Foodchain modelling of Nordic conditions

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Published in:
EcoDoses: Improving radiological assessment of doses to man from terrestrial ecosystems

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Andersson, K. G., & Nielsen, S. P. (2009). Foodchain modelling of Nordic conditions. In S. P. Nielsen, & K. G. Andersson (Eds.), EcoDoses: Improving radiological assessment of doses to man from terrestrial ecosystems: A status report for the NKS-B activity 2006 (pp. 29-43). Roskilde: NKS. (NKS-184).

Nordisk kernesikkerhedsforskning
Norrænar kjarnöryggisrannsóknir
Pohjoismainen ydinturvallisuustutkimus
Nordisk kjernesikkerhetsforskning
Nordisk kärnsäkerhetsforskning
Nordic nuclear safety research

NKS-184
ISBN 978-87-7893-250-1

EcoDoses
Improving radiological assessment of doses to man from terrestrial ecosystems: A status report for the NKS-B activity 2006

Edited by Sven P. Nielsen and Kasper Andersson
Risø National Laboratory, Denmark

March 2009

Abstract

The overall aim of the NKS-B EcoDoses activity is to improve the prediction of doses to humans from consumption of radioactively contaminated food. For this purpose, various published and unpublished datasets have been compiled and applied in developing refined parameterisation for existing food dose models. The ECOSYS model developed in Germany after the Chernobyl accident has been applied as the basis for the investigations. This model can be operated both with discrete releases adequately representing a nuclear power plant accident, and with continuous or multiple releases, as observed in the nuclear weapons testing period. The modelling has revealed that it is essential to ensure that case-specific values are applied for a range of parameters, adequately reflecting the actual conditions with respect to geology, season, climate and demography. In connection with this year's work on the activity, sensitivity studies have been conducted with the ECOSYS model, in which the influence on ingestion dose estimates of a number of parameters has been evaluated in relation to Faroese conditions. The importance of applying location specific data to estimate dose is pinpointed, and it is also concluded that dose predictions for a small and distinct area like the Faroese, where not all of the many parameters required to run ECOSYS optimally have been adequately assessed in recent years, can be associated with considerable uncertainty. A Finnish study has been made in relation to modelling of radiocaesium behaviour in lakes. This study was carried out using a compartmental model that is included as a module in the DETRA dose assessment tool. A total of nine different input parameters (distribution coefficients, run-off from the catchment, erosion from the catchment, sedimentation rate in the lakes, lake water exchange rate, and biological half-lives in four fish species) were varied, and particularly distribution coefficients and lake water exchange rates were demonstrated to have high influence on doses. The model showed reliable performance when compared with Chernobyl data. Also a study of consumption habits and leaf area indices in Denmark has been made and the new datasets exhibit significant differences compared to the ECOSYS default values. ECOSYS model runs highlight the importance of these findings for dose estimates. Also the influence of local deviations in weathering half-lives, feeding regimes, aerosol particle sizes and deposition velocities have been studied.

Key words

Nuclear weapons fallout, deposition modelling, food-chain modelling, ecological half-lives radiological sensitivity, Chernobyl accident

NKS-184
ISBN 978-87-7893-250-1

Electronic report, March 2009

The report can be obtained from
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NKS-776
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DK - 4000 Roskilde, Denmark
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EcoDoses

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Edited by Sven P. Nielsen and Kasper Andersson

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Acknowledgment

NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

Contents

1 Introduction

The NKS B-programme EcoDoses activity started in 2003 as collaboration between all the Nordic countries. The aim of the activity is to improve the radiological assessments of doses to man from terrestrial ecosystems.

The EcoDoses activity focuses on collation and review of published and unpublished data from the Nordic countries for the nuclear weapons fallout period and the post-Chernobyl period. This includes data on radionuclides in air, precipitation and soil. Based on this, improved models for estimating radioactive fallout based on precipitation data during the nuclear weapons fallout period are developed. The data are used to compare modelling results with observed concentrations. The importance of applying case-specific and updated data of, e.g., geological, seasonal, climatic and demographic nature, in the modelling is demonstrated. In 2006 all groups have collecting data on precipitation for the prediction of historic fallout and collected information on values of model parameters representative of Nordic conditions. During the project period the participants have identified unclear points from using the model software and have addressed these to the model originator who subsequently has sent explanations and an updated version of the model software.

The present report sums up the work performed in 2006. In this third phase the main topics have been:

- Collection of precipitation data for prediction of historic fallout
- Adaptation of the ECOSYS model to local conditions in the Faroe Islands
- Uncertainty analyses for freshwater ecosystems
- Foodchain modelling of Nordic conditions

2 Adaptation of the ECOSYS model to local conditions in the Faroe Islands

Hans Pauli Joensen, University of the Faroe Islands, October 2006.

2.1 *Introduction*

One objective of the NKS ECODOSES project is to assess transfer of radionuclides to foodstuffs. The ECOSYS model can be used for this purpose.

ECOSYS is essentially the foodchain module in the European state-of-the-art decision support systems ARGOS and RODOS, currently used by some of the Nordic countries. The model was developed in the 1980's by Heinz Müller and Gerhard Pröhl at the company ConRad (e.g. Müller & Pröhl, 1993). The default model parameters refer to environmental conditions of Southern Germany, making parameter adjustments necessary when the model is to be used elsewhere.

This section presents results using the ECOSYS model with data from the Faroe Islands. It mainly concerns a sensitivity study of input parameters.

2.2 *Data and Parameters*

The site Sandur has been chosen for the study. Precipitation data are available for the period from May 1986 to December 1988. A time series for ^{137}Cs deposition at Sandur has been constructed for the same period (Fig. 2.1), using measurements of ^{137}Cs in precipitation from the capital Tórshavn.

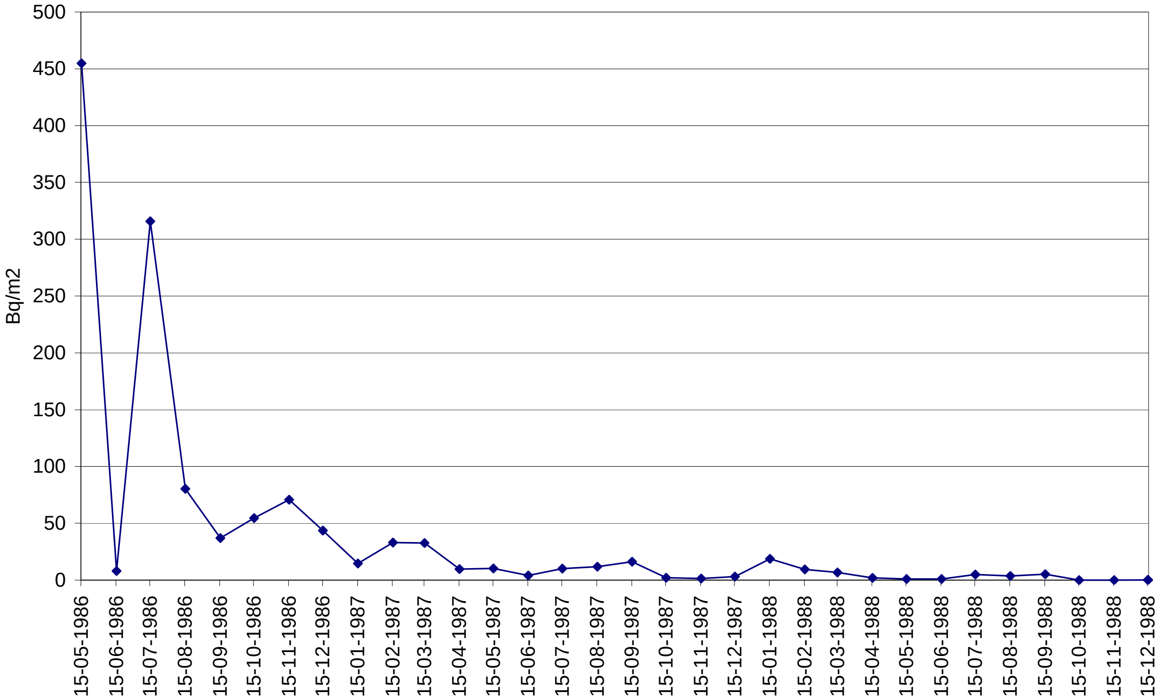

Figure 2.1. Cs-137 deposition (Bq/m^2) at Sandur from May 1986 to December 1988.

A radioecological study of semi-natural pastures has been carried out in the Faroe Islands during the 1990's (Joensen, 1999). The soil-to-grass transfer factor for ^{137}Cs at Sandur varies from 0.007 to 0.123 (using 10cm upper soil layer), with an average of 0.034 for the years 1990-99. The average value has been used in this study (Table 2.8), but the minimum and maximum have been used in test runs of the model as presented in Figs. 2.14 and 2.15. The soil-to-grass transfer factor in the ECOSYS model is defined as the ratio of the activity concentration in plant (fresh mass) and soil (dry mass).

The parameter settings are presented in Tables 2.1-2.8. Most of the local adjustments derive from personal communications, mainly with Mr. Peter Haahr and Mr. Gunnar Bjarnason.

Table 2.1. Yield of grass (kg/m² FM) and Leaf Area Index, LAI, for potatoes defined as ratio of the leaf area per unit soil area. A good correlation exists between the leaf area and the yield for grass.

	Adjusted Faroese data				German data			
	Grass intensive	Grass Extensive	Lawn	Potatoes	Grass intensive	Grass Extensive	Lawn	Potatoes
Date1	01-jan	01-jan	01-jan	01-jan	01-jan	01-jan	01-jan	01-jan
Yield1	0,02	0,02	0,02	0,00	0,03	0,03	0,03	0,00
Date2	15-mar	15-mar	15-mar	20-maj	15-mar	15-mar	15-mar	20-maj
Yield2	0,02	0,02	0,02	0,00	0,05	0,05	0,05	0,00
Date3	30-jun	30-jun	30-jun	15-jul	16-maj	30-jun	15-maj	01-jul
Yield3	0,40	0,40	0,40	4,00	1,50	1,50	0,30	4,00
Date4	06-jul	06-jul	06-jul	15-aug	31-okt	31-okt	31-okt	31-jul
Yield4	1,00	0,50	0,50	4,00	1,50	1,50	0,30	4,00
Date5	25-sep	25-sep	25-sep	15-sep	01-nov	01-nov	01-nov	15-sep
Yield5	0,20	0,20	0,20	0,00	0,05	0,05	0,10	0,00
Date6	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec
Yield6	0,02	0,02	0,02	0,00	0,03	0,03	0,03	0,00
Date7	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec
Yield7	0,02	0,02	0,02	0,00	0,03	0,03	0,03	0,00
Date8	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec
Yield8	0,02	0,02	0,02	0,00	0,03	0,03	0,03	0,00
Date9	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec	31-dec
Yield9	0,02	0,02	0,02	0,00	0,03	0,03	0,03	0,00
Begin growth	01-apr	01-apr		01-maj	15-mar	15-mar		20-maj
Begin grazing	01-jan	01-jan		01-okt	20-apr	20-apr		15-aug
End of grazing	31-dec	31-dec		10-okt	10-nov	10-nov		24-sep
Yield (FM, kg/m²)	time-dependent	time-dependent	time-dependent	3,0	time-dependent	time-dependent	time-dependent	3,0

Table 2.2. Preparation of Hay and Silage. Winter feed (hay and grass silage) in Germany is prepared during from 16 May to 15 September. The weighting factor in the German case means that from 16 May to 15 July a factor of 2 more winter feed is prepared than from 16 July to 15 September.

	Adjusted Faroese data	German data
Begin	01-jul	16-maj
End	15-aug	15-sep
End of 1st interval	15-aug	15-jul
Weighting factor of 1st interval	1	2

Table 2.3. Storage time (days) for feedstuffs. The storage times give the minimum time between harvest/production and consumption.

	Adjusted Faroese data	German data
Feedstuffs		
Grass Intensive	60	0
Hay Intensive	60	0

Table 2.4. Feeding (kg per day) of lactating sheep.

Adjusted Faroese data ("User defined")			German data		
Date	Feed1 / Index	Feed2 / Index	Date	Feed1 / Index	Feed2 / Index
	Grass, exten/3	Hay, inten/2		Grass, exten/3	Hay, exten/4
01-jan	9	0	01-jan	0	1,8
15-feb	6	1,5	20-apr	0	1,8
15-mar	6	1,5	10-maj	0	1,8
15-apr	6	1,5	20-okt	9	0
15-maj	9	0	09-nov	9	0
31-dec	9	0	31-dec	0	1,8

Table 2.5. Feeding (kg per day) of lamb.

Adjusted Faroese data ("User defined")			German data		
Date	Feed1 / Index	Feed2 / Index	Date	Feed1 / Index	Feed2 / Index
	Grass, exten/3	Hay, inten/2		Grass, exten/3	Hay, exten/4
01-jan	5	0	01-jan	0	1
15-feb	2,5	0,5	20-apr	0	1
15-mar	2,5	0,5	10-maj	5	0
15-apr	2,5	0,5	20-okt	5	0
15-maj	5	0	09-nov	0	1
31-dec	5	0	31-dec	0	1

Table 2.6. Age (days) at slaughter.

Animal	Adjusted Faroese data	German data
Cow	2190	1600
Sheep	2190	1600
Veal	550	100

Table 2.7. Soil mass given as (kg/m²). These values give the mass of soil in kg/m² (dry mass) to a depth of 25 cm for arable soil and of 10 cm for Pasture soil. These values are needed for the estimation of the activity concentration in soil. The adjusted value for pasture soil is based on measurements, while the value for arable soil is just multiplied by 2 in lack of better information.

Animal	Adjusted Faroese data	German data
Arable soil	162	350
Pasture soil	81	140

Table 2.8. Soil-to-Plant Transfer factors for Cs-137. The transfer factors are defined as the ratio of the activity concentration in plant (fresh mass) and soil (dry mass). The factor for intensive grass has been set equal to value for extensive grass in lack of better information.

	Adjusted Faroese data	German data
Grass Intensive	0,034	0,05
Grass Extensive	0,034	1

2.3 Method

The study involves 11 sequential changes of parameters, as described in Table 2.9.

Table 2.9. Description of the test runs of ECOSYS. The descriptions refer to previous tables.

Adjust-ment number	Adjusted parameters	Ref. Table
1	Beginning of growth. Beginning and end of grazing. Beginning and end of preparation of hay and silage.	2.1 2.2
2	Adj. 1 + Adjusted Dates and yields of grass and lawn	2.1
3	Adj. 2 + Adjusted storage times for intensive grass and intensive hay	2.3
4	Adj. 3 + Adjusted values for feeding of lactating sheep	2.4
5	Adj. 4 + Adjusted values for feeding of lamb	2.5
6	Adj. 5 + Adjusted values for age at slaughter	2.6
7	Adj. 6 + Adjusted values for soil mass	2.7
8	Adj. 7 + Adjusted values for soil-to-grass transfer factor for Cs-137	2.8
9	Adj. 8 + Adjusted values for beginning and end of harvest of potatoes	2.1
10	Adj. 9 + Adjusted soil-to-grass transfer factor for Cs-137 to 0.007 (min)	
11	Adj. 9 + Adjusted soil-to-grass transfer factor for Cs-137 to 0.123 (max)	

2.4 Results and discussion

The results are presented in Figs. 2.2-2.15. The adjustment numbers in Table 2.9 have been attached to the names of the data series in the figure legends.

No differences were observed by going from adjustment 2 to adjustment 3, except for cow milk. Number 3 in the figure legends therefore actually refers to adjustment 2 for all cases except cow milk.

The time series in Figs. 2.2 and 2.4 show the effect of the grazing period. Sheep, in particular, are allowed to graze throughout the year in the Faroe Islands, while the default grazing period in the model is from March to November.

Figs. 2.3 and 2.5 highlight the effect of adjusting the grass yield, the soil mass and the soil-to-grass transfer factor. The ^{137}Cs activity concentration is mostly affected in the summer period. The decreased transfer factor reflects lower ^{137}Cs activity concentration in extensive grass, but the vice versa tendency for intensive grass has not explained as yet. Decreasing the soil mass implies a higher ^{137}Cs activity concentration in both extensive and intensive grass.

Figs. 2.6 and 2.7 show the effect of local parameter settings for intensive hay. The time series is transformed in time because of adjustments of the beginning and end of preparation of intensive hay. The adjustments of the soil-to-grass transfer factor implied similar results as for intensive grass.

The results for lamb can be seen in Figs. 2.8 and 2.9. The adjustments of the beginning of growth and the beginning and end of grazing implied lower ^{137}Cs activity concentration as compared to the default German condition. The adjusted dates and yields of grass and lawn increased the activity concentrations in lamb as compared to the default German case in the early part of the period. The adjustment of lamb feeding decreased the activity concentration. Further adjusting the soil-to-grass transfer factor implied an expected additional decrease of the activity concentration in lamb. Adjustment of age at slaughter did not affect the results, as should be expected since the biological half-life of ^{137}Cs in lamb is short compared to the lifetime of the animal.

Adjusting the beginning of growth and the beginning and end of the grazing period did not make any changes in the ^{137}Cs activity concentration in cow milk as compared to German conditions (Figs. 2.10 and 2.11). Adjusting dates and yields of grass and lawn to Faroese conditions did, however, imply higher activity concentration in milk in the first part of the period. Adjustments of soil mass and soil-to-grass transfer factor did not imply further changes in the activity concentration.

An expected time delay of the ^{137}Cs activity concentration in potatoes was found as a consequence of adjusting the values for the beginning and end of harvest. A decrease is, however, seen in the early part of the period as compared to German conditions (Figs. 2.12 and 2.13). Adjusting the soil mass and the soil-to-grass transfer factor did practically not affect the activity concentration.

The results of adjustments 2.10 and 2.11 (cf. Table 2.9), i.e. running the model with minimum respectively maximum observed yearly average of the soil-to-grass transfer factor, can be seen in Figs. 2.14 and 2.15. The results reflect a range of activity concentrations as a consequence of natural variability of the soil-to-grass transfer factors.

2.5 Conclusion

The study confirms the importance of adjusting the default model parameters to local conditions. It should be noted that the ECOSYS model contains many parameters (many of which have not been discussed in this report) that for different reasons can be difficult to evaluate, simply because the data are not available. This means that there may be large uncertainties in evaluation of parameters, and consequently also large uncertainties in the output from the model.

2.6 References

Bjarnason, G.: Personal communication, 2006.

Haahr, P.: Personal communication, 2006.

Joensen, H.P., 1999. Long-term variation of radiocaesium in the food chain of lamb in the Faroe Islands. *Journal of Environmental Radioactivity*, 46.

Müller, H. & Pröhl, G.: ECOSYS-87: a dynamic model for assessing radiological consequences of nuclear accidents, *Health Physics* 64(3), 1993.

