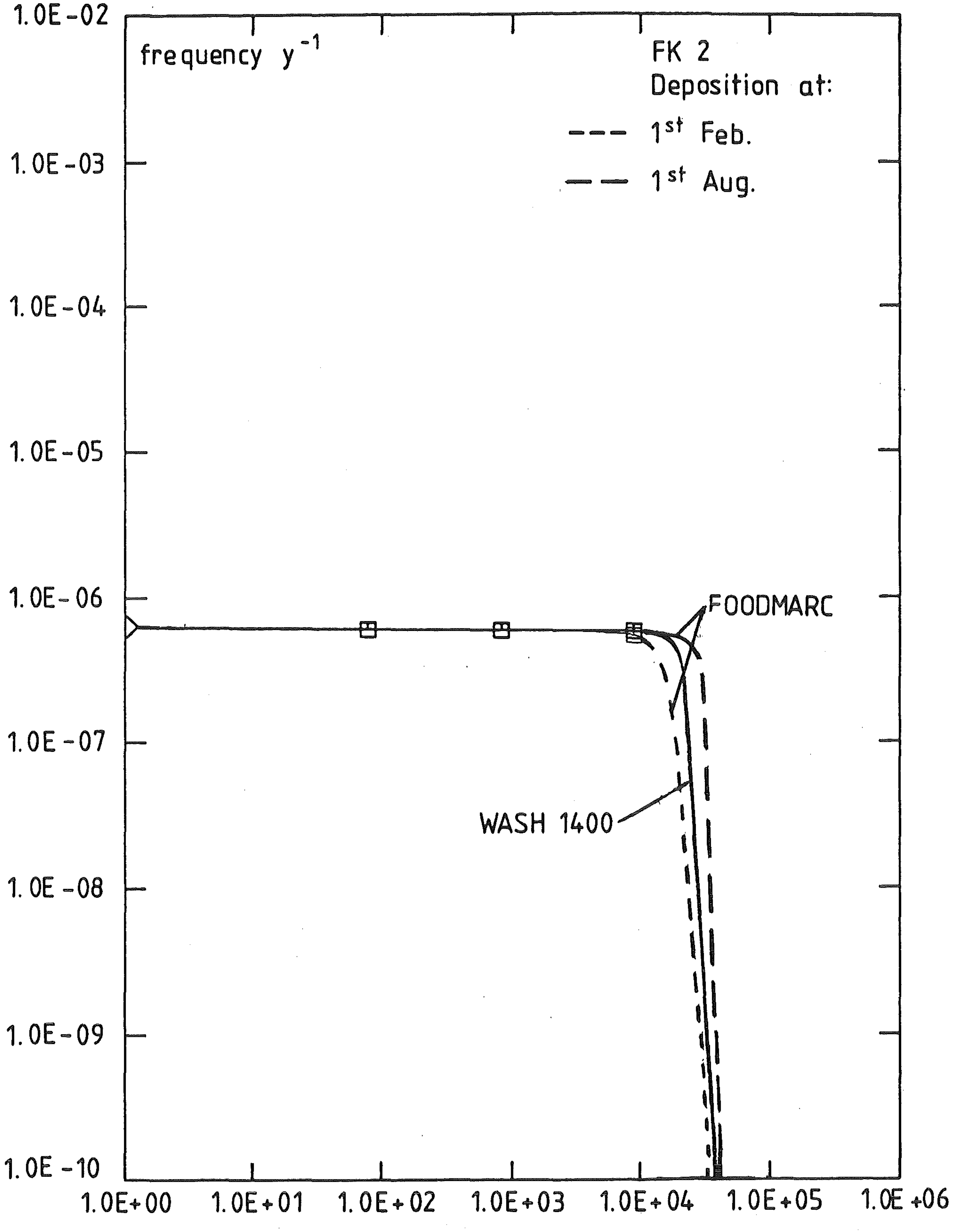


Fig.10: CCFDs of the number of Late fatalities from UFOMOD with input from different foodchain models

Appendix A

Summary of the WASH-1400 foodchain transport model

The foodchain transport model is fully described in /7/, in this appendix only the essential ideas and parameters are given.

Two processes leading to a contamination of the vegetation are considered:

1) contamination by direct deposition of activity onto vegetation
2) contamination of the plants by root-uptake of activity

These two processes give rise to contamination of the food-stuffs

a) milk
b) other agricultural products

Iotopes of the following elements are taken into account: iodine, strontium and caesium

The daily intake I(t) of a person due to ingestion of contaminated food is calculated for an initial deposition of 1 Ci/m^2 .[1]

A.1 Direct deposition

A.1 a Milk

The daily intake of radioactive iodine, strontium or caesium via milk is calculated using equation:

$$I(t+d) = C \cdot R \cdot L \cdot A \cdot S \cdot V$$

---

[1] In appendix A the former unit Ci for activity is used: 1 Ci = $3.7 \cdot 10^{10}$ Bq

where

t is the number of days from start of ingestion of activity by the cow.

d is the number of days between milk production and consumption.

C is the intake of radioactive materials during the first day by a cow. C is 22.5 Ci for a deposition of 1 $\text{Curie} \cdot m^{-2}$. This value is derived from the assumption that the grass from 45 m^2 is eaten by the cow per day with a forage density of 0.25 kg/m^2 (dry weight).

R is an exponential factor accounting for radioactive decay occuring between deposition on pasture and t.

L is an exponential factor accounting for a weathering half life of 14 day.

A is the fraction of the daily intake of radioactive material that is found in one litre of milk. A is time-dependent, since there will be a gradual build-up of radioactive materials in the body of the cow, and accordingly in the milk. The following three expressions are used in the calculations:

For iodine: $A = 0.0091 \cdot \exp(0.021t) \cdot [1-\exp(-0.292t)]$
For strontium: $A = 0.0013 \cdot \exp(0.017t) \cdot [1-\exp(-0.45t)]$
For caesium: $A = (0.0138+0.000073t) \cdot [1-\exp(-0.3t)]$

S is an exponential factor to take account of radioactive decay during the period from production of the milk until consumption. This delay is given to be, on average, 3 days.