Müller, H. and Pröhl, G.: ECOSYS for Excel. A radioecological model for assessing contamination of foodstuffs and radiation exposure following a release of radionuclides. *ConRad Consulting in Radioecology.*

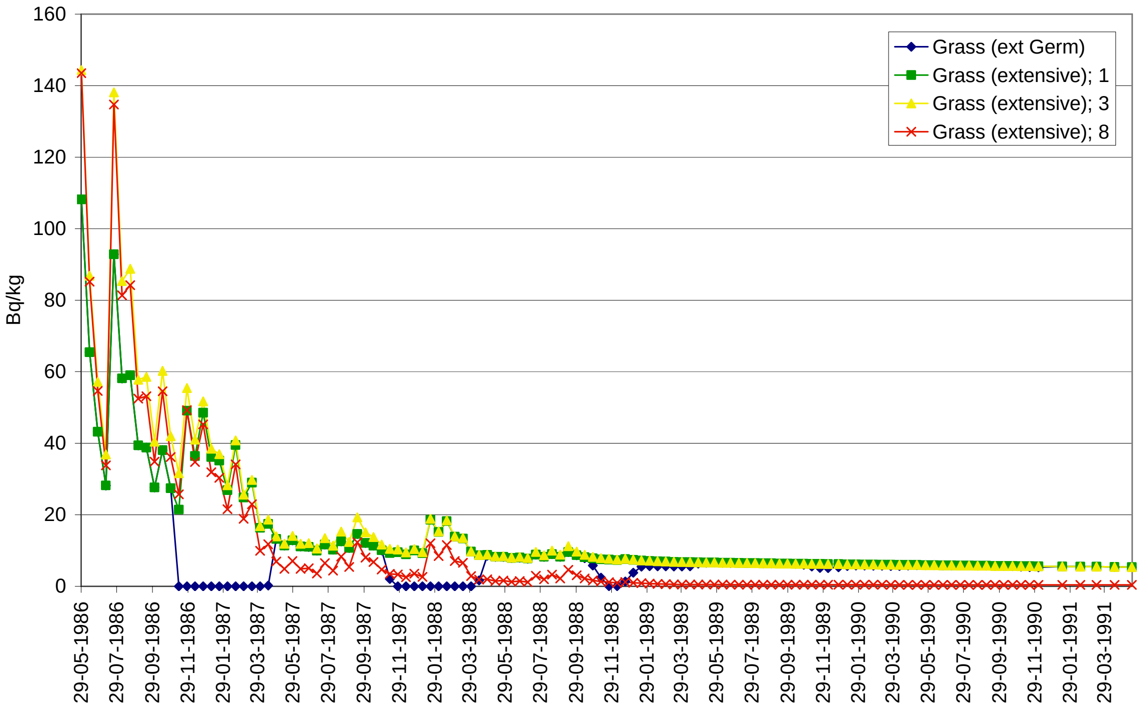

Figure 2.2. Cs-137 activity concentration in extensive grass. Results using German parameters are shown for comparison. Numbers in the legend refer to Table 2.9.

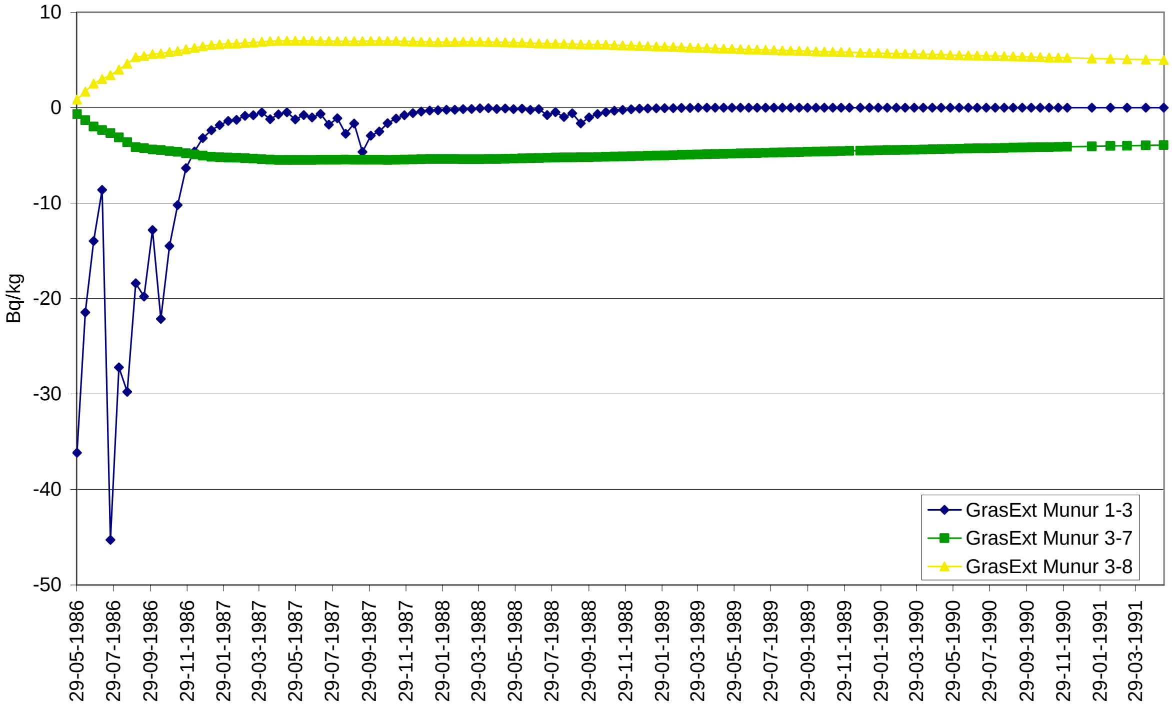

Figure 2.3. Differences in Cs-137 activities in extensive grass. The notation "1-3" denotes, e.g., difference between adjustments 1 and 3 in Table 2.9.

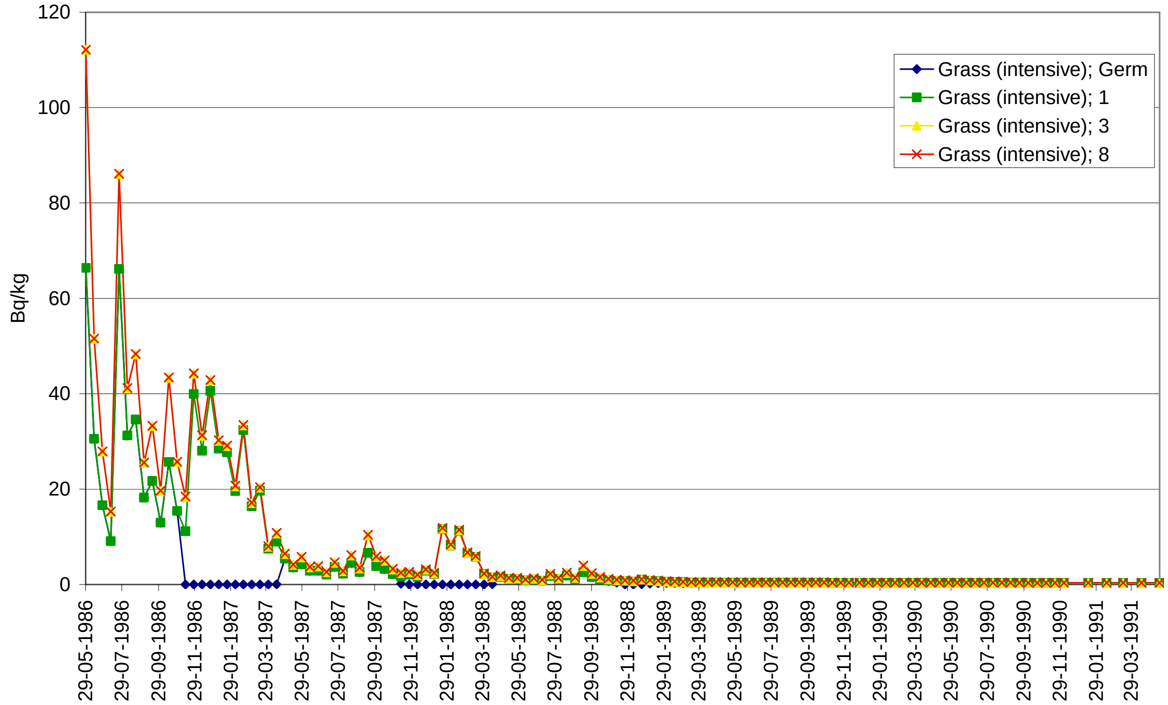

Figure 2.4. Cs-137 activity concentration in intensive grass. Results using German parameters are shown for comparison. Numbers in the legend refer to Table 2.9.

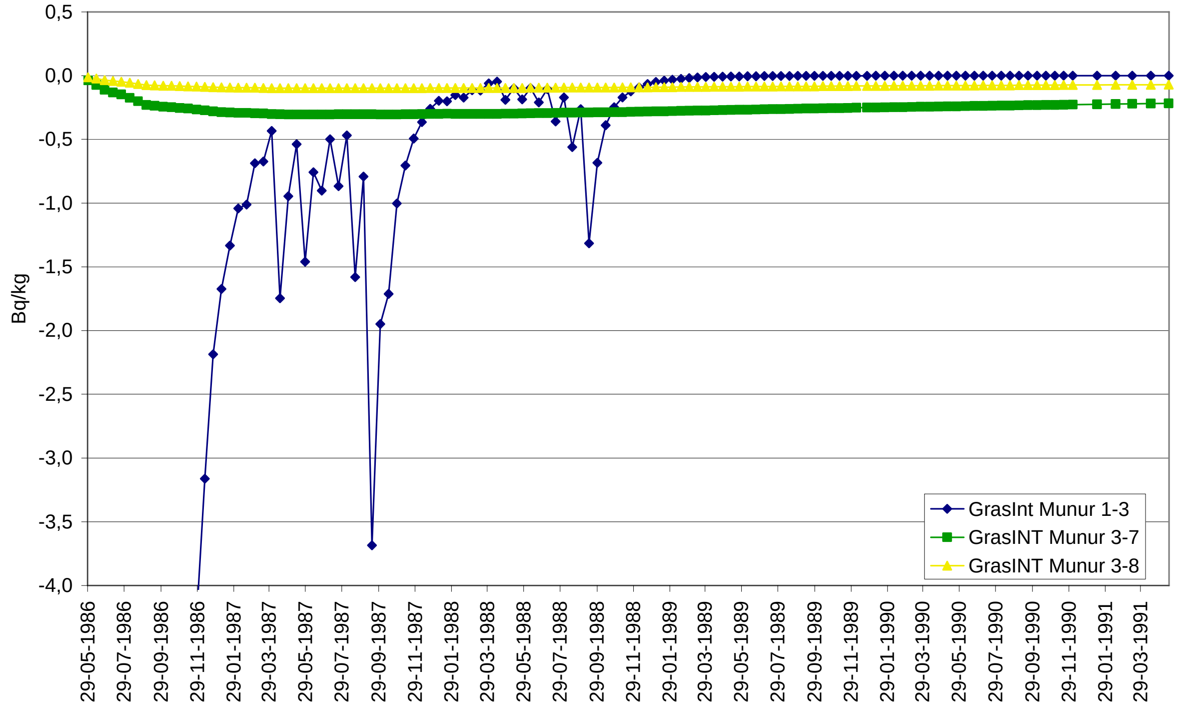

Figure 2.5. Differences in Cs-137 activities in intensive grass. The notation "1-3" denotes, e.g., difference between adjustments 1 and 3 in Table 2.9.

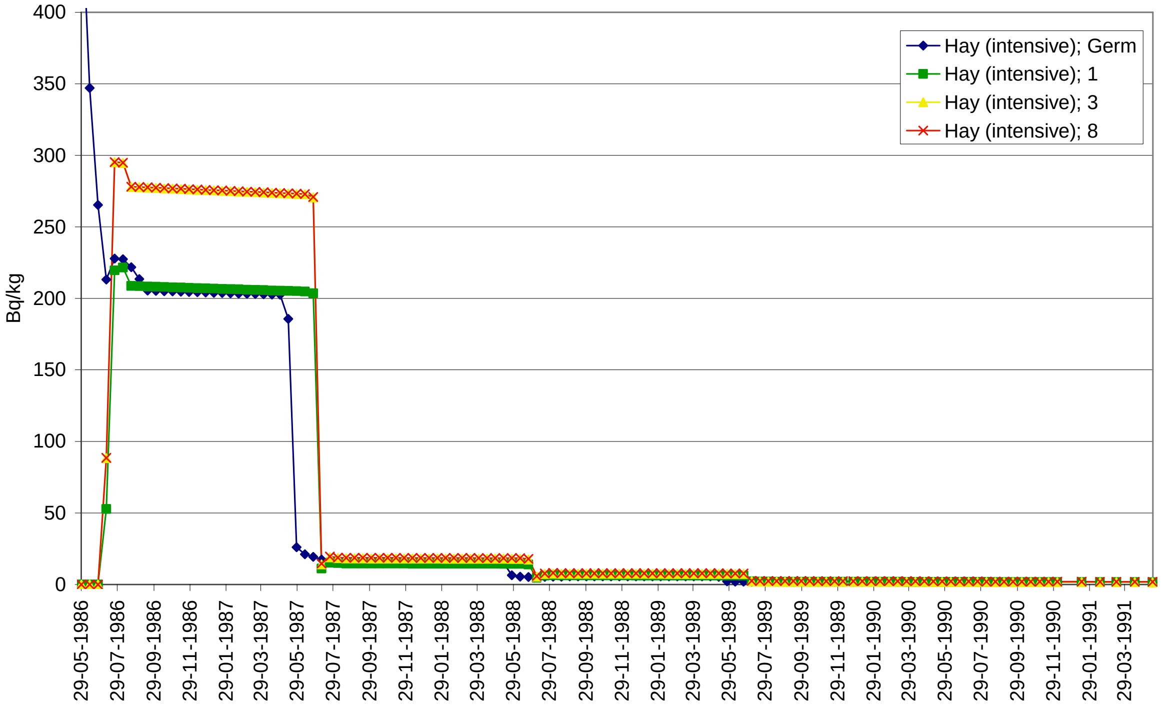

Figure 2.6. Cs-137 activity concentration in intensive hay. Results using German parameters are shown for comparison. Numbers in the legend refer to Table 2.9.

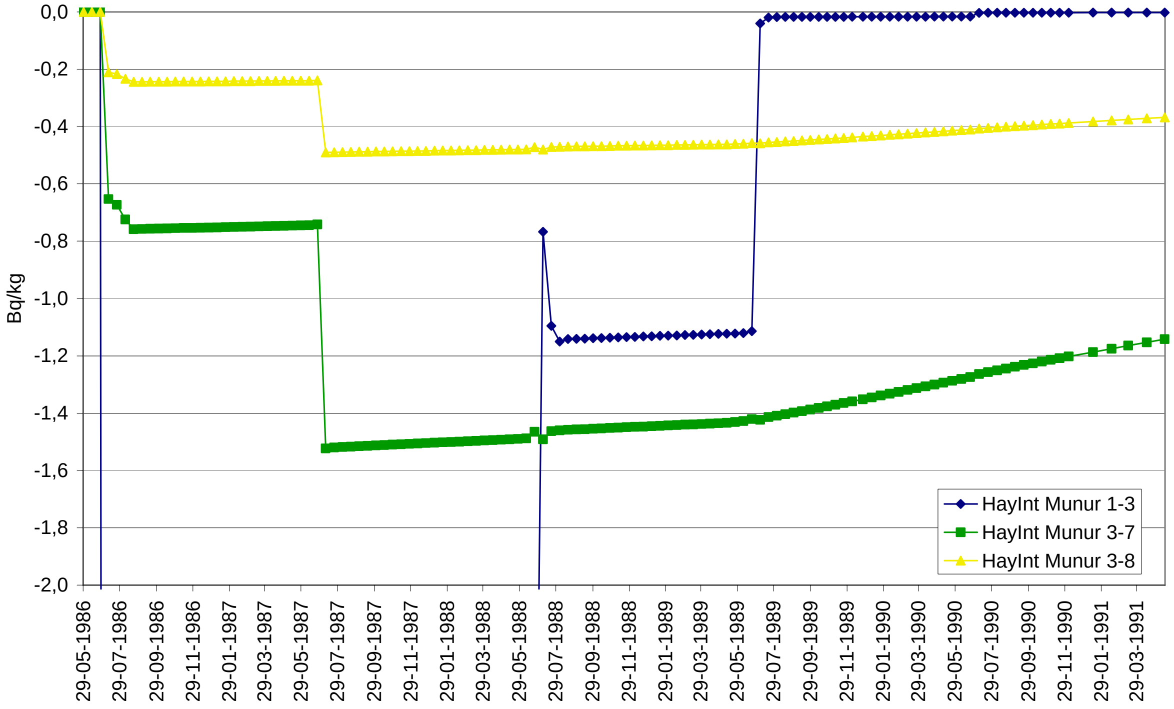

Figure 2.7. Differences in Cs-137 activities in intensive hay. The notation "1-3" denotes, e.g., difference between adjustments 1 and 3 in Table 2.9.

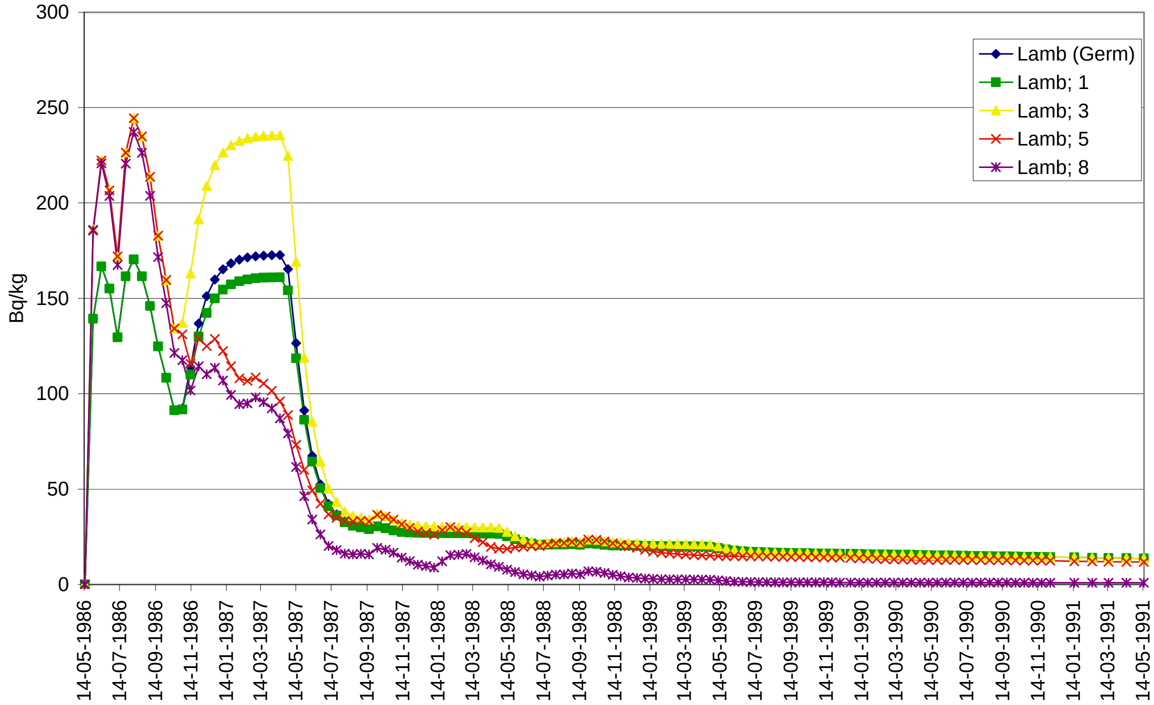

Figure 2.8. Cs-137 activity concentration in lamb. Results using German parameters are shown for comparison. Numbers in the legend refer to Table 2.9.

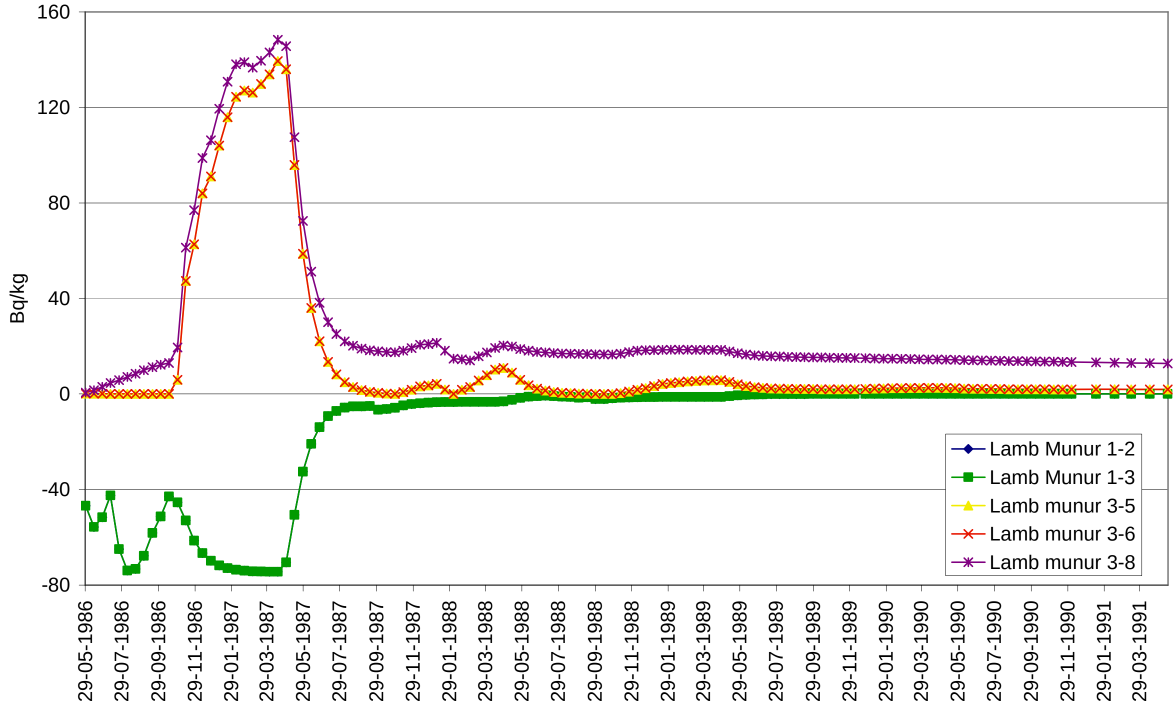

Figure 2.9. Differences in Cs-137 activities in lamb. The notation "1-3" denotes, e.g., difference between adjustments 1 and 3 in Table 2.9.

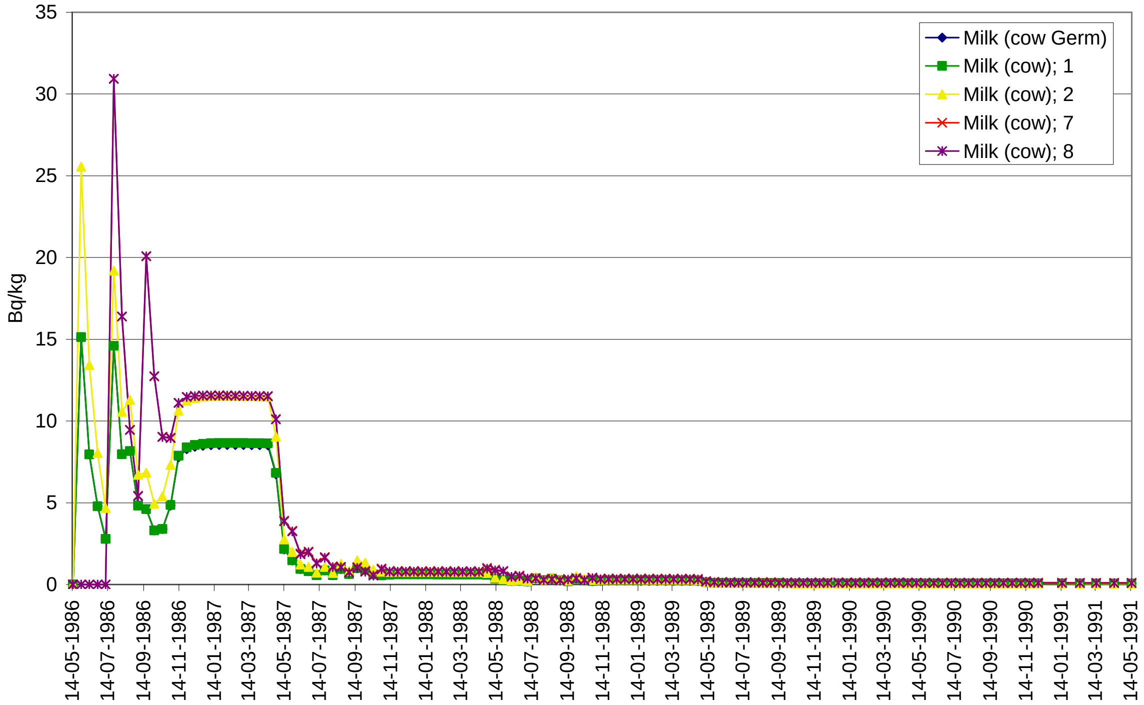

Figure 2.10. Cs-137 activity concentration in cow milk. Results using German parameters are shown for comparison. Numbers in the legend refer to Table 2.9.

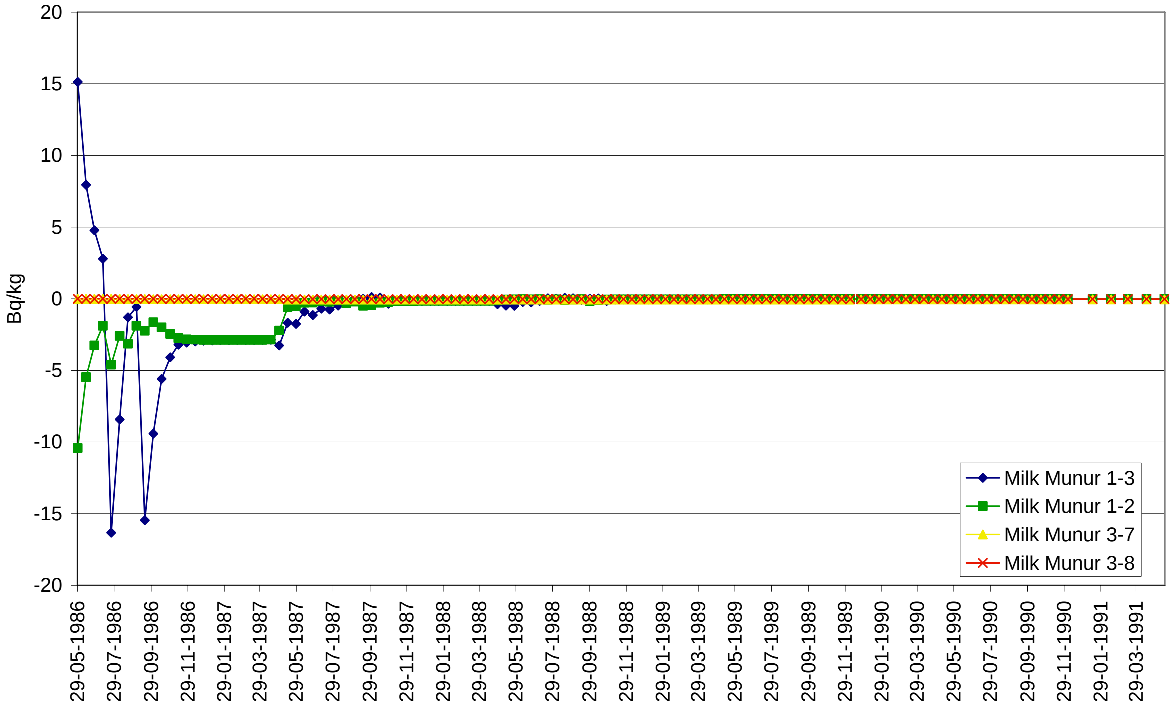

Figure 2.11. Differences in Cs-137 activities in cow milk. The notation "1-3" denotes, e.g., difference between adjustments 1 and 3 in Table 2.9.

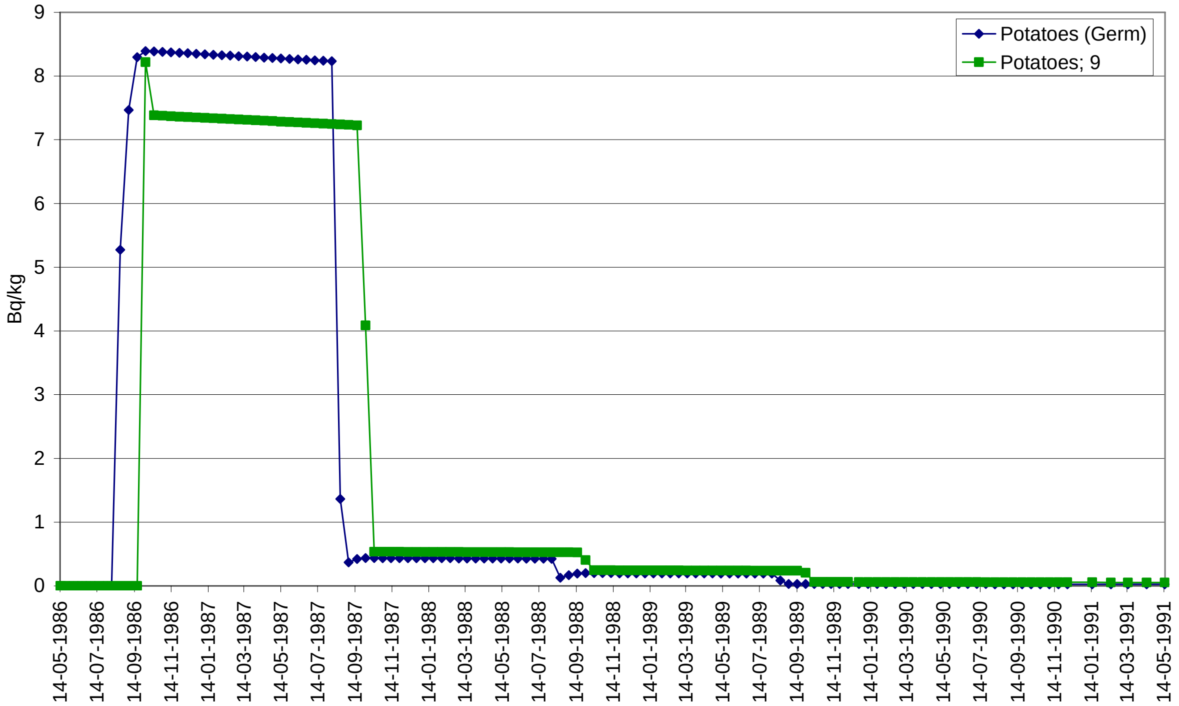

Figure 2.12. Cs-137 activity concentration in potatoes. Results using German parameters are shown for comparison. Numbers in the legend refer to Table 2.9.

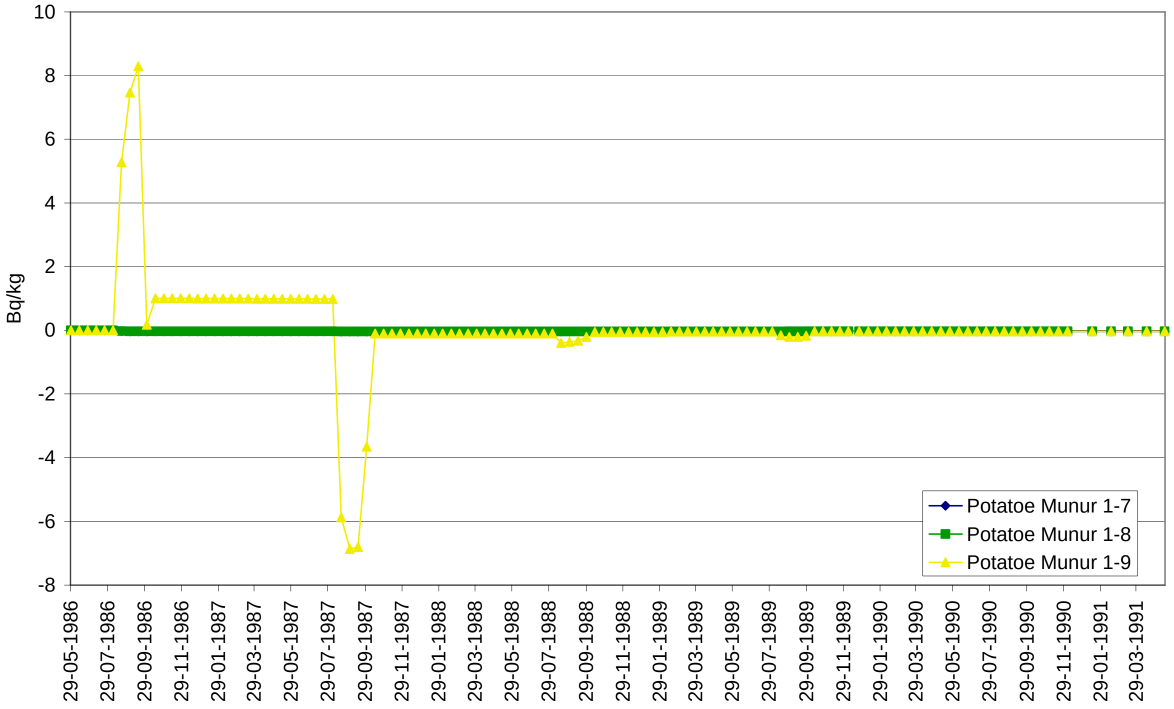

Figure 2.13. Differences in Cs-137 activities in potatoes. The notation "1-7" denotes, e.g., difference between adjustments 1 and 7 in Table 2.9.

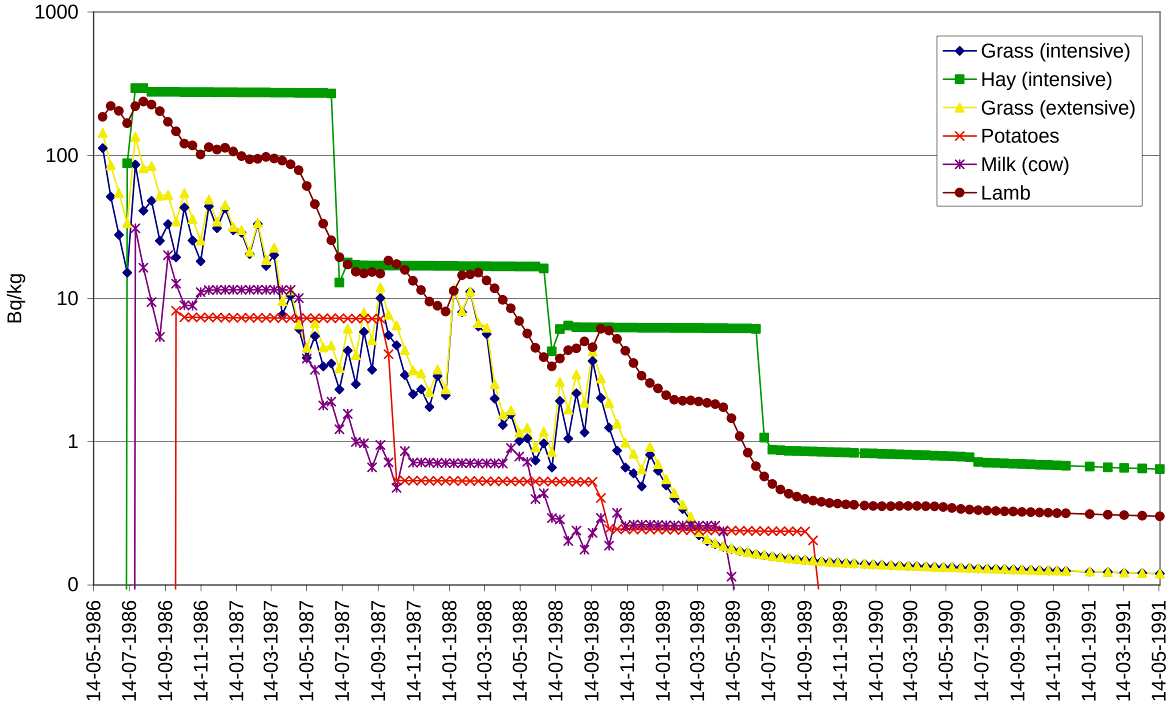

Figure 2.14. Cs-137 activity concentrations when the soil-to-grass transfer factor is set to the minimum yearly average observed at Sandur during the years 1990-99.

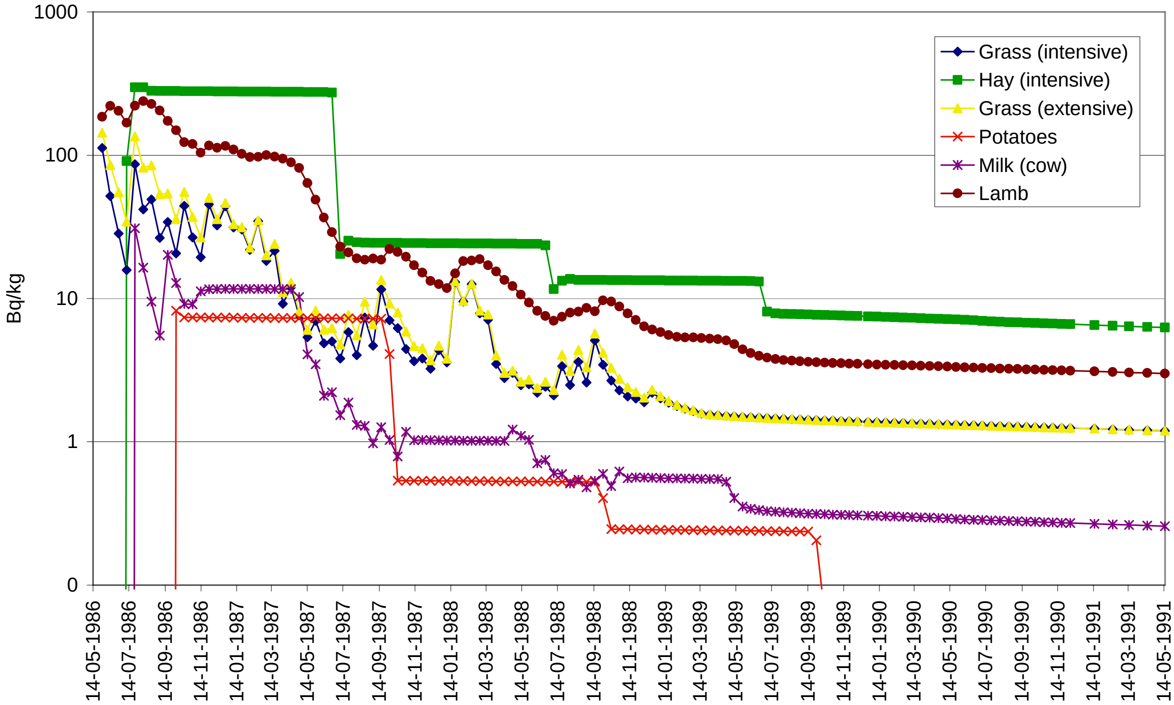

Figure 2.15 Cs-137 activity concentrations when the soil-to-grass transfer factor is set to the maximum yearly average observed at Sandur during the years 1990-99.

3 Uncertainty analyses for freshwater (lake) ecosystems

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3.1 Introduction

In this study uncertainties related to radionuclides transfer in Nordic type freshwater ecosystem will be analysed. The applied calculation model is DETRA with its uncertainty module [1]. Sensitivities of element specific and of system specific parameters will be studied.

The radionuclides dispersion in freshwater ecosystem (lake) was estimated by a compartmental model. The dynamic model consists of a lake model and of a fish chain model. For illustrating the time dependent behaviour of concentrations, an example of a deterministic calculation case was also carried out. In uncertainty analyses, nine most relevant input parameters were selected as varied parameters. After computer runs the result distributions of concentrations will be studied. Ranking of input parameters were qualitatively and partly also quantitatively performed. The dose estimates will also be shortly produced. The main purpose of this study is to find the parameters which contribute most to the uncertainty of concentration results in freshwater ecosystem.

3.2 Conceptual dispersion model applied

3.2.1 Model

The applied model for dispersion of radionuclides in Nordic freshwater ecosystem was based on compartmental modelling approach (Fig. 3.1). In each of the selected model compartments sufficient homogenization of concentrations were assumed to happen in a relative short period of time. Radionuclides transfer between compartments was assumed by convective carry flows of water and suspended sediment material. As consideration of radionuclides transfer, the main flow rates are generally related to lake water turnover and to sedimentation of suspended material from water to lake bottom sediment layer. Additionally, there are also other important transfer mechanisms like erosion from catchment towards lake recipient. This erosion can be caused by runoff and by wind induced erosion where radionuclides are first dispersed into the atmosphere and further deposited onto the lake surface.

Although in this study the ultimate target will be to analyze uncertainties related to radionuclides transfer in Nordic freshwater ecosystems, some characteristic model parameter values are indicated in the following (Table 3.1). Mechanisms which tend to dilute (e.g. lake water turnover) or on the other hand mechanisms which tend to concentrate (e.g. sedimentation rate) are essential factors when estimating the build up of radionuclide concentrations in various parts of the considered freshwater ecosystem. Additionally, the element specific sorption features determine the final distribution between water phase and solid matter. Therefore, the soluble nuclides are mainly carried by water and strongly sorbing nuclides are mainly carried by solid matter (sedimentation).