V is the daily consumption rate of 0.7 $l \cdot d^{-1}$. This value is the average milk consumption rate of a small child in the US but is conservative for the average of the population.

It is assumed that 50% of the deposited activity remains on the pasture grass initially.

A.1.b Other agricultural products

For iodine it is assumed that milk is the only important pathway. For strontium it is assumed that intake via meat products is insignificant since strontium is a bone seeking material. Strontium intake via vegetables is calculated using the following equation:

$$I(t) = K \cdot 0.5 \cdot (1/CY) \exp(-0.693t/T_{eff})$$

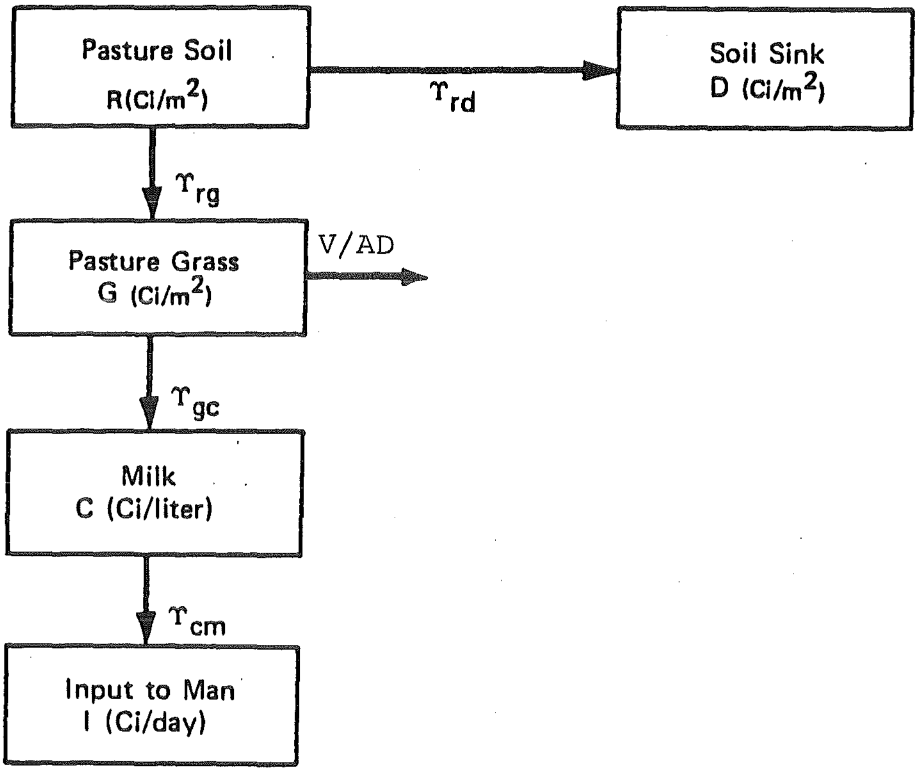
K	is the daily consumption rate ($0.12\ kg \cdot d^{-1}$)
0.5	represents 50% initial interception by the plant
CY	is the crop yield of large leafy vegetables ($2.4\ kg/m^2$ - probably wet weight)
T_{eff}	is the effective half-life (days) on vegetation, taking weathering and radioactive decay into consideration (Weathering half-life is 14 days).

For a caesium data from measurements on nuclear bomb debris has been used. This data indicates that 1/3 of the caesium intake is via milk, and 2/3 via other agricultural products.

A.2 ROOT UPTAKE

A.2.a Milk

The behaviour of radionuclides in soil and the transport mechanism to man via milk are described using a very simple compartment-type model illustrated below:



where

λ_R	$= 0.693/T_{1/2}$ ($T_{1/2}$ = radioactive half-life of the radionuclide in days).
V/AD	is the loss term for the pasture grass compartment due to grass consumption by a cow, V is the dry weight of grass consumed by a cow each day (11.8 kg/day), A is the pasture area utilized per cow (8500 m^2/cow), D is the dry weight areal grass density (0.25 kg/m^2)
γ_{milk}	is the loss of milk from the cow's udder (2 $l \cdot day^{-1}$).
γ_{cm}	is the average daily consumption of milk by a small child (0.7 $l \cdot d^{-1}$).
γ_{rd}	describes the phenomenon that radioactive materials are transferred to chemical forms which make them inaccessible to the plants. For strontium it is $2.89 \cdot 10^{-4}$ per day, corresponding to a decrease in available activity of 10% per year. For caesium it is $2.6 \cdot 10^{-3}$ per day. In /7/ this is quoted to correspond to a decrease of 61% per year, which is in contradiction to the value above: $2.6 \cdot 10^{-3} d^{-1} = 0.95 y^{-1}$ ($T_{1/2} = 8.9$ m) or 95%.

γ_{rd} describes the root uptake. For strontium it is $1.41 \cdot 10^{-4}$ per day, corresponding to an uptake of 5% per year. For caesium it is $6.31 \cdot 10^{-6}$ per day, corresponding to an uptake of 0.23% per year.

A.2.b Other agricultural products

Intake via other agricultural products is calculated using information from measurements during time periods when deposition of radioactive products from nuclear bomb tests was small. During these time periods most of the intake for the nuclides considered will be via root uptake. These measurements show that 1/3 of the uptake is via milk and 2/3 via other agricultural products for strontium. For caesium 1/4 is via milk and 3/4 via other agricultural products.

The daily intake calculated as described above is then integrated to infinity giving the total intake, called Concentration Factor, for an initial deposition of 1 Ci/m^2. Since it is based on the milk consumption rates of a small child these values apply for a member of the critical group of the population.

Appendix B

Summary of the MARC foodchain transport model

The dynamic foodchain transport model of MARC was originally designed for assessing the consequences of routine, continuous releases of radionuclides to the atmosphere and of accidental releases occurring at a specific time of the year (i.e. in summer). Since then the model has been developed further to enable the assessment of accidental releases at various times of the year.

The processes and parameters used to produce the results discussed in this report are summarized in the following sections. In section B.1 the element - independent parameters are given. Sections B.2 to B.4 deal with the specific features of the models for green vegetables, grain, and of the pasture - milk/beef-pathway. Only the basic features are given, a more comprehensive description of the processes involved and how they are modelled is given elsewhere.1)

B.1 Element-independent parameters

The element-independent parameter values for crops and pasture are collected in tab. B1, they represent average values appropriate for the UK.

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1) A general description of the (old) model is given in /9/ and /10/. The pasture-cow-milk-pathway is described in /15/. The revised model and parameters will be documented in /14/.

Tab. B1

Element-independent parameters for crops and pasture appropriate for the UK

Parameter	Value			
	Grain	Green Vegetables	Pasture grazed	Pasture hay/silage
Yield, fresh weight $kg \cdot km^{-2}$	4×10^5 1)	1×10^6	$1 \cdot 10^5$	$2 \cdot 10^5$ 2)
Interception factor	0.3/0.012 3)	0.3	0.25	0.45
Soil on plant surface % of dry plant weight	0.01 4)	0.1 5)	-	4
water content of plant %	0	90	80	80
Half-life on plant surface, d	14	14	14	14
soil density $g.cm^{-3}$(dry)	1.5	1.5	1.5	1.5
Depth of soil, cm	30	30	15	15
half life in 30 cm soil, a	100	100	50	50
activity retained after preparation %	10 6)	20 6)	-	-

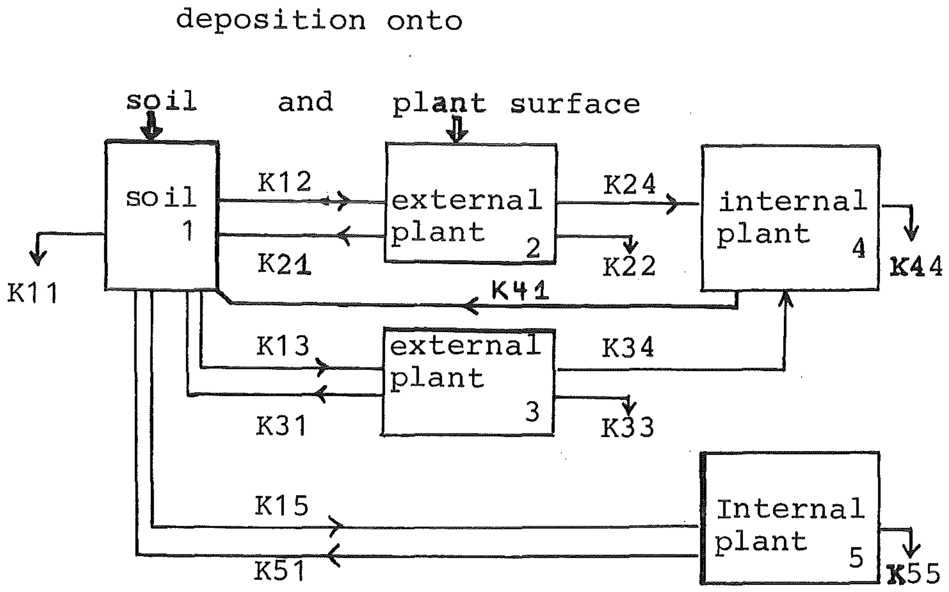
Notes:

1. Grain seed
2. Dry weight
3. First values for whole plant, second value for grain ears only
4. Before processing and removal of husks
5. Before kitchen preparation
6. Applies to surface contamination only

B.2 Green vegetables

Green vegetables are assumed to be produced continuously throughout the year. No processing (i.e. canning, freezing, drying) is taken into account, so that the vegetables are considered to be consumed immediately after harvesting.

The model for green vegetables is based on data for cabbage, its structure is illustrated below:



notes:

K22, K33, K44, K55 represent periodic cropping ($5.48 \cdot 10^{-3} . d^{-1}$)

K31, K51 are derived from K13 and K15 for fast equilibrium

Fig. B1: Structur of model for green vegetables

The soil is assumed to be well-mixed (box 1); the half life for leakage from soil is 100 y for all elements. Weathering of intercepted activity and initial resuspension is represented by box 2. Box 3 stands for the final soil contamination of the plant surface. Activity from the external plant can be translocated into the plant interior (box 4). Root uptake transfers activity from the soil into the plant (box 5). The parameters for root uptake and translocation are given in tab. B2.

Tab. B2

Parameters for root uptake and translocation in the model for green vegetables

	root uptake		translocation	
Element	Concentration factor 1)	K15 (d^{-1})	K24=K34 2) (d^{-1})	K41
Sr	$2 \cdot 10^{-1}$	$3.84 \cdot 10^{1}$	$2.46 \cdot 10^{-4}$	$1.35 \cdot 10^{-2}$
Cs	$2 \cdot 10^{-2}$	3.84	$2.34 \cdot 10^{-3}$	$3.43 \cdot 10^{-2}$
I	$2 \cdot 10^{-2}$	3.84	$2.34 \cdot 10^{-3}$	$3.43 \cdot 10^{-2}$
Ru	$4 \cdot 10^{-3}$	$7.68 \cdot 10^{-1}$	0	0

1) concentration factor = $\frac{\text{activity/unit wet weight plant}}{\text{activity/unit dry weight soil}}$