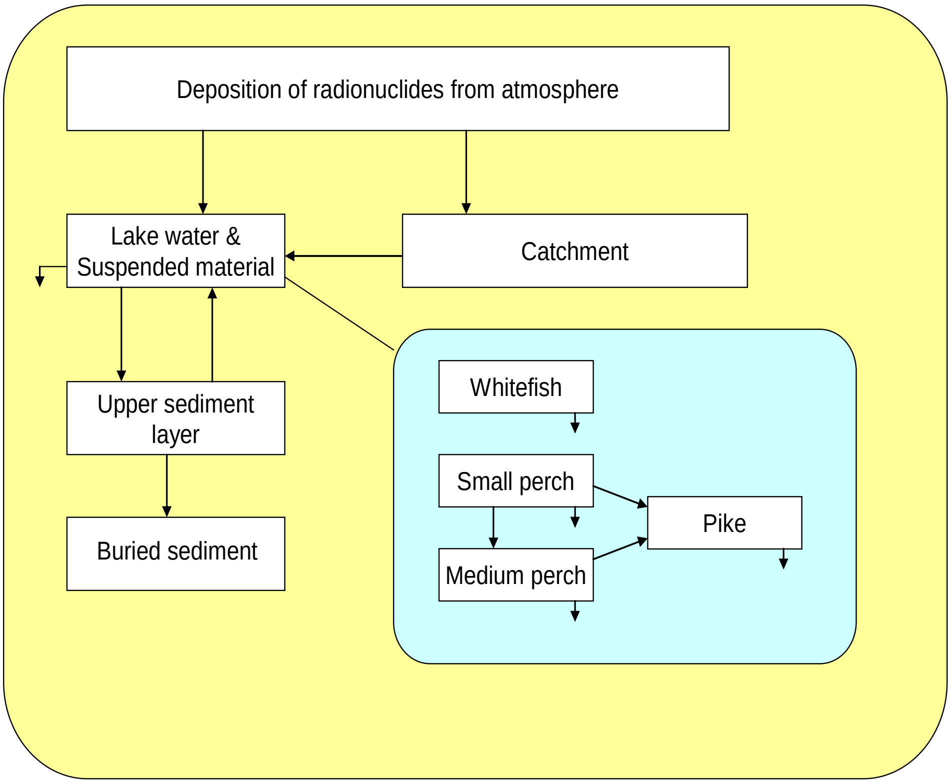


Fig. 3.1.Conceptual model for radionuclides dispersion in Nordic freshwater ecosystem. Dynamic fish contamination model is included.

3.2.2 Deterministic calculation case

In order to illustrate the development of concentration responses in freshwater ecosystem after deposition, the results of a deterministic calculation case (i.e. one round calculation) is presented in Fig. 3.2. The assumed instantaneous deposition amount was 10 kBq(Cs-137)/m^2, which represents about the average deposition in the southern part of Finland after the Chernobyl reactor accident [2].

For other deposition amounts, one can approximate the arising concentrations by simply multiplying presented concentration values with deposition proportional coefficient.

Table 3.1. Some default type parameter values for characterization of the lake model.

Parameter	Value
Lake area	1 km^2
Average depth of lake	2.5 m
Lake water turnover	2 times / year
Suspended sediment load of lake water	1.5 g$_s$/m^3
Sedimentation rate	0.5 kg$_s$/m^2/year
Resuspension of solid matter to lake water	10 % of sedim. rate
Water volume fraction in sediments	
· upper layer (0- 5 cm)	90 %
· buried (5-35 cm)	72 %
Catchment area	2 km^2
Effective infiltration of water at catchment	
i.e. precipitation – evaporation	200 kg$_w$/m^2/year

From the graph it can be seen that cesium concentration in lake water decreases relatively rapidly mainly due to effective dilution. In the later phase, after one or two years, the so called secondary source term from catchment to lake maintains certain concentration level in the lake water. Cesium transfers from catchment to lake water with runoff and with wind induced erosion via the atmosphere. In the consideration of sediments, the upper layer concentrations increase first and the buried layer concentrations are build up in the later phase. The concentration responses of prey fish occur quite soon, but the maximum of predatory fish concentration can be seen after certain period of time. Predatory fish is placed later in the food chain than prey fish and biological half-life of predatory fish is also longer compared to prey fish. Cesium concentration in soil layer of catchment is estimated to decrease very slowly. Studies after Chernobyl deposition confirm that cesium was effectively sorbed on e.g. forest soils containing organic compounds.

3.3 Uncertainty analyses

3.3.1 Varied parameters and distributions

The used uncertainty module of DETRA model allow as such variation of all the input parameters related to a certain calculation case. However, due to experience gathered of several simulations of radionuclides transfer in aquatic environment, only a representative group of parameters (Table 3.2) were selected for uncertainty considerations. Simplified uncertainty analyses have earlier shown that these major parameters potentially contribute to quantitative predictions of biospheric dispersion analyses. The probability distributions applied for varied parameters were truncated Gaussian (normal and logarithmic) and triangular. The means and standard deviations of parameter values were based on model specific selection of Finnish lake ecosystem and e.g. element specific K_d-values on international publication of environmental parameter values [3]. Additionally earlier projects with Finnish Centre for Radiation and Nuclear Safety (STUK) were utilized when selecting parameter values. An example distribution of one of the nine varied input parameters is presented in Fig. 3.3.

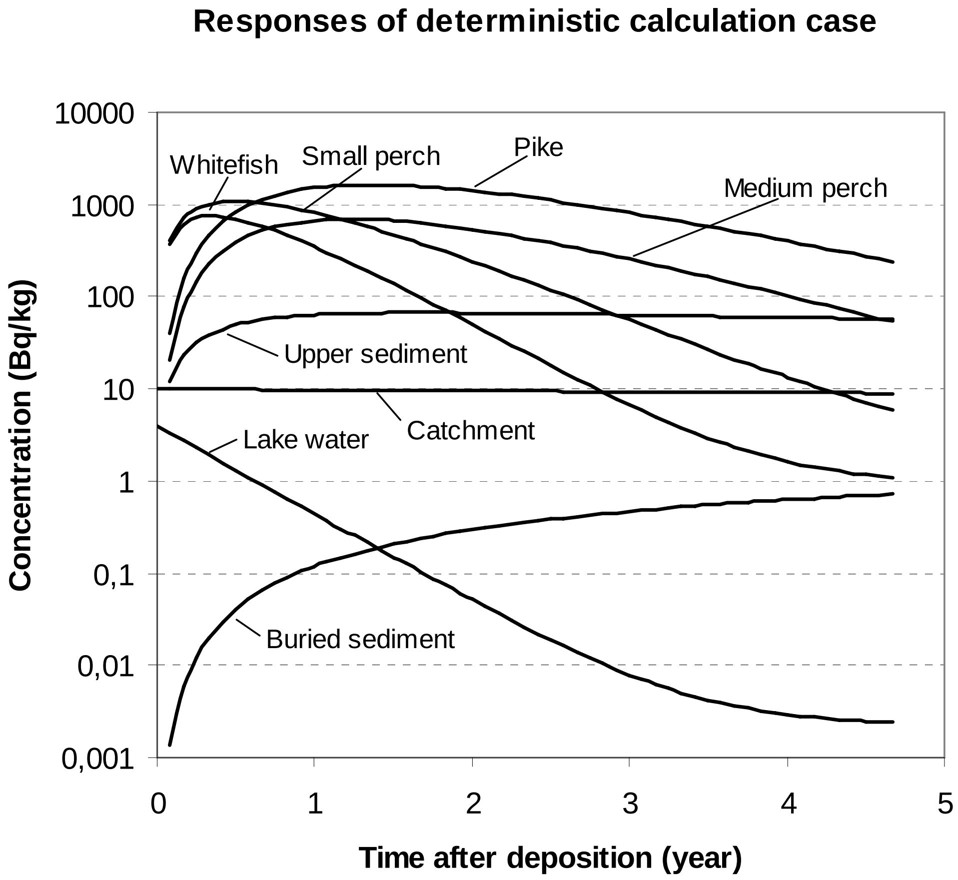


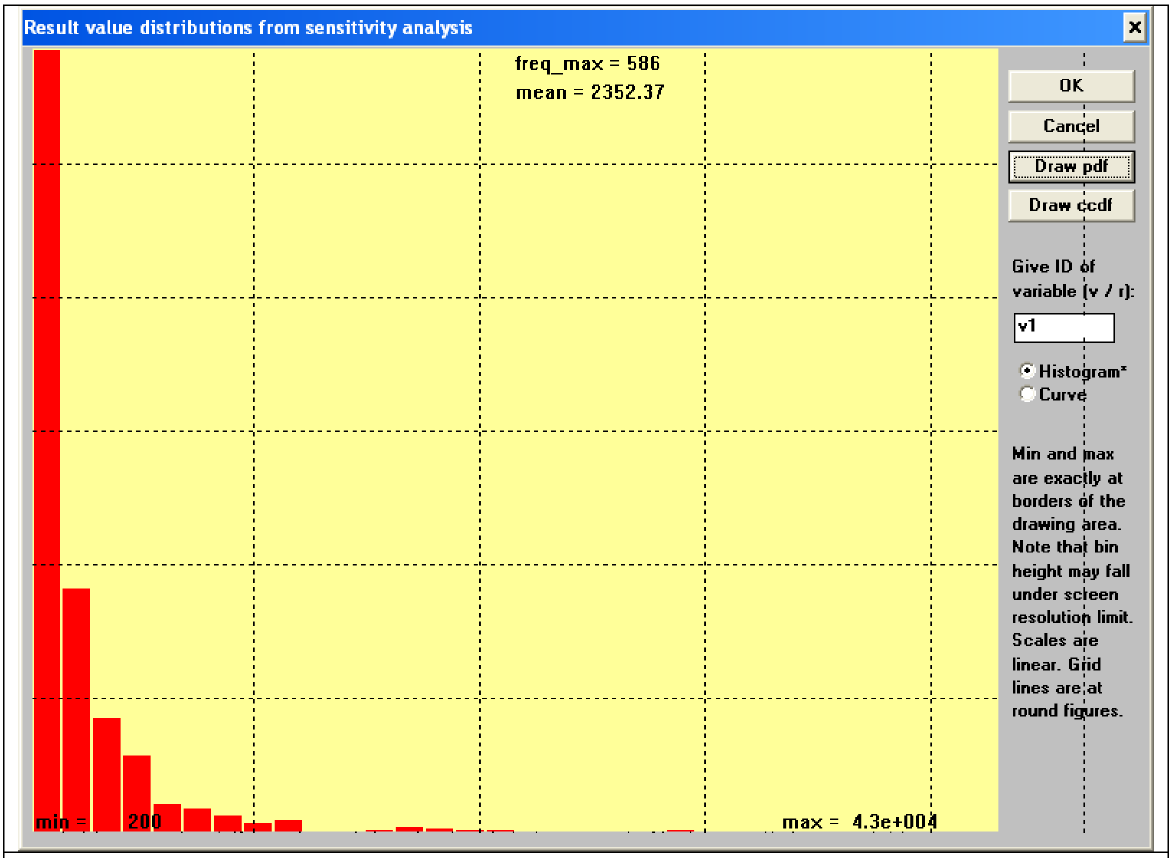
Fig. 3.2. Concentrations in freshwater ecosystem after a 10 kBq(Cs-137)/m^2 deposition.

Table 3.2. Varied parameters, distributions and characteristic values used in analyses.

Parameter	Distribution	mean (μ)	std_dev (σ)	min	max	peak
K_d (Cs)	log truncated Gaussian	3* (1000)	0.54* (3.5)	2.30* (200)	4.78* (60000)	
R_w	triangular			1.47E+08	8.84E+08	4.42E+08
E_s	truncated Gaussian	3.30E+05	1.15E+05	9.90E+04	5.60E+05	
S_s	truncated Gaussian	5.00E+05	1.75E+05	1.50E+05	8.50E+05	
Q_w	triangular			1.67E+09	1.00E+10	5.00E+09
$T_{½,b1}$	truncated Gaussian	70	10.5	49	91	
$T_{½,b2}$	truncated Gaussian	200	30	140	260	
$T_{½,b3}$	truncated Gaussian	250	37.5	175	325	
$T_{½,b4}$	truncated Gaussian	300	45	210	390	

*) as they are input in DETRA

K_d (Cs)	is distribution coefficient for Cesium (Bq/kg$_s$)/(Bq/litre$_w$)
R_w	is effective runoff from catchment into lake (kg$_w$/year)
E_s	is erosion from catchment to lake (kg$_s$/year)
S_s	is sedimentation rate (kg$_s$/year) ; 5.00E+05 kg$_s$/year corresponds to about 0.5 kg$_s$/m^2/year
Q_w	is lake water exchange rate (kg$_w$/year) ; 5.00E+09 kg$_w$/year corresponds to lake water turnover value of 2 times per year in this case
$T_{½,b1}$	is biological half-life of whitefish (day)
$T_{½,b2}$	is biological half-life of small perch (day)
$T_{½,b3}$	is biological half-life of medium perch (day)
$T_{½,b4}$	is biological half-life of pike (day)



freq_max = 586

mean = 2352.37

min = 200

max = 4.3e+004

v1

● Histogram*

○ Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

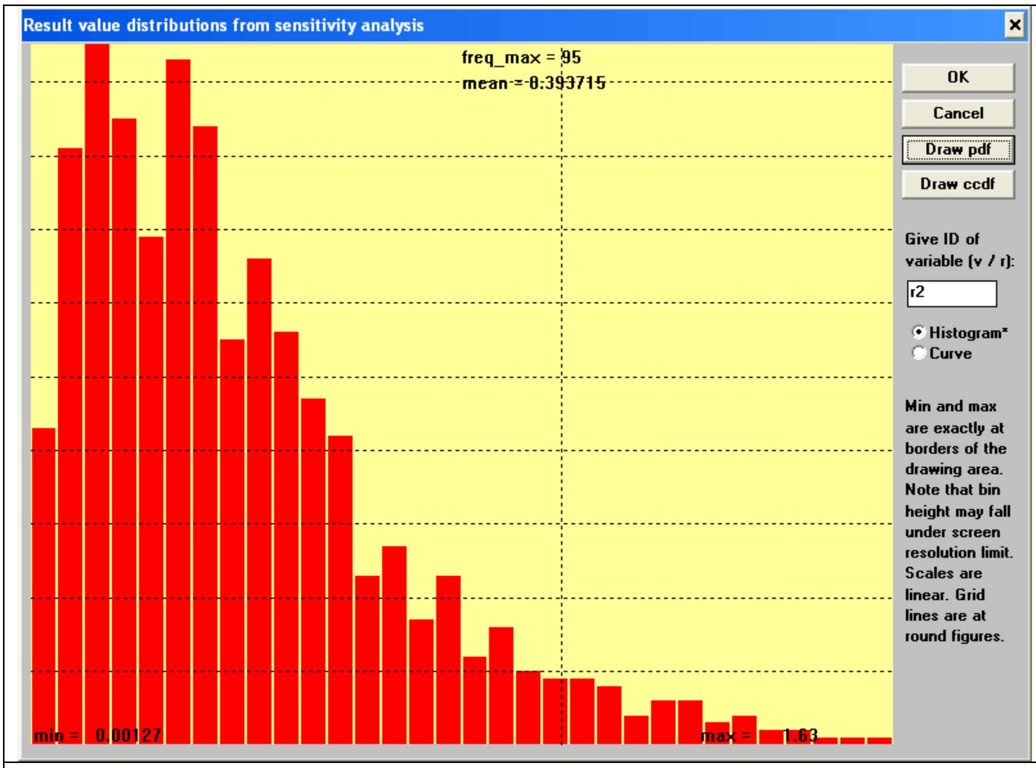
Fig. 3.3. Distribution of K_d-value (pdf) as an example of varied parameters.

3.3.2 Result distributions

The result distributions of concentrations are presented as probability density functions (pdf) and as complementary cumulatively probability density functions (ccdf). The number of calculation rounds of simulation was 1000. In the following graphs (Fig. 3.4-3.13) concentration distributions of lake water, upper sediment layer, whitefish, small perch and pike are visualized. These concentrations give a picture of radiation exposure to human. All the concentration values are per deposition of 10 kBq(Cs-137)/m^2. The considered time point is one year after the deposition event. The characteristic values of concentration results are gathered in Table 3.3.

Table 3.3. Characteristic values of concentration results per deposition of 10 kBq(Cs-137)/m^2.

Target	(Bq/kg)		
	mean	min	max
Lake water	0.39	0.0013	1.63
Upper sediment layer	102	10.8	586
White fish	520	26.6	3600
Small perch	1314	98.4	7600
Pike	2574	201	31700



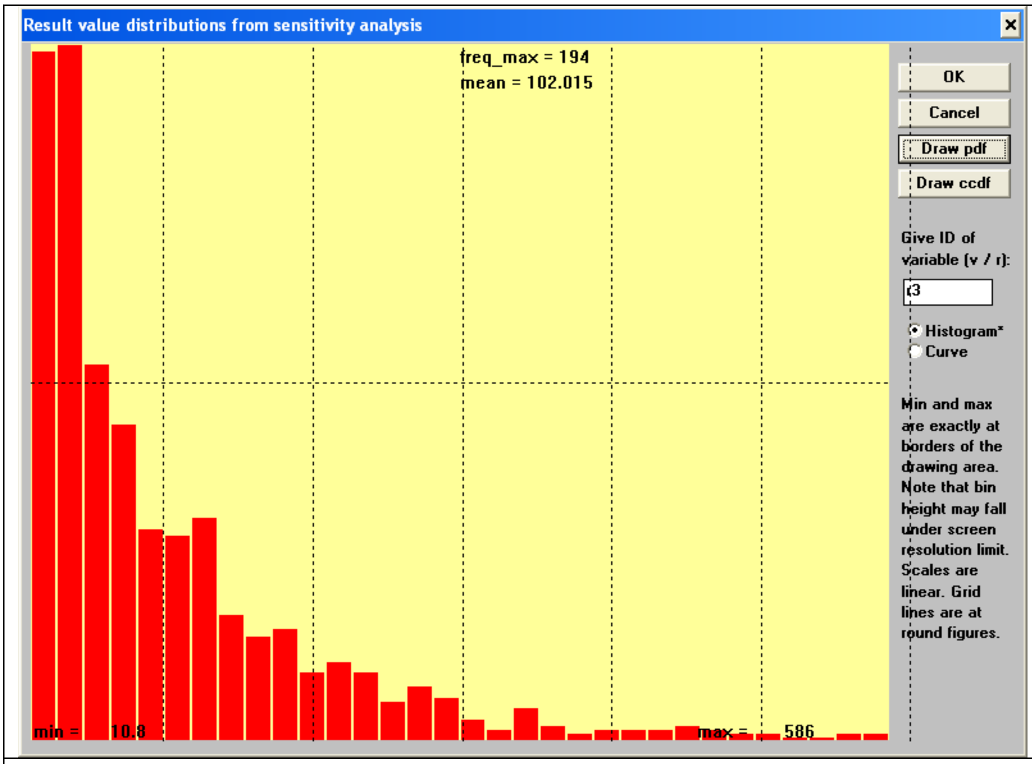
freq_max = 95
mean = 0.393715
min = 0.00127
max = 1.63

Give ID of variable (v / r): r2

● Histogram*
○ Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.4. *Lake water concentration (pdf, Cs-137).*