2) obtained by fitting to experimental data

B.3 Grain

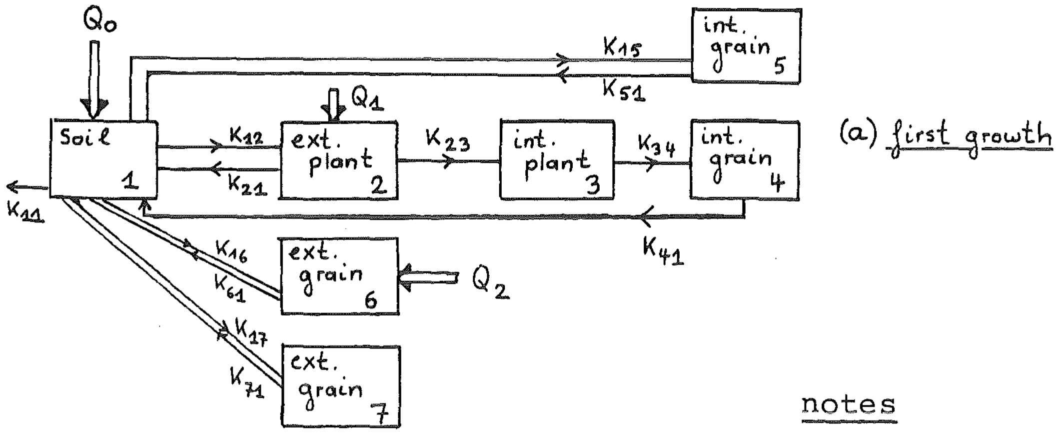
In the first two years, grain is assumed to grow for 123d from 1st of May to 31st of August, followed by a fallow period of 242d. In the subsequent years continuous harvesting is assumed. Taking the day of the assumed deposition as time zero, growth and fallow occur over the following times in the first two years after the accident:

day of deposition	fallow before deposition	growth before 1st harvest	fallow after first harvest	growth before 2nd harvest	fallow after 2nd harvest
		(all times in days)			
1st Febr.	0 - 89	90 - 212	213 - 454	455 - 577	578 - 730
1st Apr.	0 - 30	31 - 153	154 - 395	396 - 518	519 - 730
1st June	-	0 - 92	93 - 334	335 - 457	458 - 730
1st Aug.	-	0 - 31	32 - 273	274 - 396	397 - 730

The grain harvested at 1st of September is assumed to be consumed until next harvest, taking into account the radioactive decay over this time. In calculating the intake of activity in the first year after the deposition, the time between 1st harvest and end of year 1 after deposition must be determined:

day of deposition	1st Febr.	1st April	1st June	1st Aug.
time of consumption of 1st crop in 1st year after deposition (d)	153	212	273	334

The model for grain is based on data for wheat, the model structure is illustrated in fig. B2 and B3. The parameters for root uptake are given in tab. B3.



notes

Q_o : deposition onto soil

Q1, Q2 : deposition onto plant and grain

K11 : leakage from soil ($T_{1/2}=100y \mathrel{\widehat{=}} K11=1.9\cdot10^{-5}d^{-1}$)

K55, K77 : continuous cropping (1 yield/year $\mathrel{\widehat{=}} 2.74\cdot10^{-3}\ d^{-1}$)

K12 : initial resuspension } whole

K21 : weathering (*) } plant

K16 : initial resuspension } grain

K61 : weathering } only

K23 : } translocation of inter-

K34 : } cepted activity

K41 : derived for fast equilibrium

K15 : root uptake from soil

K51 : derived from K15 for fast equilibrium

K17 : final soil contamination of external grain

K71 : derived from K17 for fast equilibrium

(*) K21 : in case (b) represents transfer to soil by straw left on field and ploughed under

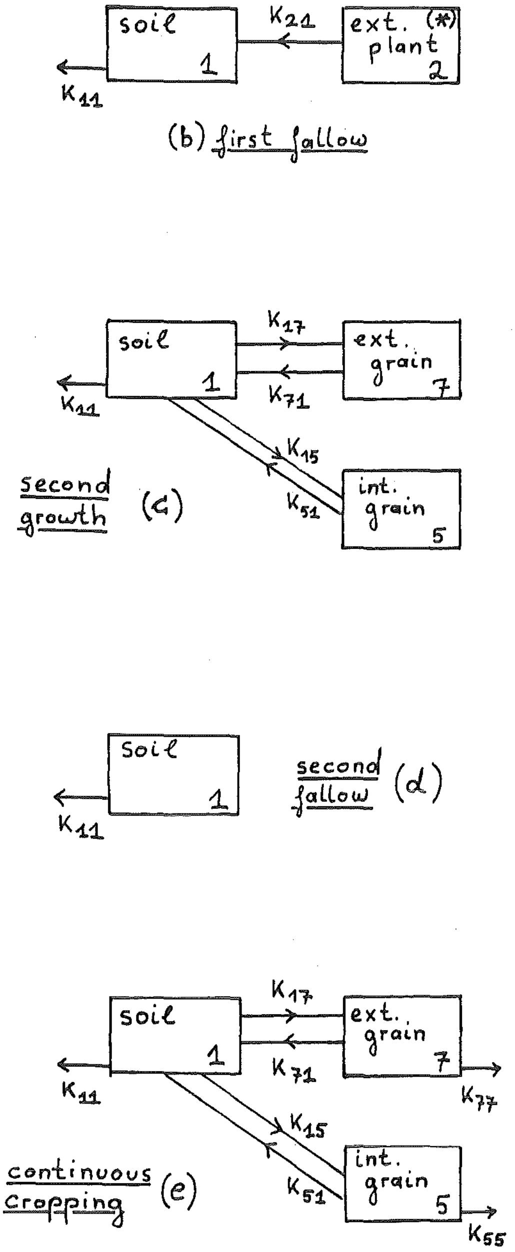
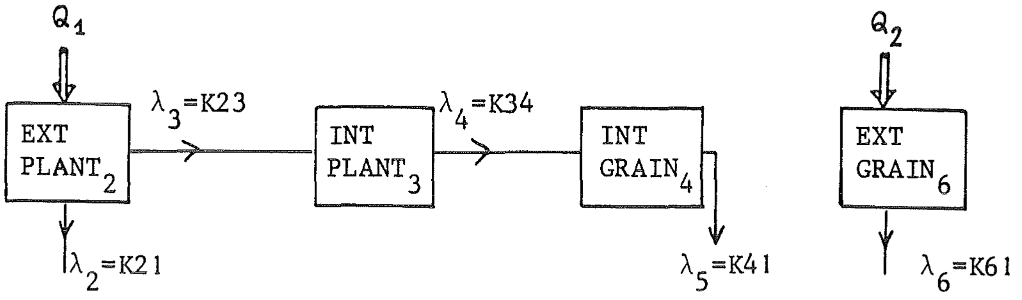


Fig. B2

Structure of the grain model

Fig. B3: Model for the deposition onto grain plants



Notes

a) The concentration in grain is obtained by summing the contributions from external and internal grain compartments.

b) Q1 and Q2 represent interception of the deposit by the whole plant and by the grain respectively. They have values of 0.3 and 0.012 respectively for all elements.

c) λ_2 and λ_6 represent losses due to weathering from the whole plant and the grain respectively. λ_2=4.95 10^{-2} d^{-1} and λ_6 = 4.82 10^{-2} d^{-1} for all elements.

d) The values of λ_3, λ_4 and λ_5 are obtained by fitting to experimental data and are element dependent. The values for strontium and caesium are:

Transfer coefficient	Strontium d^{-1}	Caesium d^{-1}
λ_3	3.7 10^{-2}	3.4 10^{-2}
λ_4	6.9 10^{-2}	6.4 10^{-2}
λ_5	4.5 10^{-1}	5.2 10^{-2}

In the model it is assumed that iodine behaves like caesium and that for ruthenium no translocation occurs.

Tab. B3: Parameters for root uptake of grain

Element	Concentration factor[1)]	K15 (d^{-1})
Sr	8.10^{-2}	6.14
Cs	$1\cdot10^{-2}$	$7.68\cdot10^{-1}$
I	$2\cdot10^{-2}$	1.54
Ru	$6\cdot10^{-2}$	4.61

[1)] concentration factor = $\frac{\text{activity/unit wet weight plant}}{\text{activity/unit dry weight soil}}$

B.4 Pasture-milk/beef

Cows are assumed to graze on pasture from 17th April to 30th October (198d) and stay indoors from 1st November to 16th April (167d). During this time they are fed hay or silage. The hay or silage is assumed to have the same concentration of radionuclides, on a dry weight basis, as the grass from which it is obtained. Harvesting is assumed to be continuous between 1st of May to 15th of September (138 days) at a rate equivalent to three complete cuts during this time. Hay/silage is then stored until 1st November (46 d), allowing for radioactive decay, and fed to the animals until the next 16th April (167 d). From the time when the cows return to pasture after the first winter after the accident, when the effect of the direct deposition on the pasture is no longer felt, they are assumed to graze outside permanently. The time schedules relative to the data of deposition are given below.

Time schedule for hay/silage model (all times in days)

day of deposition	pasture without harvesting	harvesting	storage	fed to animals (total)	fed to animals in 1st year after deposition
1st Febr.	0 - 89	89 - 227	227 - 273	273 - 440	92
1st April	0 - 30	30 - 168	168 - 214	214 - 381	151
1st June	-	0 - 107	107 - 153	153 - 320	-
1st Aug.	-	0 - 46	46 - 92	92 - 259	-

Time schedule for cow model (all times in days)

day of deposition	cows inside (fodder not yet contaminated)	cows outside	cows inside (fed contaminated fodder)	cows outside permanently
1st Febr.	0 - 75	73 - 273	273 - 440	≥ 440
1st April	0 - 16	16 - 214	214 - 381	≥ 381
1st June	-	0 - 153	153 - 320	≥ 320
1st Aug.	-	0 - 92	92 - 259	≥ 259

The following table gives the basic parameters of the cow-model:

Tab. B4

Basic parameters of the cow-model

depth of soil for root uptake	15 cm
half-life in 30 cm soil	50 a
yield of edible pasture	$5 \cdot 10^{5}$ kg·km^{-2} (wet weight)
soil contamination on plant	4%
grass consumption (dry weight)	12/15 kg·d^{-1} for pasture/hay
number of animals per km^{2}	250
resuspension coefficient	10^{-6} m^{-1}
deposition velocity	$3 \cdot 10^{-3}$ m·s^{-1}
inhalation rate	$1{,}5 \cdot 10^{-3}$ m^{3}·s^{-1}
lung class	W
gut transfer fraction	$5 \cdot 10^{-4}$
mean life for slaughter	6 a
milk production rate	10 l·d^{-1}
carcass/lean meat per animal	360/150 kg
weight of liver per animal	6 kg

The basic model for undisturbed pasture is illustrated in fig. B4 and tab. B5. The soil is subdivided into four layers (boxes 1-4) and a deep soil sink (box 5). From the top soil layer (box 1) the external plant can be contaminated by resuspension (k1 6) or by soil contamination (k1 7), and activity is removed from the external plant (box 6) by weathering processes (k2 1). For caesium, additional compartments are introduced to account for fixation in the clay components of the soil and for the possibility of contamination of the external plant by the fixed activity (fig. B5 and tab. B5). The internal plant compartments 8-10 represent root uptake from the first 15 cm of the soil.

Activity is transfered to the cow by consumption of pasture grass (k6 11, k8 11 to k10 11), soil consumption (k7-11) and inhalation of resuspended activity (k1 18, only for cows outdoors).

The features of the model for the cow's metabolism are shown in fig.B6 (p. 67) and the transfer coefficients are given in tab. B6 (p. 68). For iodine, account is taken of uptake by the thyroid and the different behaviour of the organic and inorganic fractions of iodine in the body. For strontium, recycling between the bone surface and the body fluids is considered. For caesium box 15 represents the diffusion from the blood to the rest of the body, and box 16 represents a slower concentration mechanism in the soft tissues. For ruthenium, a simpler model is used.