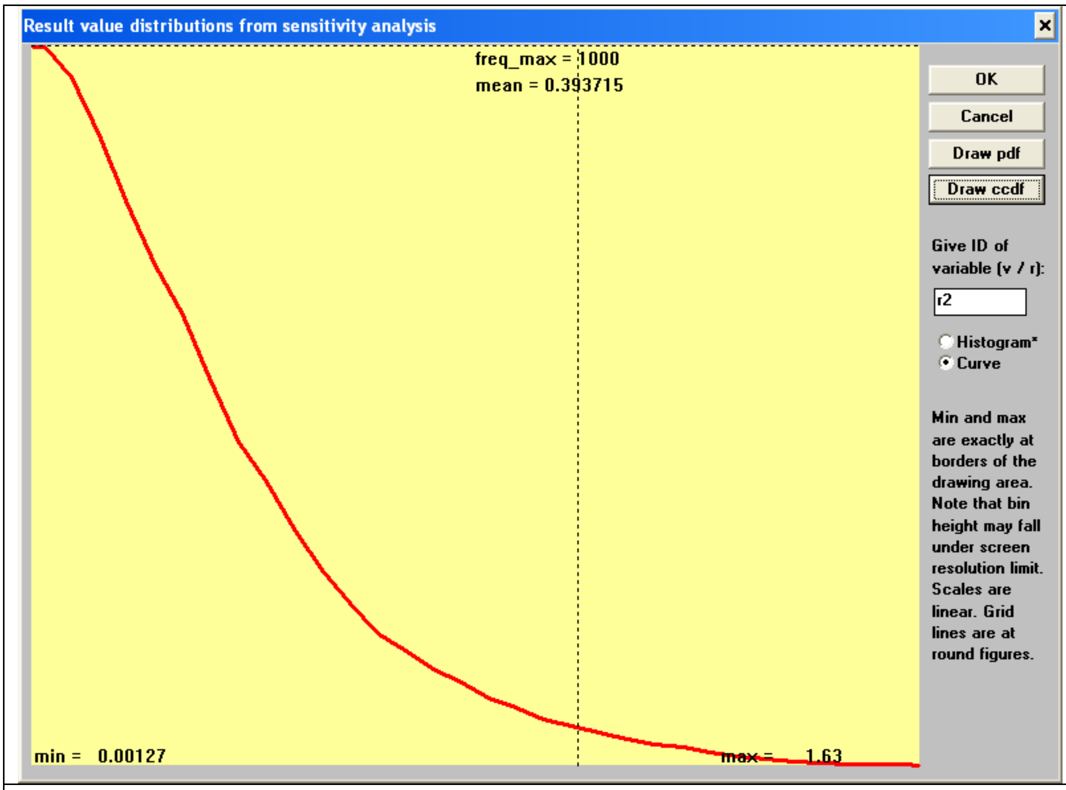
freq_max = 194
mean = 102.015
min = 10.8
max = 586

Give ID of variable (v / r): r3

● Histogram*
○ Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.5. *Upper sediment concentration (pdf, Cs-137).*



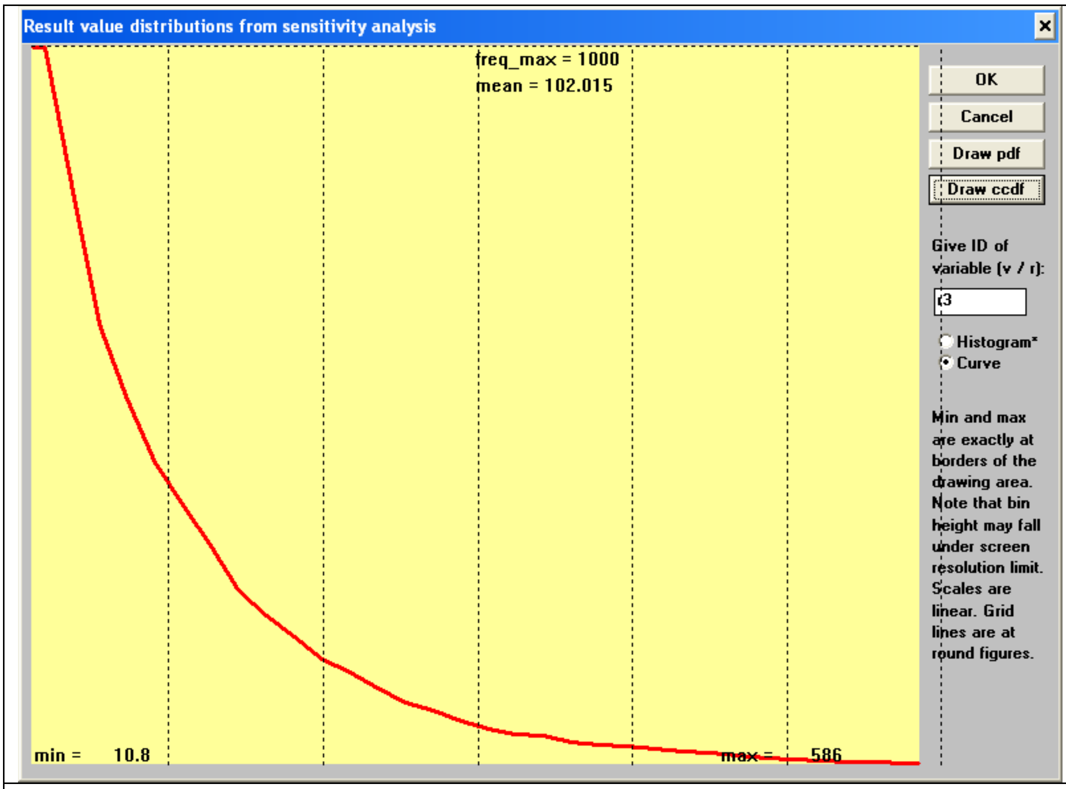
freq_max = 1000
mean = 0.393715
min = 0.00127
max = 1.63

Give ID of variable (v / r): r2

○ Histogram*
● Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.6. Lake water concentration (ccdf, Cs-137).



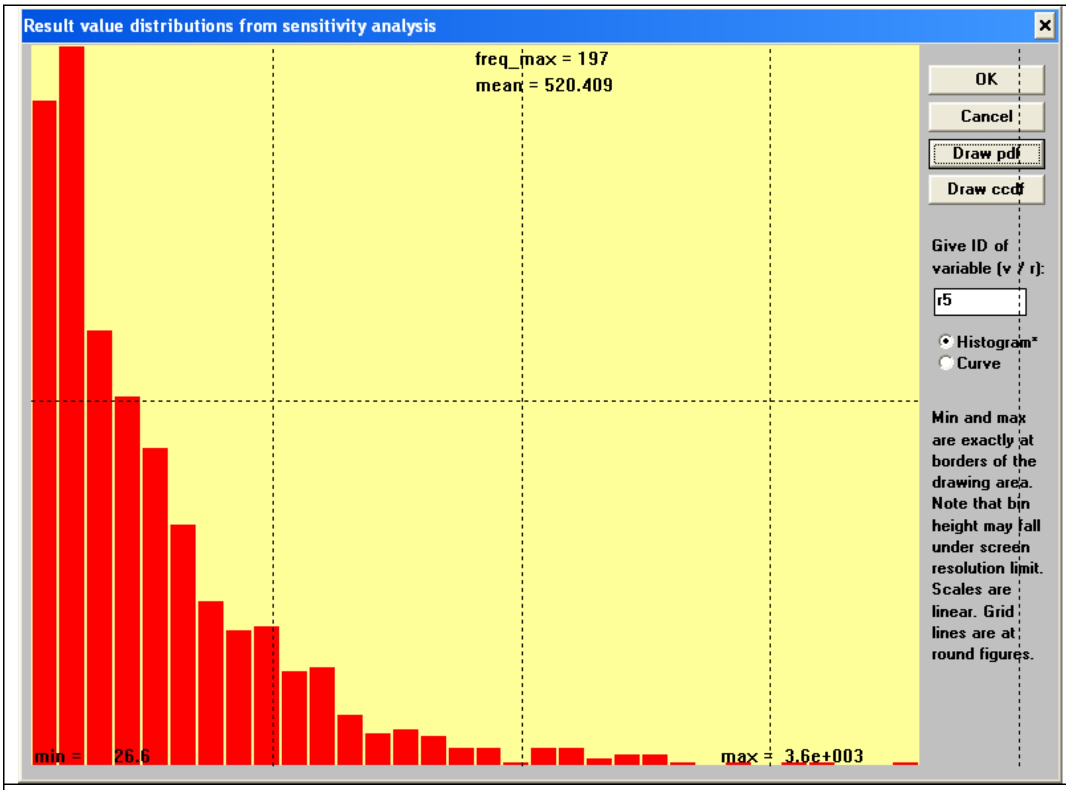
freq_max = 1000
mean = 102.015
min = 10.8
max = 586

Give ID of variable (v / r): r3

○ Histogram*
● Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.7. Upper sediment concentration (ccdf, Cs-137).

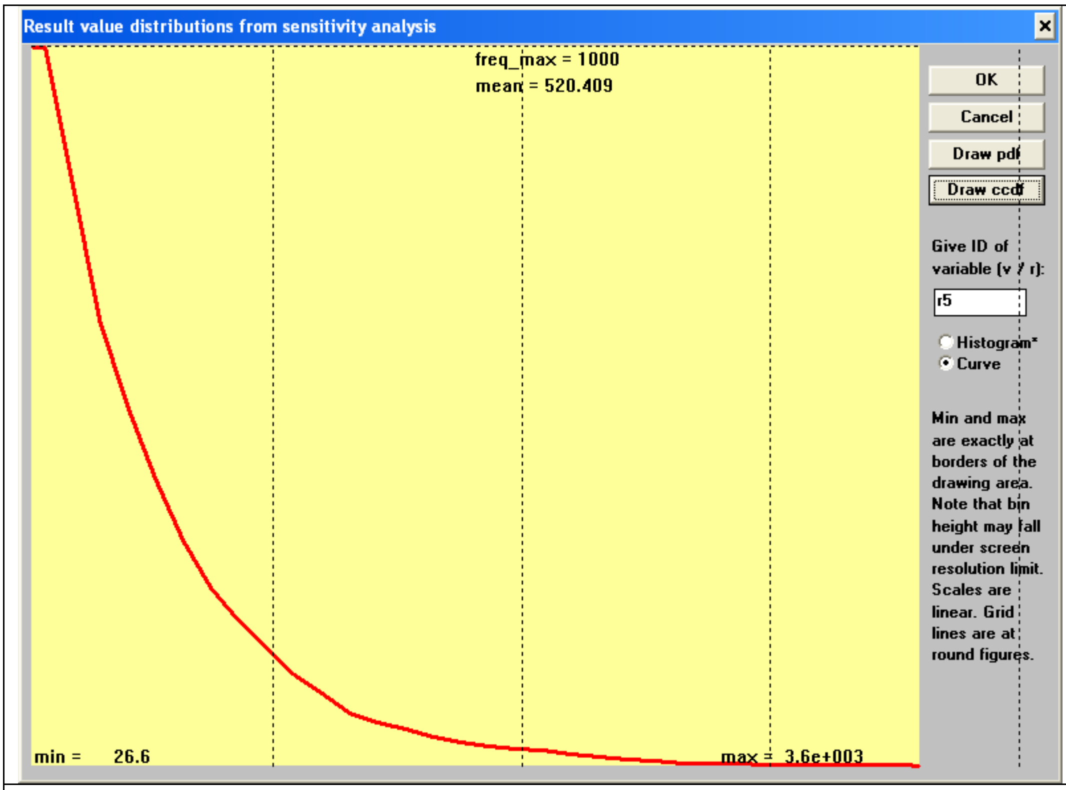


Give ID of variable (v / r): r5

● Histogram*
○ Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.8. Whitefish concentration (pdf, Cs-137).

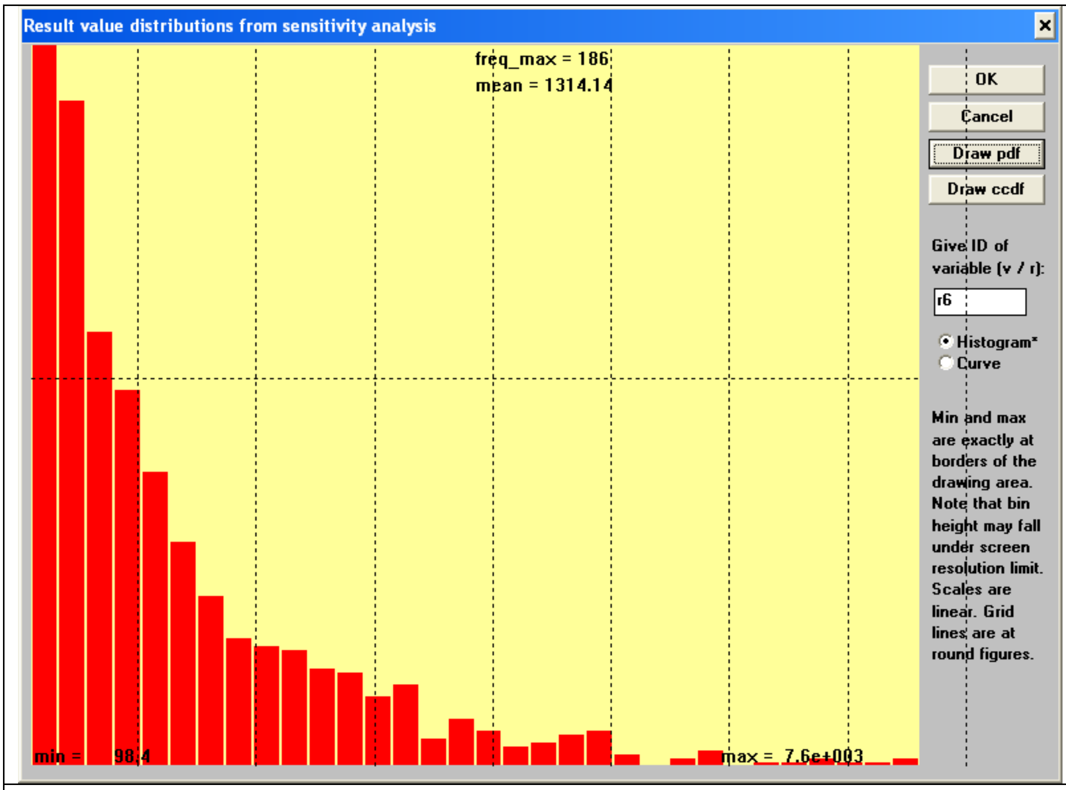


Give ID of variable (v / r): r5

○ Histogram*
● Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.9. Whitefish concentration (ccdf, Cs-137).

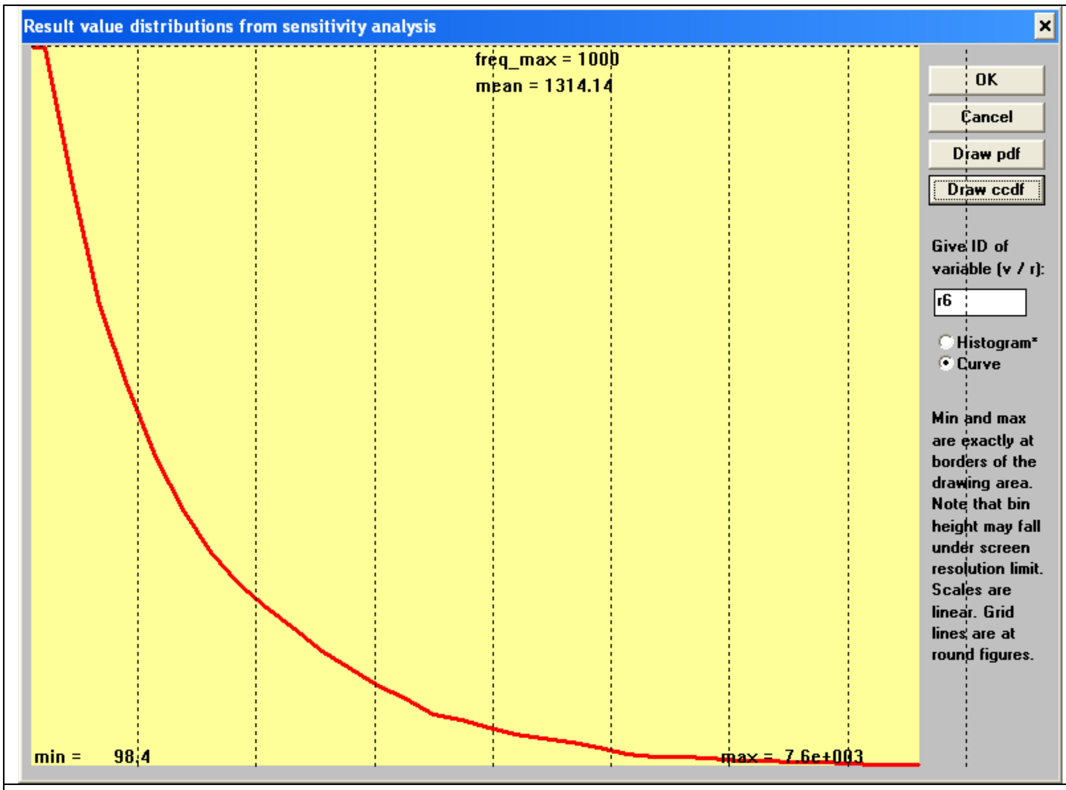


Give ID of variable (v / r): r6

● Histogram*
○ Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.10. Small perch concentration (pdf, Cs-137).

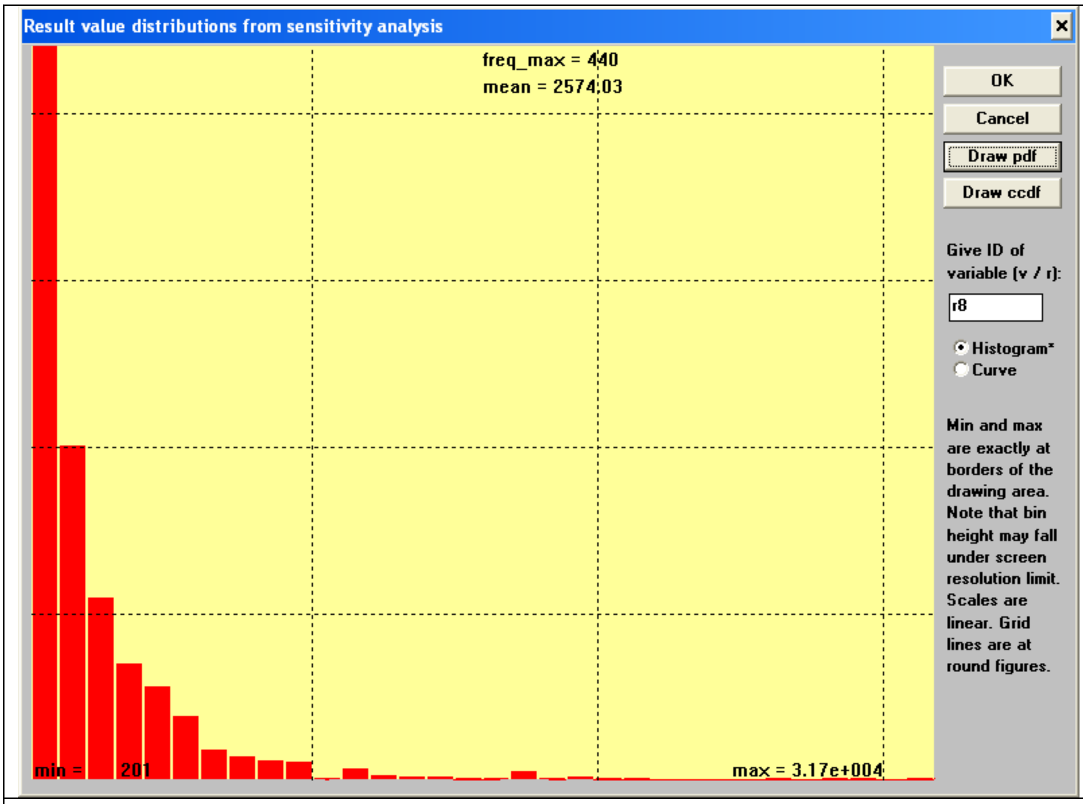


Give ID of variable (v / r): r6

○ Histogram*
● Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.11. Small perch concentration (ccdf, Cs-137).