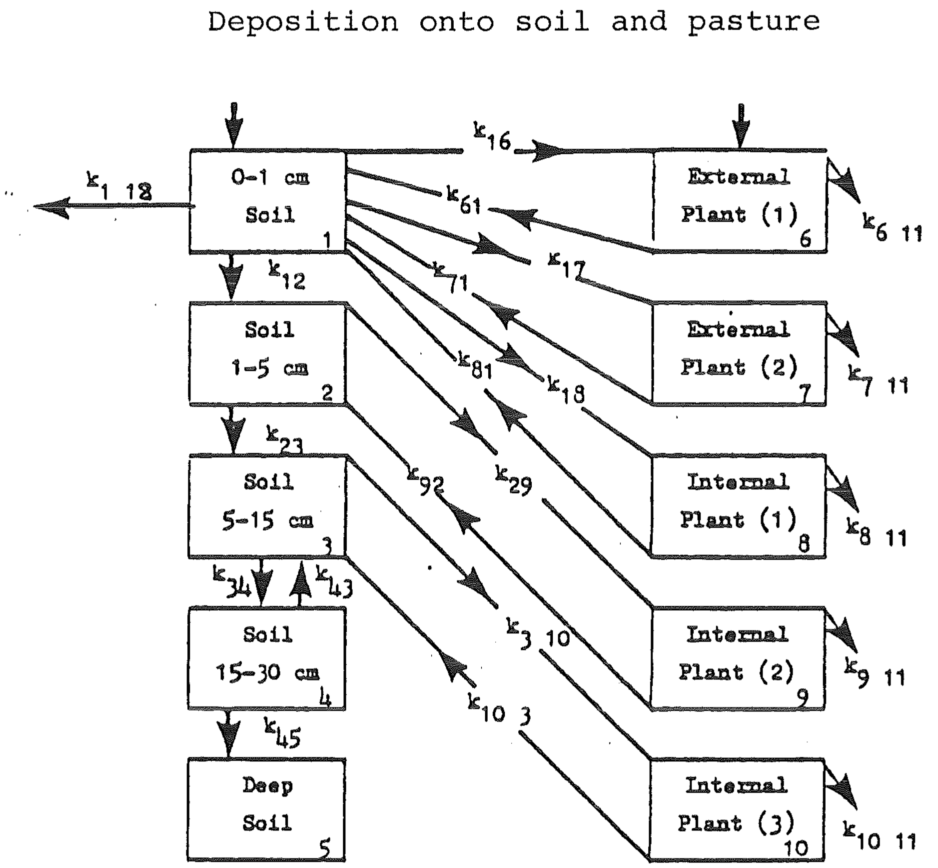


Fig. B4: Basic model of undisturbed pasture

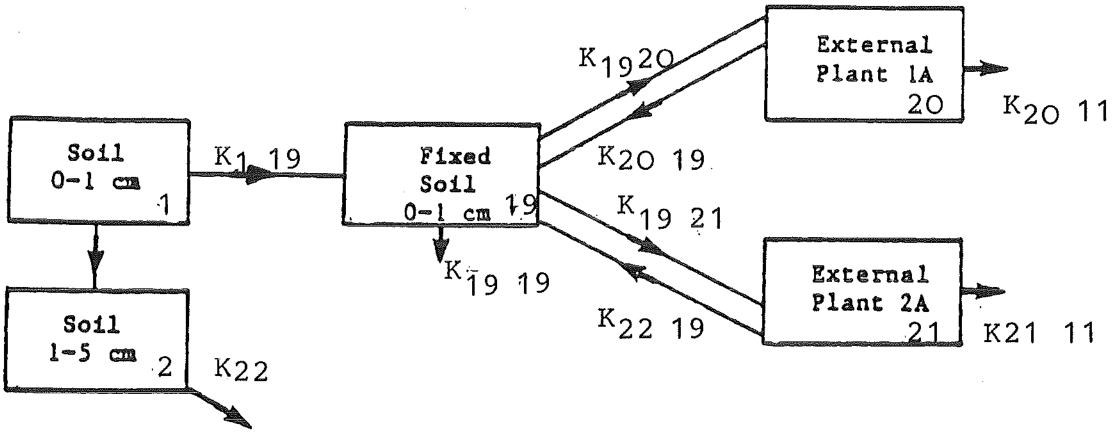


Fig. B5: Extended model for caesium (in connection with fig. B4)

Tab. B5

Transfer coefficients for pasture

a) Element-independent transfer coefficients

Transfer coefficient	Value d^{-1}	
	Pasture	Hay/silage
k_{12}	$6.65\ 10^{-4}$ 1)	$6.65\ 10^{-4}$ 1)
k_{23}	$1.72\ 10^{-4}$	$1.72\ 10^{-4}$
k_{34}	$1.07\ 10^{-4}$	$1.07\ 10^{-4}$
k_{43}	$4.03\ 10^{-6}$	$4.03\ 10^{-6}$
k_{45}	$3.80\ 10^{-5}$	-
k_{44}	-	$3.80\ 10^{-5}$
k_{16}	$6.48\ 10^{-6}$	$1.18\ 10^{-5}$
k_{61}	$4.95\ 10^{-2}$ 2)	$4.95\ 10^{-2}$ 2)
k_{17}	$2.31\ 10^{1}$	$4.98\ 10^{1}$
k_{71}	$8.64\ 10^{4}$	$8.64\ 10^{4}$
k_{81}	$8.64\ 10^{4}$	$8.64\ 10^{4}$
k_{92}	$8.64\ 10^{4}$	$8.64\ 10^{4}$
k_{103}	$8.64\ 10^{4}$ 3)	$8.64\ 10^{4}$ 3)
$k_{65}, k_{75}, k_{85}, k_{95}, k_{105}$	-	$2.17\ 10^{-2}$ 4)

Notes:

1. $k_{12} = 1.27\ 10^{-3}$ for strontium.
2. $k_{6\ 1} = 2.48\ 10^{-2}$ during winter months ie. November - April.
3. $k_{10\ 3} = 0.0$ for caesium.
4. In the hay/silage model, k_{65} to $K_{10\ 5}$ represent cropping. The deep soil sink is then represented by k_{44}.

b) Animal dependent

Transfer coefficient for cows	value (d^{-1})
$k_{6\ 11}, k_{7\ 11}, k_{9\ 11}, k_{10\,11}$	$3.00\ 10^{-2}$
$k_{1\ 18}$	$3.24\ 10^{-9}$

Tab. B5 cont'd

Transfer coefficients for pasture

c) Element-dependent transfer coefficient

Element		value d^{-1}			Concentration factor 1)
		$K_{1\,8}$	$K_{2\,9}$	$K_{3\,10}$	
Strontium	Pasture	$5.76\ 10^{2}$	$3.60\ 10^{1}$	$1.44\ 10^{1}$	$5 \cdot 10^{-2}$ 2)
	Hay/silage	$1.24\ 10^{3}$	$7.78\ 10^{1}$	$3.11\ 10^{1}$	$5 \cdot 10^{-2}$
Caesium	Pasture	$5.76\ 10^{1}$	$1.44\ 10^{1}$	0.0	$2 \cdot 10^{-2}$ 3)
	Hay/silage	$1.24\ 10^{2}$	$3.11\ 10^{1}$	0.0	$2 \cdot 10^{-2}$
Iodine	Pasture	$5.76\ 10^{1}$	$1.44\ 10^{1}$	5.76	$2 \cdot 10^{-2}$
	Hay/silage	$1.24\ 10^{2}$	$3.11\ 10^{1}$	$1.24\ 10^{1}$	$2 \cdot 10^{-2}$
Ruthenium	Pasture	$1.15\ 10^{1}$	$2.88\ 10^{1}$	$1.15\ 10^{1}$	$4 \cdot 10^{-2}$
	Hay/silage	$2.48\ 10^{2}$	$6.22\ 10^{1}$	$2.48\ 10^{1}$	$4 \cdot 10^{-2}$

Notes:

1. Concentration factor = $\dfrac{\text{activity/unit wet weight plant}}{\text{activity/unit dry weight soil}}$

3. This value applies to uptake from lower layers of soil, for the top 1 cm a value of 2·10−1 is appropriate

3. This is the initial value for the concentration factor but it is modified in time by fixation.

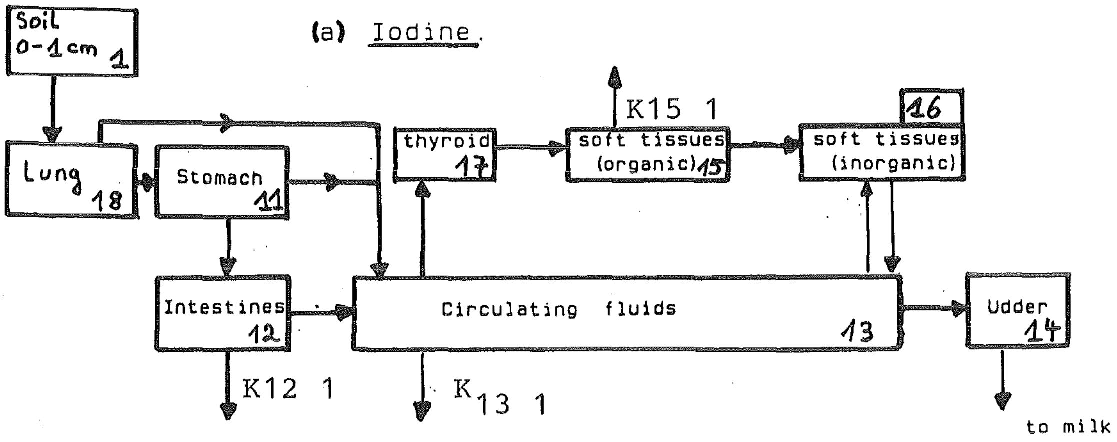
e) Additional parameters for caesium

$K_{1\,19}$	2.07E-3	$K_{19\,20}$	6.48E-6	$K_{19\,21}$	2.33E+1
$K_{2\,2}$	2.07E-3	$K_{20\,19}$	4.95E-2	$K_{21\,19}$	8.64E+4
$K_{19\,19}$	6.65E-4				

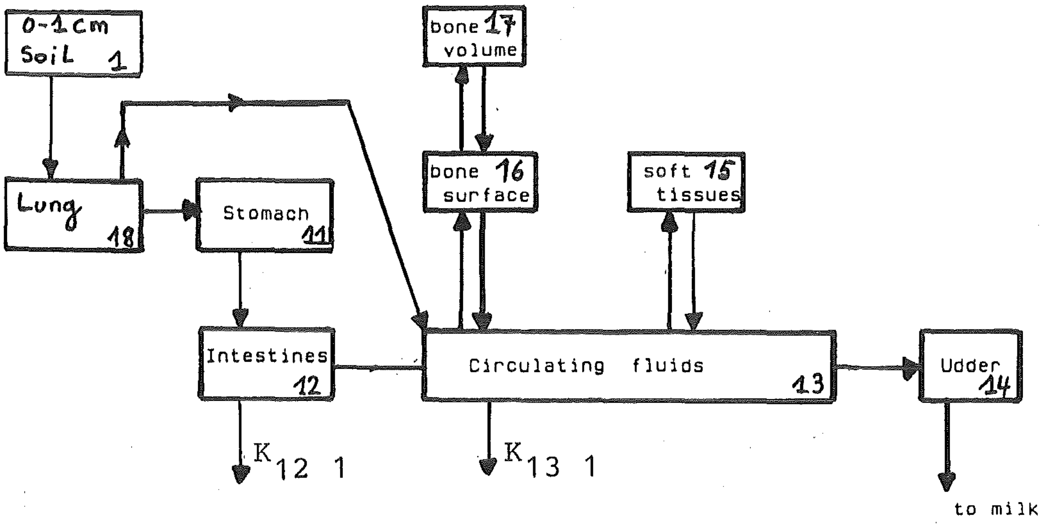
Note:

The values given are for pasture. For hay/silage, $K_{19\,20}$ = 1.18E-5 and $K_{19\,21}$ = 4.98E+1.