Result value distributions from sensitivity analysis

freq_max = 440
mean = 2574.03

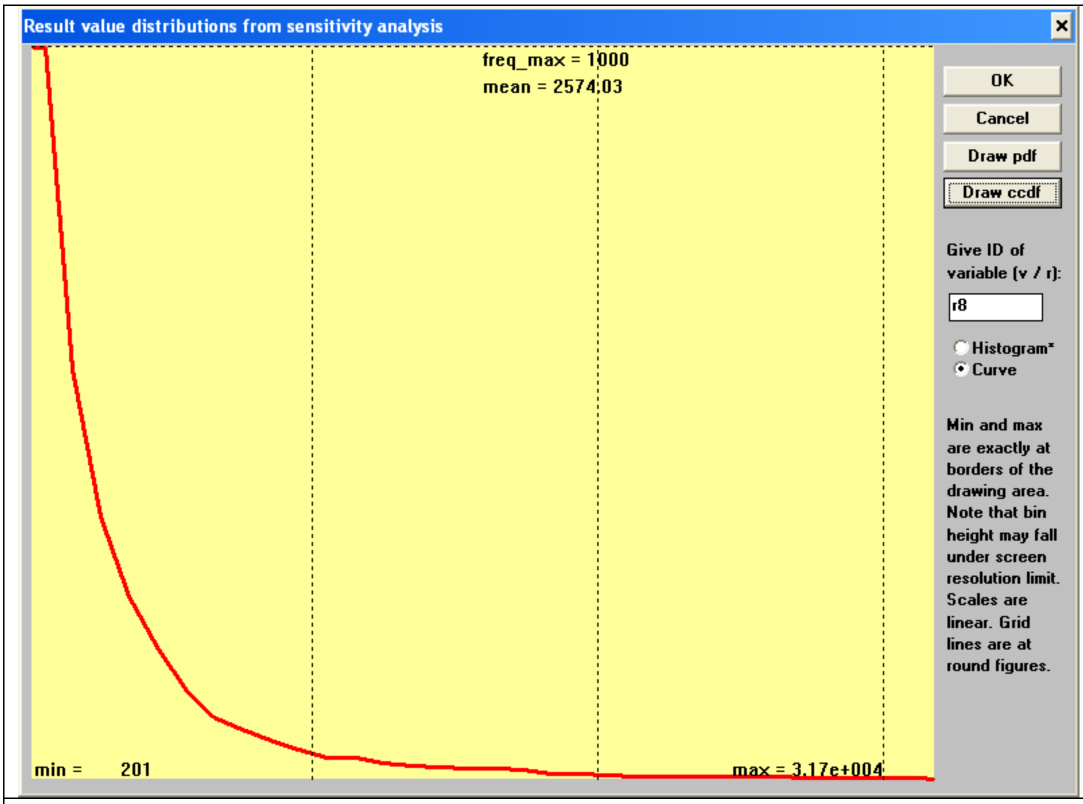
min = 201
max = 3.17e+004

Give ID of variable (v / r): r8

● Histogram*
○ Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.12. *Pike concentration (pdf, Cs-137).*


Result value distributions from sensitivity analysis

freq_max = 1000
mean = 2574.03

min = 201
max = 3.17e+004

Give ID of variable (v / r): r8

○ Histogram*
● Curve

Min and max are exactly at borders of the drawing area. Note that bin height may fall under screen resolution limit. Scales are linear. Grid lines are at round figures.

Fig. 3.13. *Pike concentration (ccdf, Cs-137).*

3.3.3 Ranking of parameters

The applied calculation model (DETRA) doesn't yet automatically rank parameters. Therefore the contribution of different input parameter to the calculation results were studied by some separate computer runs, where single input parameter at a time was considered as a deterministic one (Table 3.4). For the other input parameters, probability distributions were applied. By this procedure it was possible at least qualitatively consider effect of a certain input parameter to the result distributions.

The considered parameters can be classified to:
system parameters, and
element specific parameters.

The system parameters are mainly flow rates of water and solids, and the element specific parameters are e.g. K_d-values and biological half-lives.

Table 3.4. Single parameter contribution to mean values and to output distributions.

Parameter which was not varied during this computer simulation	$C^{i}_{mean} / C^{bc}_{mean}$					
	lake water	qualitative contribution to distribution of lake water concentration	upper sediment	whitefish	small perch	pike
K_d	1.15	minor	0.57	0.68	0.60	0.54
R_w	0.97	minor	0.99	1.0	0.98	1.0
E_s	0.97	minor	1.0	1.0	1.02	1.03
S_s	1.0	minor	0.95	0.97	0.95	0.96
Q_w	1.03	major	0.95	1.0	0.99	0.99
$T_{\frac{1}{2},b2}$	1.0	minor	1.0	1.0	1.0	1.0
$T_{\frac{1}{2},b4}$	1.0	minor	1.0	1.0	1.0	1.0

Changes of the mean concentrations of different compartments were considered against the 'base case' mean concentrations C^{bc}_{mean}. In the base case all the considered input parameters were varied in a same computer run. According to the results, mean concentrations seem to be sensitive to variation of element specific K_d-value. In general, distribution coefficients (K_d) affect efficiently concentration levels.

In the consideration of the result quantities, the lake water concentration is important, because it further affects fish concentration. Looking qualitatively at the lake water concentration distribution, it appears that the water exchange rate (Q_w) distribution clearly dominates the concentration profile of lake water. All the other parameters have only a minor or insignificant effect to that. In fact this was also an expected result, because lake water exchange rate as a system parameter forms the main driving force. Although the distribution of a result may change significantly in one calculation case, the mean value doesn't necessarily will changes, because the mean value is only a computational quantity (see Table 3.4 above). As the occasional results are picked up from a result distribution, the right shape of the distribution is relevant.

3.4 Uncertainty of human doses

In the fresh water ecosystem the arising doses to human are caused by internal and by external doses. The main internal dose pathway is the consumption of fish. Inhalation of resuspended contaminated material is also a possible pathway. Drinking water is not normally taken directly from the lake recipient. External exposure is caused by radiation from shore sediment. If the lake water is used for irrigation then some foodstuffs may be contaminated.

In this study only a short glance for the doses arising by consumption of predatory fish will be made. This consideration gives conservative dose estimates of the uncertainty related to human doses in freshwater ecosystem. Assuming that the fish consumption rate per person is 13 kg/year (i.e. 250 g/week) and the dose conversion factor for Cs-137 is 1.36E-8 Sv/Bq, the estimated mean, minimum and maximum ingestion doses are presented in Table 3.5 per deposition of 10 kBq(Cs-137)/m^2. The concentration values of pike are taken from the result distributions of uncertainty analyses (Section 3.3 before).

Table 3.5. Uncertainty of individual ingestion doses in freshwater ecosystem.

Pathway	Ingestion Dose (mSv/year) / (10 kBq(Cs-137)/m^2)		
	mean	min	max
Consumption of predatory fish from lake	0.46	0.036	5.6

The mean dose estimate is about tenth of the normal background dose of environment in Nordic countries. This additional dose rate level (about 1 mSv/year) was also observed in some areas after the Chernobyl reactor accident where the Cs-137 deposition was also about 10 kBq/m^2. Looking at the uncertainty of doses, it is significant that some persons might get even ten fold doses compared to mean values. This is due to uncertainty of transfer in freshwater ecosystem.

3.5 Summary and conclusions

The study focussed on uncertainties related to radionuclides transfer in Nordic type freshwater ecosystem. The used compartmental dispersion model consists of dynamic models for lake and for connected fish chain of prey and predatory species. For illustrating the time behaviour of various concentrations, a deterministic calculation example with the model was carried out.

The simulation of uncertainties in freshwater ecosystem was performed with the module of DETRA computer model [1]. Nine input parameters were selected for varied parameters: distribution coefficient, runoff from catchment, erosion from catchment, sedimentation rate in lake, water exchange rate of lake, biological half-lives in fish (four species). The concentrations result distributions of all the eight model compartments were produced and studied. Characteristic values, such as mean, minimum and maximum of the distribution were available after simulations. The results were graphically presented in the forms of probability density functions and of complementary cumulative probability density functions.

Qualitative and partly quantitative ranking of input parameters were performed. The work concentrated in element specific parameters and in system parameters. From element specific parameters, the distribution coefficient (K_d) seems to contribute mostly for general concentration levels of obtained concentrations. From system parameters the lake water exchange rate clearly dominates the distribution of lake water concentration and further affect to fish concentrations profiles.

Uncertainty estimates of individual doses were derived from concentration distributions. The conservative mean individual ingestion dose estimate was 0.046 mSv/year per kBq(Cs-137)/m^2. This dose estimate seems to be reasonable if it is compared to the consequence estimates after Chernobyl reactor accident.

As a conclusion the compartment model applied showed reliable performance and the responses of concentrations were acceptable. Consequently, the dose estimates seem to be right order of magnitude. In the consideration of uncertainties, the element specific distribution coefficient and the lake water exchange rate seem to contribute most to the obtained concentration and dose values.

3.6 References

[1] Suolanen, V. (VTT) & Ilvonen, M. (VTT), Generic uncertainty model for DETRA for environmental consequence analyses – Application and sample outputs. Published in STUK-YTO-TR 149, Helsinki 1998.
[2] Saxen, R. & Rantavaara, A., Radioactivity of fresh water fish in Finland after the Chernobyl accident in 1986. Supplement 6 to Annual Report STUK-A55, STUK-A61, 1987.
[3] Handbook of parameter values for the prediction of radionuclide transfer in temperate environments. Technical Reports Series No. 364, IAEA, Vienna, 1994.

4 Foodchain modelling of Nordic conditions

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Risø National Laboratory

4.1 Introduction

Last year's work on the ECODOSES project outlined a number of aspects that might need particularly careful consideration in connection with food chain modelling. The emphasis is on the adaptation of the German ECOSYS system for use in Nordic countries, as this system currently constitutes the core of the food chain models in both of the two major European decision support systems for radiological emergencies, ARGOS and RODOS. A number of rather sensitive parameters were identified, which could be particularly important to address and adjust in the local Nordic contexts, as the default parameterisation in ECOSYS reflects conditions relevant to Southern Germany (Bavaria). An objective of this year's work is to more quantitatively identify the importance of discrepancies between parameter values relevant to Nordic (specifically Danish) areas and the ECOSYS defaults. This required the identification of a number of alternative parameter values.

4.2 Human consumption habits

Consumption habits play a central role in the ECOSYS dose model, as doses are estimated on the basis of consumption in the modelled area rather than production. In reality, part of the food produced in a contaminated area would be exported and consumed outside the given region or country, unless the local contamination situation is sufficiently severe that restrictions on trade are introduced (for instance, the Council of European Communities have issued a series of regulations specifying maximum permitted contamination levels in marketed food products, which would be legally binding within the European Union in the event of a contaminating incident (CEC, 1989 a; CEC, 1989 b; CEC, 1990)). In any case, people will need to be fed, and other large areas in Europe may in a given contamination scenario have become even more contaminated. Table 4.1 shows the extent to which different countries in Europe (including the Nordic countries and their major trade partners) are self-suppliant in some selected food products. It is clear from these values that a significant part of the beef and veal consumed in Sweden, and of the eggs consumed in Denmark, must be of foreign produce. It should be noted that foreign products are also imported to countries that produce sufficient to be self-supplying. This is illustrated in Table 4.2, which shows the Danish production, import and export of some food products in the year 2000.

Table 4.1. Degree of self-supply of animal products in Europe [%] (Danmarks Statistik, 2001).

Country	Beef and veal	Pork	Poultry	Milk	Eggs
Belgium/Lux.	149	222	147	118	137
Denmark	115	490	214	100	89
Germany	113	85	65	112	75
Greece	25	41	79	96	96
Spain	100	112	94	96	107
France	113	106	152	103	102
Ireland	148	190	108	101	91
Italy	62	67	108	91	102
Netherlands	160	283	221	85	225
Austria	140	107	-	103	81
Portugal	58	77	97	108	100
Finland	93	102	-	100	114
Sweden	79	101	-	100	98
Great Britain	66	77	-	99	95

Table 4.2. Danish production, import and export of a selection of food products [thousands of tonnes] (Danmarks Statistik, 2001).

Product	Production	Import	Export
Butter (incl. butter oil)	46	21	40
Cheese	306	43	249
Eggs	63	27	16
Wheat	4337	227	1119
Rye	240	36	118
Barley	3564	125	789
Oats	126	25	1
Chicken	181	22	126
Potatoes	1352	230	114
Carrots	77	7	5
Green salad	7	11	1

For instance, a very large part of the Danish butter is exported, so that most of the butter actually consumed in Denmark (including industrial use) is of foreign origin, although Denmark is a major butter supplier on the European market. It is clear from these data that very significant parts of a contaminated food production from a given area may, at least under some circumstances, be consumed in a different country. It is problematic in using ECOSYS for decision support on implementation of countermeasures that the potentially highly significant 'exported' problem is not addressed. It is in ECOSYS possible to specify a fraction of a given dietary component that is imported, but it is rigidly assumed that the imported food products are completely free of contamination, which may well not be the case in reality. Also, these food product import factors are in ECOSYS assumed to be season-invariant. This can be highly problematic, for instance in connection with estimation of doses from consumption of leafy vegetables and fresh fruit. In Denmark, leafy vegetables are typically supplied by local producers in the period from mid-April to mid-October (Yding Grønt A/S, 2006). Outside this season they are imported from abroad. The typical annual diet of an adult Dane includes about 40 kg leafy vegetables (Danmarks Statistik, 2001). According to runs of the ECOSYS model the average ingestion dose received in Denmark over the first month after the Chernobyl accident would have been nearly 7 times less if uncontaminated leafy vegetables had in this period been imported.

Table 4.3 shows a comparison of the default diets in ECOSYS (reflecting conditions in Bavaria) with the typical diet in Denmark, based on the most recent Danish consumption analysis made in 2000-2002 (Fagt et al., 2002; Groth & Fagt, 2002; Danmarks Statistik, 2001). Naturally, it should be noted that there are a large number of food products that have been omitted, both on German and Danish side, in this list, but it is considered plausible that all major dietary components that could potentially contribute to dose are represented. Overall, the differences between the diets are surprisingly limited. There are however some few quite significant differences. For instance, the German adult consumption of beer is more than 3 times higher than that of the Danish, and about two-thirds of the beef consumed in Germany is from bulls, whereas this is in Denmark only about one-third. Figure 4.1 shows an example of implementation of these different consumption data sets in ECOSYS runs based on the ^{137}Cs air concentrations, rainfall and wet deposition recorded at Tranvik (Sweden) in the first month after the Chernobyl accident (Köhler et al., 1991). As can be seen, the difference between the dose curves for German and Danish adults deviate by only some 10-20 %, and the curve for Danish 4-14 year olds lies between the curves for German 5 and 15 year olds. However, this does not necessarily imply that there could not be significant deviations in other countries. In the rightmost column of Table 4.3, also some figures from a nationwide Swedish consumption habit survey in 1997-98 ('Riksmaten') are shown (Becker & Pearson, 2006). Some of these figures blend in well with the German, but for instance the milk consumption is significantly higher and the cream consumption significantly lower in Sweden. Also, the Swedish fruit consumption is comparatively very high. In Finland, the annual milk consumption per inhabitant is as high as about 140 kg, whereas corresponding values are ca. 65 kg for potatoes and 75 kg for fruit (Puska, 2005). It can not be ruled out that part of the variation observed between countries can be explained by differences in categorisation/interpretation of the various dietary constituents. Some of the Danish data was not readily available, but could be estimated from datasets in the reference.

Table 4.3. Typical diets in Germany (ECOSYS default) and in Denmark (2000-2002 statistics) for different age groups. Also some dietary components from Sweden are shown (1997-98 statistics).

	Consumption (kg/y)					
Product:	Germany			Denmark		Sweden
	5 y old[+]	15 y old[+]	Adults[+]	4-14 y old	Adults*	Adults*
Spring wheat, whole grain	0.5	0.7	0.9	0.0	0.0	
Spring wheat, flour	3.0	4.4	5.5	0.4	0.5	
Spring wheat, bran	0.0	0.0	0.0	-	-	
Winter wheat, whole grain	4.7	6.6	8.4	1.0	1.3	
Winter wheat, flour	26.6	36.5	47.5	44.0	55.0	
Winter wheat, bran	0.0	0.0	0.0	-	-	
Rye, whole grain	1.8	2.5	3.2	4.1	4.9	
Rye, flour	6.9	10.2	12.8	10.9	13.6	
Rye, bran	0.0	0.0	0.0	-	-	
Oats	1.1	1.6	2.0	1.2	0.8	
Potatoes	12.8	30.3	58.4	28.4	40.2	51.8
Leafy vegetables	27.0	31.4	34.3	30.0	40.5	35.9
Root vegetables	8.8	12.0	12.0	5.0	12.0	4.7
Fruit vegetables	13.1	16.8	17.2	5.0	9.0	
Fruit	26.3	36.5	43.8	40.5	59.0	126
Berries	3.7	5.1	5.1	2.0	2.0	
Milk	51.1	76.7	84.0	191.0	87.7	125
Condensed milk	4.0	5.8	6.6	2.0	2.0	
Cream	3.5	5.1	5.8	2.0	5.0	1.1
Butter	2.2	4.4	6.6	3.0	5.0	6.4
Cheese, Rennet coagulation	3.7	6.9	9.5	5.3	6.8	Rennet/acid 11.0
Cheese, Acid coagulation	2.4	4.4	6.2	2.7	3.4	
Goat's milk	0.0	0.0	0.0	-	-	
Sheep milk	0.0	0.0	0.0	-	-	
beef (cow)	6.6	8.4	9.9	7.0	14.5	
beef (bull)	12.8	16.8	20.1	3.0	6.2	
Veal	0.5	0.7	0.8	0.3	0.5	
Pork	26.3	32.9	39.4	21.0	38.0	
Lamb	0.0	0.0	0.0	0.1	0.0	
Chicken	4.0	5.1	6.2	5.4	8.0	
Roe deer meat	0.0	0.0	0.0	-	-	
Eggs	6.6	13.1	15.7	4.4	6.2	5.5
Beer	0.0	47.5	222.7	0.0	65.7	

* Adults in the Danish survey were 15-75 years old; Adults in the Swedish survey were 18-74 years old. The Swedish survey comprised 2000 persons, and the Danish comprised 4000 persons.

[+] The ECOSYS default values are based on data from Deutsche Gesellschaft für Ernährung (1988) and Becker et al. (1982).

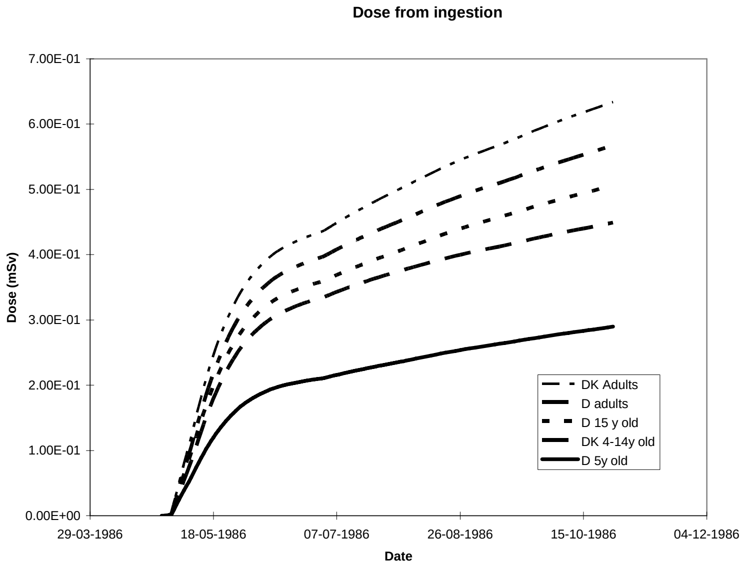

Fig. 4.1. Modelled (ECOSYS) effective dose from consumption according to German and Danish diets. Example based on Chernobyl-related data. Different age groups are represented.

4.3 Leaf area indices

As mentioned in last year's annual report of the ECODOSES project, leaf area index (LAI) is the parameter that controls the state of growth of crops in the ECOSYS model. The Danish Institute of Agricultural Sciences has, based on large amounts of measurement data, developed a decision support system, which is in practical use in Denmark for optimisation of means for, e.g., irrigation, nitrogen fertilisation, weed control, pest control, disease control and harvest time for a given area of land grown with a specific crop (Danish Agricultural Advisory Service, 2006; Olesen et al., 1997). The system comprises the exponential model presented in last year's ECOSOSES report, for dynamic description of LAI (Plauborg & Olesen, 1991). Key variables are sowing times, harvest times, soil temperature and fertilising status. The model can be applied for different climates, and should be applicable also for other Nordic conditions, where the variation over the year in soil temperature is known. Figures 4.2 – 4.9 show comparisons between the ECOSYS default LAI functions and those of the DSS of the Danish Institute of Agricultural Sciences. Soil temperatures for the Danish LAI functions were supplied by the Royal Veterinary and Agricultural University of Denmark (2006). Sowing time for spring crops was assumed to be the 10th of April (Farsø Markservice, 2006; Kaarde, 2006; Danish Agricultural Advisory Service, 2006). For winter crops, the growth is not sensitive to the exact sowing time, which is typically in September. It is evident that the shape of the German LAI functions (denoted 'D'), with a distinct peak and a rather steep slope on both sides, is not in agreement with observations from real life (Plauborg & Olesen, 1991; Olesen, 2006). This is for instance confirmed from experiments made at Jyndevad (Denmark) in 1985 (Plauborg & Olesen, 1991). It is therefore recommended to introduce more realistic LAI time functions when using ECOSYS.

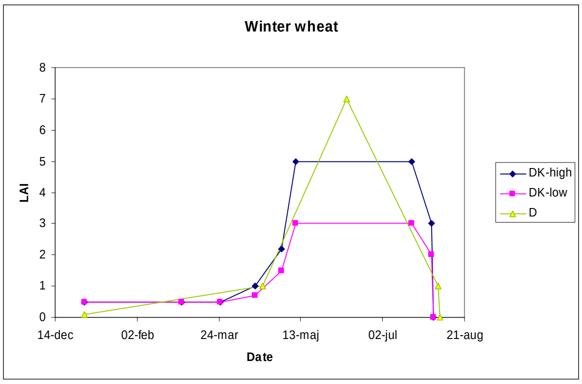

Fig. 4.2. LAI for winter wheat. Estimates used by default in ECOSYS (D) and in the Danish model (DK) for high and low fertilisation status.

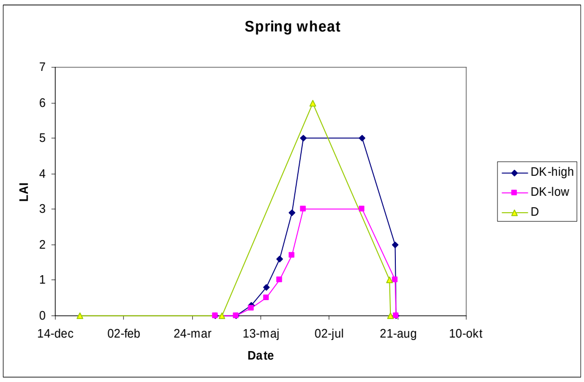

Fig. 4.3. LAI for spring wheat. Estimates used by default in ECOSYS (D) and in the Danish model (DK) for high and low fertilisation status.

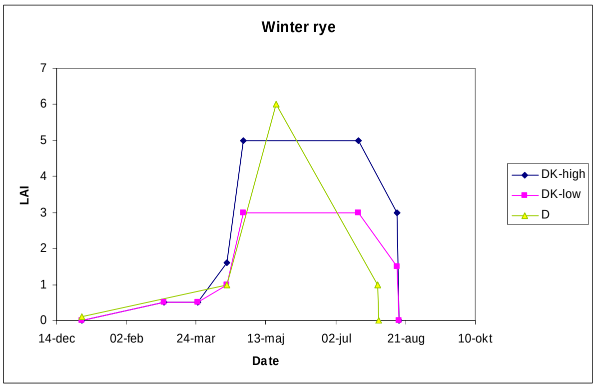

Fig. 4.4. LAI for winter rye. Estimates used by default in ECOSYS (D) and in the Danish model (DK) for high and low fertilisation status.

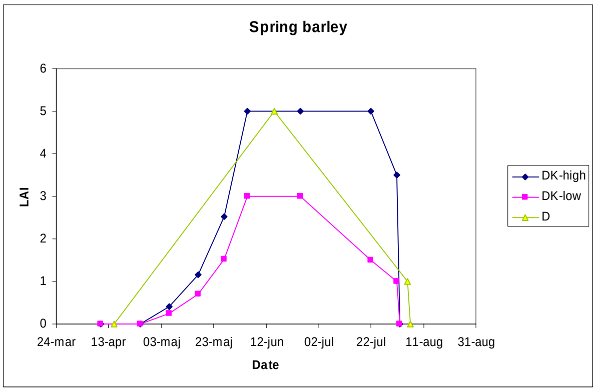

Fig. 4.5. LAI for spring barley. Estimates used by default in ECOSYS (D) and in the Danish model (DK) for high and low fertilisation status.

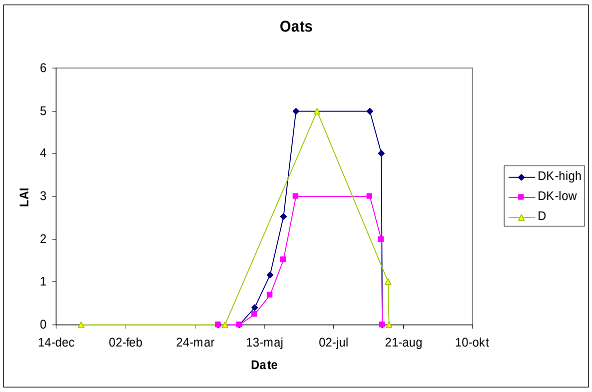

Fig. 4.6. LAI for oats. Estimates used by default in ECOSYS (D) and in the Danish model (DK) for high and low fertilisation status.

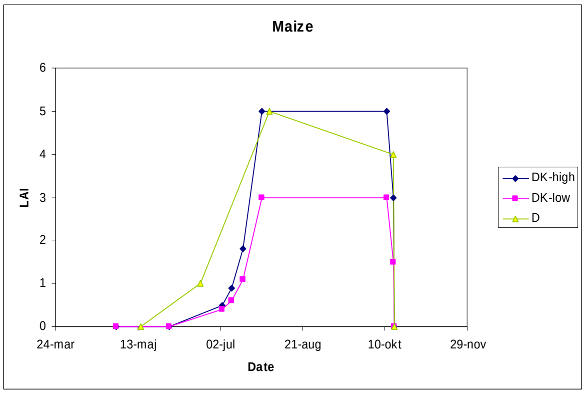

Fig. 4.7. LAI for maize. Estimates used by default in ECOSYS (D) and in the Danish model (DK) for high and low fertilisation status.

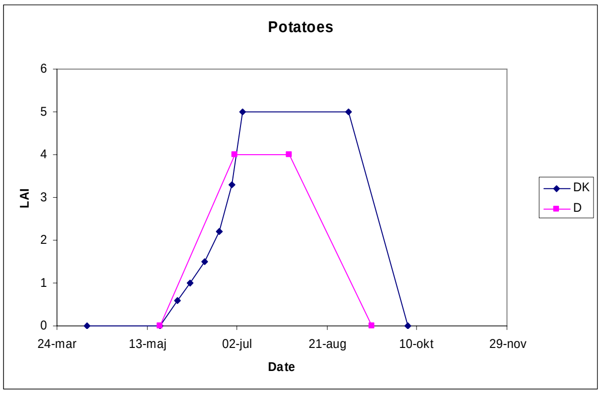

Fig. 4.8. LAI for potatoes. Estimates used by default in ECOSYS (D) and in the Danish model (DK). Values in model are insensitive to fertiliser status.

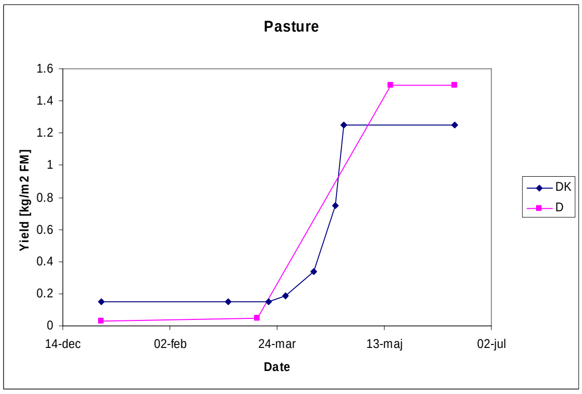

Fig. 4.9. LAI for pasture. Estimates used by default in ECOSYS (D) and in the Danish model (DK) for low fertilisation status.

As can be seen the seasonal variation in LAI does not seem to differ very greatly between the two localities (Southern Germany and Denmark), although growth of spring crops generally starts earlier in Germany. Also, for most crops, LAI_{max} of the fully developed crop is somewhat higher for Germany than for Denmark, even in cases where the Danish soil is assumed to have high fertilisation status. For study of scenarios where deposition occurs continuously over a whole year or longer (e.g., weapons fallout in the 1960's), there may potentially be some limited, though significant, difference between whether German or Danish values are applied in ECOSYS (see examples in Figs. 4.10 and 4.11).

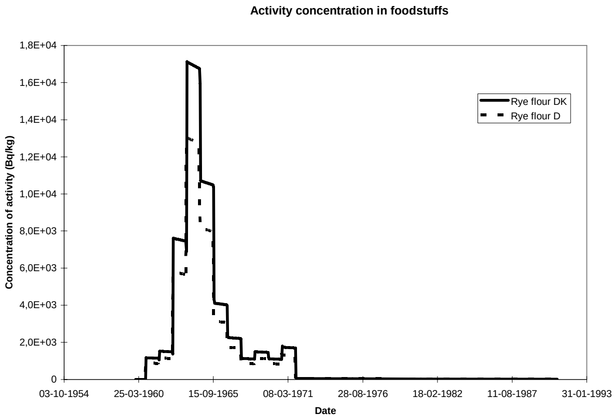

Fig. 4.10. An example showing the influence of the LAI seasonal function for rye (German –D or Danish with low fertilisation status in soil –DK) on the ^{137}Cs activity concentration in rye flour. ECOSYS simulation using measured data from Roskilde for total annual deposition to a lawn of nuclear weapons testing fallout over the period 1960-1970 (Aarkrog et al., 1995). A fraction of 90 % wet deposition and 2 mm rain per event were assumed in the data used in the ECOSYS pre-processor to calculate deposition events.

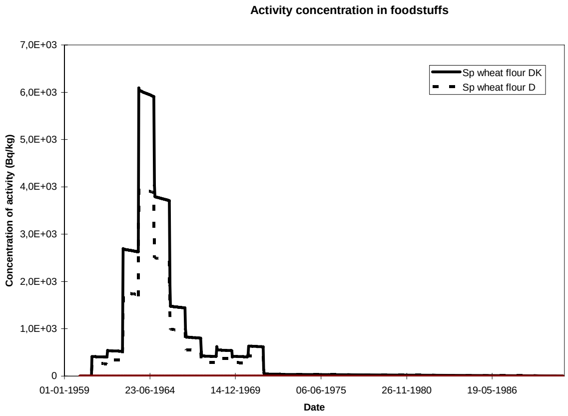

Fig. 4.11. An example showing the influence of the LAI seasonal function for spring wheat (German –D or Danish with high fertilisation status in soil –DK) on the ^{137}Cs activity concentration in spring wheat flour. ECOSYS simulation using measured data from Roskilde for total annual deposition to a lawn of nuclear weapons testing fallout over the period 1960-1970 (Aarkrog et al., 1995). A fraction of 90 % wet deposition and 2 mm rain per event were assumed in the data used in the ECOSYS pre-processor to calculate deposition events.

If deposition occurs predominantly over a short time-interval, there could be a more significant influence of the exact functional specification. Table 4.4 shows an example of the differences in ^{137}Cs concentrations in spring wheat products resulting from application of different LAI data. The calculations were based on a hypothetical scenario, where dry deposition occurs only on the 15th to 18th of April. As the contamination occurred over a short time interval, the results become highly sensitive to the LAI at that particular point in time. This would, depending on weather conditions, be likely to often be the case in connection with a 'single contaminating event', such as the Chernobyl accident. It should be noted that wet deposition would be equally affected by variations in LAI.

Table 4.4. ECOSYS results [Bq kg^{-1}] from hypothetical calculation scenario with dry deposition occurring on 15-18 April. LAI figures are applied from respectively German data (D), Danish data for low soil fertilisation (DK-low) and Danish data for high fertilisation (DK-high).

	D			DK-low			DK-high		
Time	Sp wheat whole	Sp wheat flour	Sp wheat bran	Sp wheat whole	Sp wheat flour	Sp wheat bran	Sp wheat whole	Sp wheat flour	Sp wheat bran
6 mths	5.5E+01	2.8E+01	1.7E+02	1.8E+01	8.9E+00	5.3E+01	1.9E+01	9.3E+00	5.6E+01
1 year	5.5E+01	2.7E+01	1.6E+02	1.8E+01	8.8E+00	5.3E+01	1.8E+01	9.2E+00	5.5E+01
2 years	7.3E-01	3.7E-01	2.2E+00	7.3E-01	3.7E-01	2.2E+00	7.3E-01	3.7E-01	2.2E+00

4.4 Other case-specific parameters

Obviously, the ECOSYS model contains many parameters that may or may not to an adequate degree reflect the conditions in a given specific case. Therefore, it can be difficult to assess if the model behaves as intended, or if one parameter inadequacy perhaps compensates for another, still resulting in the expected total result for a given endpoint. One of the simplest (although still complex) things to study with ECOSYS is the dynamic behaviour of contamination on vegetation shortly after deposition, where the influence of uptake from the ground is negligible. Figure 4.12 shows an example of an ECOSYS simulation of ^{137}Cs concentrations for grass, as well as for cows' milk, based on the air concentrations, rainfall and wet deposition recorded at Tranvik (Sweden) in the first month after the Chernobyl accident (Köhler et al., 1991). The estimates are compared with locally measured data points for ^{137}Cs concentrations in grass and in cows' milk. The cows' fodder regime is here taken as the default in ECOSYS. As can be seen, the grass concentration estimates are in reasonable agreement with the measured values, although the estimate values for the intensive grass area seem to be in best agreement with the data points, and the cows would probably in reality have been grazing on an extensive pasture. This shows that the deposition model in ECOSYS seems to work reasonably well for this contaminant and crop. However, the ECOSYS model by default assumes a generic weathering half-life of natural removal of contamination from the plant, due to rain, wind and fog, of 25 days. Together with a growth dilution half-life of 45 days for extensive grass in the month of May, this gives an effective reduction half-life of about 16 days. Studies performed on a great number of sites after the Chernobyl accident show effective ^{137}Cs half-lives in grass, due to plant growth, translocation and weathering, of 8-10 days for the period May-July (Mück & Gerzabek, 1995), i.e., considerably shorter than assumed by default in ECOSYS, which is generally parameterised on the basis of data from before the Chernobyl accident. As can be seen from Fig. 4.13, a reduction of the weathering half-life from 25 days to 9 days would make the curve for ‘extensive grass’ significantly steeper, and thus in better agreement with the measured values.

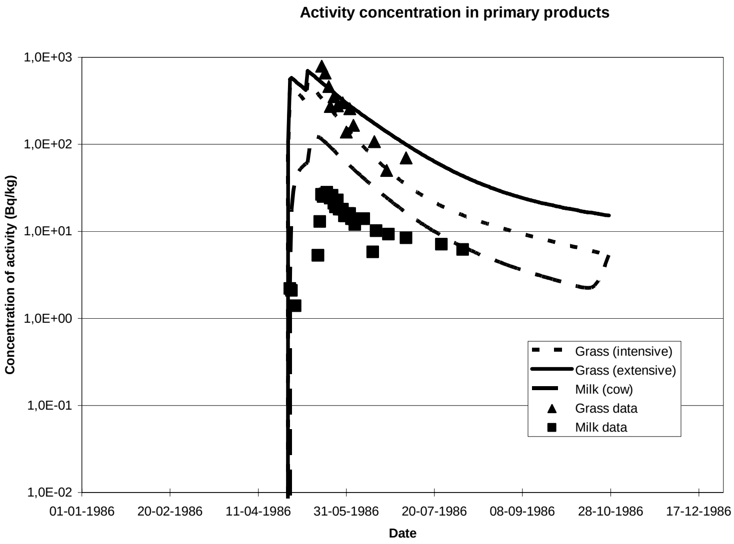

Fig. 4.12. ECOSYS estimation of ^{137}Cs content in grass (intensive and extensive) and cows’ milk, based on air concentrations, rainfall and wet deposition measured in Tranvik (S). Measurements of grass and milk contamination in the area are shown for comparison. Cows’ diet is here in the simulations taken to be the default of the ECOSYS model (hay until 10th of May, and then fresh grass).

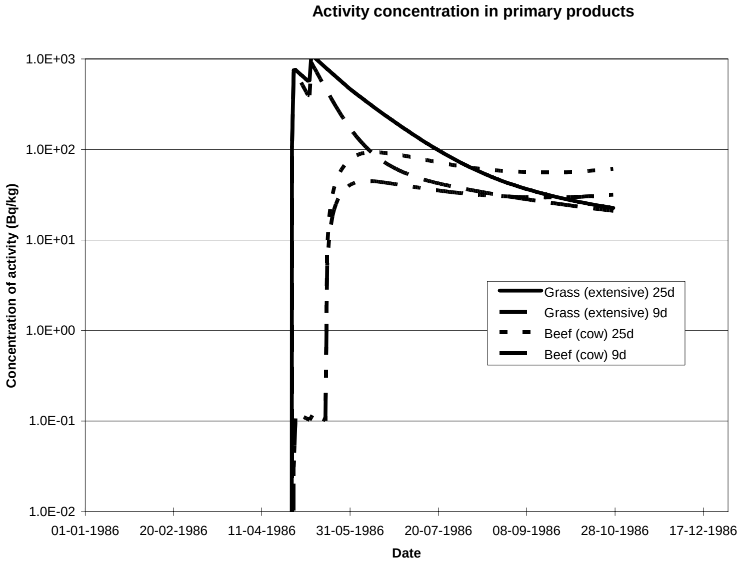

Fig. 4.13. ECOSYS estimation of ^{137}Cs content in grass (intensive and extensive) and cows’ meat. Based on a similar run as that shown in the above Figure. The influence of changing the weathering half-life from 25 days to 9 days is highlighted.

Fig. 4.14 shows the results of a simulation with ECOSYS based on the same data, but assuming the diet that is reported for Swedish cows at the time (Köhler et al., 1991). Here cows were from the 14th of May and the following week fed with a mixture of fodder concentrate and fresh grass, and after that only with grass. Fig. 4.15 shows a corresponding ECOSYS simulation, assuming the fodder regime typically used all year round in Denmark: 70 % maize silage and 30 % grass silage. As can be seen, the milk data are here in extremely good agreement with the simulation. However, it should be stressed that there are many different parameters in the ECOSYS model that could be altered, and other combinations would be likely to result in a similar effect.

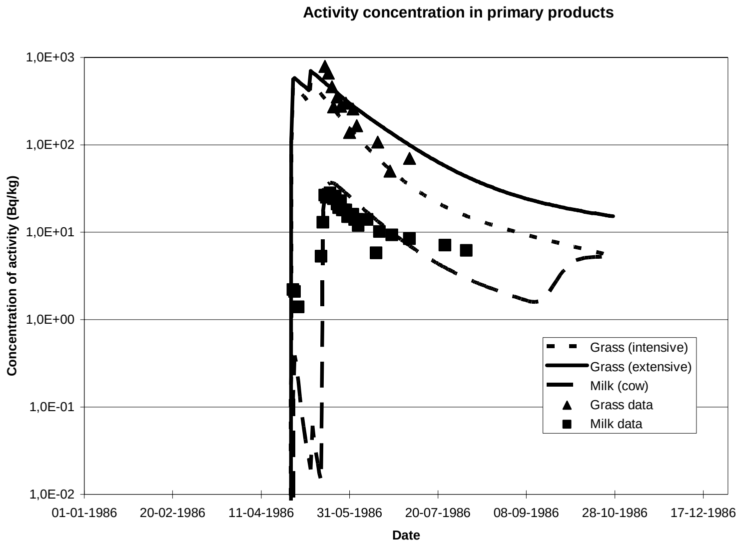

Fig. 4.14. ECOSYS estimation of ^{137}Cs content in grass (intensive and extensive) and cows' milk, based on air concentrations, rainfall and wet deposition measured in Tranvik (S). Measurements of grass and milk contamination in the area are shown for comparison. Cows' diet is here in the simulations taken to be in-line with that reported for the Swedish lactating cattle at the time.