(a) Iodine



(b) Strontium



(c) Caesium

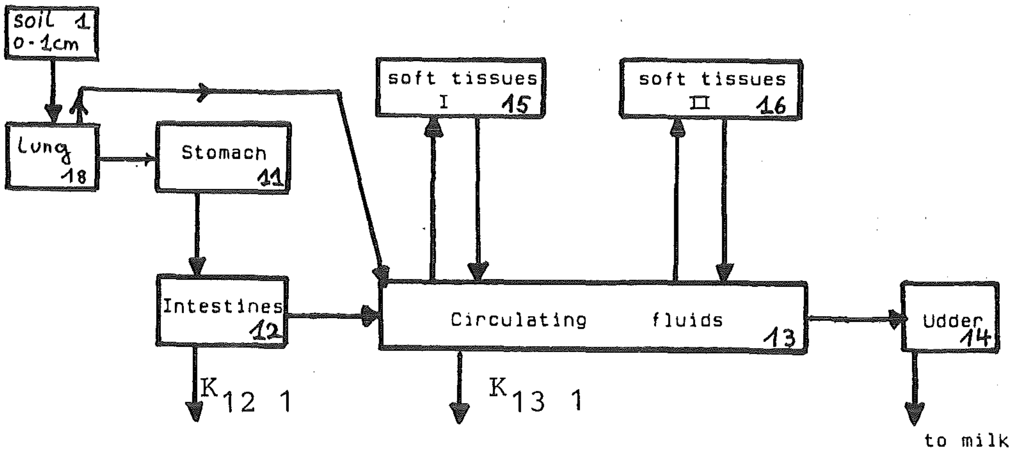


Fig. B6: Model of metabolism of cow

(e) Ruthenium

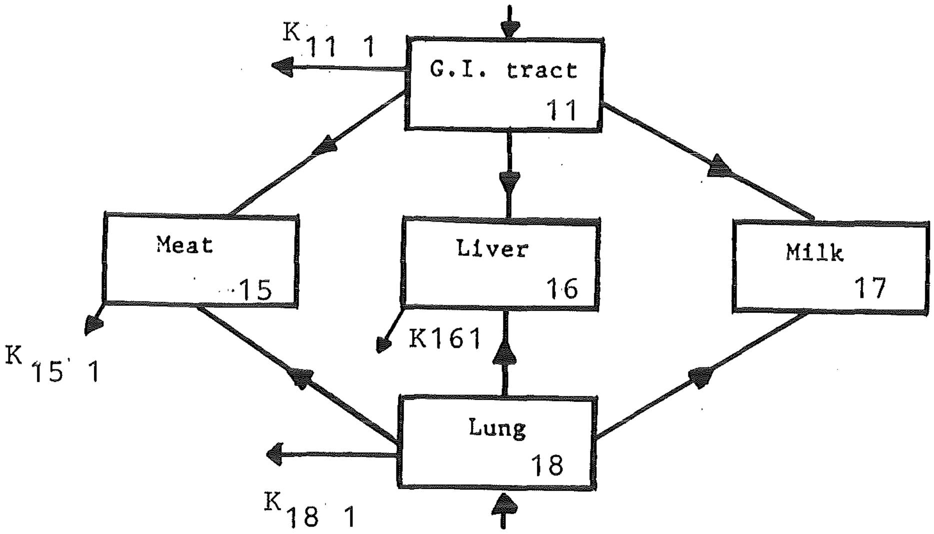


Fig. B6 cont'd: Model of metabolism of cow

Tab. B 6

Transfer coefficients for cow's metabolism

Fraction of the daily intake per litre of milk	
strontium	$1.4 \cdot 10^{-3}$
caesium	$7.1 \cdot 10^{-3}$
Iodine	$9.9 \cdot 10^{-3}$
Fraction of the daily intake per kg of muscle/liver	
strontium	$3.0 \cdot 10^{-4}$
caesium	$2.6 \cdot 10^{-2}$
iodine	$3.6 \cdot 10^{-3}$

Tab. B 6 cont'd

Transfer coefficients for cow's metabolism

(all units d^{-1})

	strontium	caesium	iodine 1)	ruthenium
K11 12	7.00E-1	7.00E-1	7.00E-1	-
K11 13	-	-	3.12	-
K11 15	-	-	-	6.86E-4
K11 16	-	-	-	1.79E-5
K11 17	-	-	-	6.60E-6
K18 11	2.11E+1	2.11E+1	2.11E+1	-
K15 16	-	-	1.68E-1	-
K17 15	-	-	1.23E-1	-
K16 17	1.10E-1	-	-	-
K17 16	8.91E-3	-	-	-
K12 13	5.56E-1	1.48E+1	4.08E+1	-
K13 14	1.26E-1	8.68E-2	3.00E-1	-
K13 15	2.24E-1	5.56E-1	-	-
K15 13	2.30E-1	2.97E-1	-	-
K13 16	1.61	2.53E-1	5.19	-
K16 13	6.43E-2	2.65E-2	1.96	-
K13 17	-	-	3.67E-1	-
K18 13	2.70E+1	2.70E+1	2.70E+1	-
K18 15	-	-	-	1.01E-3
K18 16	-	-	-	2.63E-5
K18 17	-	-	-	9.69E-6
K11 1	-	-	-	1.11
K12 1	5.00	5.00	5.00	-
K13 1	7.76E-1	8.27E-1	2.50	-
K15 1	-	-	1.45E-1	2.71E-3
K16 1	-	-	-	2.71E-3
K18 1	-	-	-	1.00
K14 14	4.00	4.00	4.00	-
K12 12, K13 13, K15 15, K16 16, K17 17, K18 18	4.57E-4	4.57E-4	4.57E-4	$4.57 \cdot 10^{-4}$

1) The transfer parameters for iodine have recently been revised. Given above are the old values.

Acknowledgement

The author is kindly indebted to Ms. Jane Simmonds, NRPB, for providing the FOODMARC data for the comparison and the helpful discussions about details of the foodchain model.

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