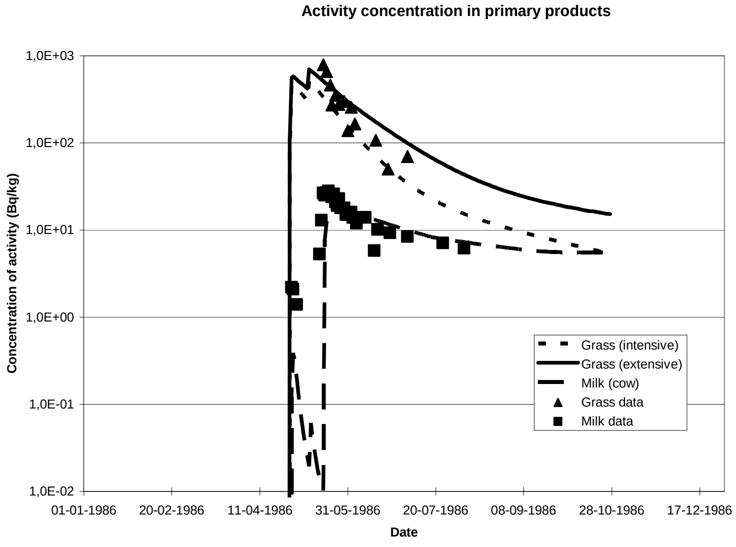

Fig. 4.15. ECOSYS estimation of ^{137}Cs content in grass (intensive and extensive) and cows' milk, based on air concentrations, rainfall and wet deposition measured in Tranvik (S). Measurements of grass and milk contamination in the area are shown for comparison. Cows' diet is here in the simulations taken to be in-line with common practise in Denmark.

Measurement data are also available for Tranvik for Chernobyl ^{131}I, to enable simulation with ECOSYS based on air concentrations, rainfall amounts and wet deposition, and local measurements of ^{131}I concentrations in grass and milk are available for comparison (Köhler et al., 1991). The environmental behaviour of iodine is somewhat more complex to model than that of caesium, since very different physicochemical species were deposited after the Chernobyl accident. Both iodine in aerosol form, elemental (or other inorganic) iodine and organic iodine (primarily CH_3I) were reported. Measurements made in Sweden, Finland, Norway and Germany showed that ^{131}I was mainly (ca. 80-90 %) in the gas phase, primarily as inorganic iodine (Devell et al., 1986; STUK, 1986; Jost et al., 1986; Pacyna et al., 1986). Practically the same distribution between iodine species was reported by Tomasek et al. (1992) for measurements in Prague and Budapest. The AMAD of aerosol iodine has after the Chernobyl accident been found to be similar to that of other volatile radionuclide aerosol, such as that carrying radiocaesium (Tschiersch & Georgi, 1987). The deposition velocity of organic iodine is generally 3-4 orders of magnitude lower than that of elemental iodine (Atkins et al., 1967; Tomasek et al., 1992). Differences in deposition velocity of the different iodine species are taken into account in the ECOSYS model. Obviously, since the various iodine species have so great differences in deposition velocity, modelling is extremely sensitive to the definition of species fractions. It would hardly be reasonable to assume that the weathering of elemental iodine would occur with as long a half-life as 25 days (the ECOSYS default for all contaminants). Elemental iodine is extremely effectively removed from surfaces by rainfall (Roed, 1987), and in field experiments, Cline et al. (1965) recorded an average weathering half-life for elemental iodine deposited on grass of the order of 4 days. Figure 4.16 shows an ECOSYS simulation example of ^{131}I concentrations in grass and milk, again based on the Tranvik data. It is here assumed that all the deposited ^{131}I was of the elemental form, and that the weathering half-life was only one day (^{131}I air concentrations were extremely high only on the 28th and 29th of April, and the rainshower on the 29th would have removed very much of the elemental radioiodine deposited on grass; it is problematic that ECOSYS operates with a discrete weathering half-life value that is not influenced by the defined rainfall). In this case, there is relatively good correspondence between the model and the measured values, but as mentioned above, the model is highly sensitive to variation of a considerable number of parameters. The modelled decline in iodine milk concentration seems too slow, but pinpointing the exact cause would require a comprehensive, systematic revision of generic parameters applied in ECOSYS.

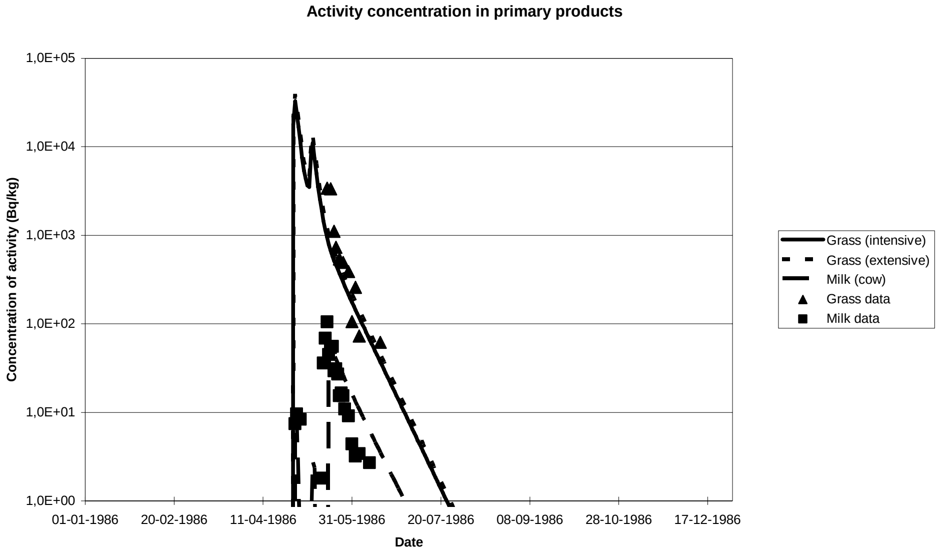

Fig. 4.16. ECOSYS estimation of ^{131}I content in grass (intensive and extensive) and cows' milk, based on air concentrations, rainfall and wet deposition measured in Tranvik (S). Measurements of grass and milk contamination in the area are shown for comparison. Cows' diet is here in the simulations taken to be in-line with common practise in Denmark.

4.5 Need for updating the ECOSYS model

It should be recognised that the ECOSYS model was developed and parameterised in 1987. Although the current version of the model contains some reflections made on the basis of data reported up to about 1990, for instance transfer factor estimates are based on early data, excluding the host of data generated since the Chernobyl accident. Work in quoted references from the 1970's and early 1980's (Müller & Pröhl, 1993) is often based on small-scale experiments with tracers whose physicochemical characteristics do not adequately reflect those expected after a large nuclear power plant accident, such as that which occurred at Chernobyl in 1986. More recent values, also very importantly distinguishing between soil types, are available (see, e.g., Nisbet et al., 1999; Kostiainen et al., 2002; Eriksson, 1997; IAEA, 1994). The default values used in ECOSYS are often rather far from the 'average' values recommended in these more recent parameter reviews, but more importantly, order of magnitude errors may in some cases arise, if the influence of soil type is neglected (see, e.g., Nisbet et al., 1999). For instance, the ECOSYS default TF's for root vegetables and leafy vegetables are respectively 0.01 and 0.02, whereas they are reported by Nisbet et al. (1999) to on average be respectively 0.03-0.08 and 0.06-0.3, depending on soil type. As an alternative to data libraries with distinct values for different soil classes, a model has been established within the EC-SAVE project for the calculation of soil-to-plant transfer factors for caesium in soils of definable characteristics (Absalom et al., 2000). A simple excel spreadsheet version of the model exists (University of Nottingham, 2006), which could be built into ECOSYS. This model, however, requires knowledge of pH and contents of organic matter, clay and exchangeable potassium, which may well not be readily available for a particular area. The 'EC-SAVE' model has been validated with independent data for barley. As mentioned in last year's ECODOSES report, also for instance fixation and migration rates of contaminants in soil need to be updated to take into account the host of findings made after the Chernobyl accident. Finally, it urgently needs to be considered in the ECOSYS system that different contaminants will have different particle sizes in connection with a radiological emergency. For instance, after the Chernobyl accident, the contaminant aerosols could be divided into a 'volatile' group with an AMAD of about 0.7 µm (carrying, e.g., ^{132}Te, ^{134}Cs, ^{137}Cs, ^{99}Mo, ^{103} Ru and ^{106}Ru) and a 'refractory' group with an AMAD of about 4 µm (carrying, e.g., ^{140}Ba, ^{95}Zr, ^{141}Ce, ^{144}Ce, ^{89}Sr and ^{90}Sr) (Reineking et al., 1987; Rulik et al., 1989; Dorrian, 1997). The deposition velocity to, e.g., grain crops and leafy vegetables, of aerosols of these two groups will differ by about a factor of 4 (Watterson & Nicholson, 1996). The difference could be considerably greater if the emergency involved malicious dispersion of radionuclides (Andersson, 2005). Currently, all aerosols have the same default deposition velocity in ECOSYS, but the values can be changed in the excel version.

4.6 References

Andersson, K.G. (2005). Dose contributions from malicious radionuclide dispersion in an urban area, in 'Radiological Protection in Transition', proceedings of the XIV Regular Meeting of the Nordic Society for Radiation Protection, Rättvik, Sweden, 27-31 August 2005, SSI report 2005:15, Swedish Radiation Protection Authority, ISSN 0282-4434, 59-62.

Aarkrog, A., Bøtter-Jensen, L., Qing Jiang, C., Clausen, J., Dahlgaard, H., Hansen, H., Holm, E., Lauridsen, B., Nielsen, S.P., Strandberg, M & Søgaard-Hansen, J. (1995). Environmental radioactivity in Denmark in 1992 and 1993, Risø report R-756(EN), ISBN 87-550-1991-9, Risø National Laboratory.

Absalom, J.P., Young, S.D., Crout, N.M.J., Sanchez, A., Wright, S.M., Smolders, E., Nisbet, A.F. & Gillett, A.G. (2000). Predicting the transfer of radiocaesium from organic soils to plants using soil characteristics. J. Environ. Radioactivity 52, pp. 31-43.

Atkins, D.H.F., Chadwick, R.C. & Chamberlain, A.C. (1967). Deposition of radioactive methyl iodide to vegetation, Health Physics 13, pp. 91-92.

Becker, A., Biesold, H. & Handge, P. (1982). Investigation on the nutrition of infants for the assessment of potential radiation exposures, Köln, Germany: Gesellschaft für Reaktorsicherheit: Report GRS-A-81977 (in German).

Becker, W. & Pearson, M. (2006). Dietary habits and nutrient intake in Sweden 1997-98 – The second national food consumption survey, Information and Nutrition Department, Swedish National Food Administration, Uppsala, Sweden, www.slv.se/templatesSLV/SLV_Page____6558.asp.

CEC (1989 a). Council Regulation (Euratom) No. 3954/87 laying down the maximum permitted levels of radioactive contamination of foodstuffs and feeding stuffs following a nuclear accident or any other case of radiological emergency, Off. J. Eur. Commun. L211/1.

CEC (1989 b). Council Regulation (Euratom) No. 770/90 laying down maximum permitted levels in minor foodstuffs following a nuclear accident or any other case of radiological emergency, Off. J. Eur. Commun. L101/17.

CEC (1990). Council Regulation (Euratom) No. 770/70 laying down maximum permitted levels of radioactive contamination of feeding stuffs following a nuclear accident or any other case of radiological emergency, Off. J. Eur. Commun. L83/78.

Cline, J.F., Wilson, D.O. & Hungate, F.P. (1965). Effect of physical and biological conditions on deposition and retention of ^{131}I on plants, Health Physics 11, 713-717.

Danish Agricultural Advisory Service (2006). www.lr.dk/applikationer.

Danmarks Statistik (2001). Landbrug 2000 – Statistik om landbrug, gartneri og skovbrug, Danmarks Statistik, Copenhagen, Denmark, ISBN 87-501-1195-7.

Deutsche Gesellschaft für Ernährung (1988). Nutrition report 1988. Frankfurt am Main, Deutsche Gesellschaft für Ernährung (in German).

Devell, L., Tovedal, H., Bergström, U., Appelgren, A., Chyssler, J. & Andersson, L. (1986). Initial observations of fallout from the reactor accident at Chernobyl", Nature 321, pp. 192-193.

Dorrian, M.D. Particle size distributions of radioactive aerosols in the environment, Rad. Prot. Dosimetry vol. 69, no.2: 117-132; 1997.

Eriksson, Å. (1997). The cultivated agricultural environment, Part 2 of the NKS report 'Reclamation of contaminated urban and rural environments following a severe nuclear accident' (eds. P. Strand, L. Skuterud and J. Melin), NKS (97) 18, 97-10-10, ISBN 87-7893-017-0.

Fagt, S., Matthiessen, J., Trolle, E., Lyhne, N., Christensen, T., Hinsch, H.J., Hartkopp, H., Biltoft-Jensen, A., Møller, A. & Daae, A.S. (2002). Danskernes kostvaner 2000-2001 – Udviklingen i danskernes kost – forbrug, indkøb og vaner, Fødevaredirektoratet, Afd. for Ernæring.

Farsø Markservice (2006). www.fmmajs.dk/kontakt.html.

Groth, M.V. & Fagt, S. (2002). Danskernes kostvaner. Måltidsvaner, holdninger, sociale forskelle og sammenhæng med anden livsstil, Ministeriet for Fødevarer, Landbrug og Fiskeri, Fødevaredirektoratet.IAEA, 1994

Jost, D.T., Gäggeler, H.W., Baltensperger, U., Zinder, B. & Haller, P. (1986). Chernobyl fallout in size-fractionated aerosol, Nature 324, pp. 22-23.

Kaarde, J.R. (2006). Danish Institute of Agricultural Sciences, Department for Variety Testing, DK-4230 Skælskør, Denmark, personal communication.

Kostiainen, E., Hänninen, R., Rosén, K., Haak, E., Eriksson, Å, Nielsen, S.P., Keith-Roach, M. & Salbu, B. (2002). Transfer factors for nuclear emergency preparedness, NKS report NKS-78, ISBN 87-7893-134-7.

Köhler, H., Peterson, S.-R., Owen Hoffman, F. (eds.) (1991). BIOMOVS technical report. Scenario A4. Multiple model testing using Chernobyl fallout data of I-131 in forage and milk and Cs-137 in forage, milk, beef and grain. Swedish Radiation Protection Inst., Stockholm (Sweden), BIOMOVS- TR--13(pt.1).

Mück, K. & Gerzabek, M.H. (1995). Trends in caesium activity concentrations in milk from agricultural and semi-natural environments after nuclear fallout, Bodenkultur 46(4), pp. 337-353.

Müller, H. & Pröhl, G. (1993). ECOSYS-87: a dynamic model for assessing radiological consequences of nuclear accidents, Health Physics 64(3), pp. 232-252.

Nisbet, A.F., Woodman, R.F.M. & Haylock, R.G.E. (1999). Recommended soil-to-plant transfer factors for radiocaesium and radiostrontium for use in arable systems, NRPB-R304, National Radiological Protection Board, Chilton, Didcot, UK.

Olesen, J.E. (2006). Department of Soil Science, Research Centre Foulum, 8830 Tjele, Denmark, personal communication.

Olesen, J.E., Pedersen, L., Christensen, S., Secher, B.J.M & Petersen, J., (1997). An integrated decision support system for management of winter wheat, paper presented at the First European Conference for Information Technology in Agriculture, Copenhagen, 15-18 June, 1997.

Pacyna, J.M., Johansen, O., Saltbones, J. & Semb, A. (1986). Air radioactivity at selected stations in Norway after the Chernobyl reactor accident, Norwegian Institute for Air Research, Report E-8642, ISBN 82-7247-735-1.

Plauborg, F. & Olesen, J.E. (1991). Development and validation of the model MARKVAND for irrigation scheduling in agriculture (in Danish), Tidsskrift for Planteavls Specialserie, Beretning nr. 2113.

Puska, P. (2005). Finnish experience on diet, cholesterol and prevention of cardiovascular diseases, National Public Health Institute – KTL, Helsinki, Finland, www.fhf.org.uk/meetings/2005-03-22_presentation_puska.pdf.

Reineking, A., Becker, K.H., Porstendörfer, J. and Wicke, A. Air activity concentrations and particle size distributions of the Chernobyl aerosol, Rad. Prot. Dos. vol.19, no.3: 159-163; 1987.

Roed, J. (1987). Run-off from and weathering of roof material following the Chernobyl accident, Rad. Prot. Dosimetry 21 (1/3), pp. 59-63.

Royal Veterinary and Agricultural University of Denmark (2006). uk.kvl.dk.

Rulik, P., Bucina, I. and Malatova, I. Aerosol particle size distribution in dependence on the type of radionuclide after the Chernobyl accident and in the NPP effluents, in proc. of the XVth regional congress of IRPA in Visby, Sweden; 1989.

STUK (1986). Second interim report on radiation situation in Finland from 5 to 16 May 1986, STUK report STUK-B-VALO 45, ISBN 951-46-9578-x, Helsinki.

Tomasek, M., Wilhelmova, L. & Horyna, J. (1992). A possible mechanism of airborne $CH_3{}^{131}I$ formation, Proceedings of the CEC/IUR/SCR International Symposium on Radioecology at Znojmo, Czech Rep., pp. 140-142.

Tschiersch, J. & Georgi, B. (1987). Chernobyl fallout size distribution in urban areas, J. Aerosol Sci. 18 (6), pp. 689-692.

University of Nottingham (2006). www.nottingham.ac.uk/environmental-modelling/AbsalomModel.htm.

Watterson, J.D. & Nicholson, K.W. (1996). Dry deposition and interception of 4-22 µm diameter particles to a lettuce crop, J. Aerosol Science, vol. 27(5), pp. 759-767.

Yding Grønt A/S (2006). Yding, DK-8752, Østbirk, Denmark, web-page: ydinggroent.dk.

5 Summary

The NKS-B EcoDoses activity aims to improve the radiological assessments of doses to man from terrestrial ecosystems. The EcoDoses activity has focused on collation and review of published and unpublished data from the Nordic countries for the nuclear weapons fallout period and the post-Chernobyl period. Based on this, improved models for estimating radioactive fallout based on precipitation data during the nuclear weapons fallout period have been developed. The data is used to compare modelling results with observed concentrations. The importance of applying case-specific and updated data of, e.g., geological, seasonal, climatic and demographic nature, in the modelling is demonstrated. During 2006 the participants have identified unclear points from using the ECOSYS food-and-dose model and have addressed these to the model originator who subsequently has provided explanations and an updated version of the software.

A sensitivity study of the ECOSYS model applied to the Faroe Islands has been carried out involving a range of model parameters (grass yield, leaf area index, times for preparing and storing hay and silage, feeding rates, age of slaughter, soil mass and soil-to-plant transfer). The study confirms the importance of adjusting the default model parameters to local conditions. The model contains many parameters that for different reasons can be difficult to evaluate. This means that there may be large uncertainties in evaluation of parameters, and consequently also large uncertainties in the output from the model.

A study on uncertainties related to the modelling of ^{137}Cs in lakes was carried out using a compartmental model including prey and predatory species of fish. The simulation was performed with a module of the DETRA model. Nine parameters were selected for varied parameters: distribution coefficient, runoff from catchment, erosion from catchment, sedimentation rate in lake, water exchange rate of lake, biological half-lives in fish. The distribution coefficient (K_d) is the single parameter that mostly affects the predicted concentrations overall and the lake water exchange rate dominates the concentrations in lake water and fish. The conservative mean individual ingestion dose estimate was 0.046 mSv/year per kBq/m^2. The compartment model showed reliable performance and the responses of concentrations were acceptable.

Assumptions of human consumption habits are essential for radiological risk assessments involving radioactive pollution of terrestrial environments. Consumption data vary considerably between countries and calculations illustrate the importance of using relevant data in order to obtain realistic dose estimates. Furthermore, the seasonal variation of leaf-area-indices for vegetation is important for reliable model prediction of the transfer of radioactive fallout to crops. This is particularly important in case of accidents that occur close to the start of the growing season but also affects scenarios that involve relatively constant fallout over the year. Other model parameters that have been studied are weathering half life, feeding regime, aerosol particle size and deposition velocity. The investigations highlight the importance of using relevant data for the model parameters and indicate areas for extending the features covered by the models.

Bibliographic Data Sheet NKS-184

Title	EcoDoses. Improving radiological assessment of doses to man from terrestrial ecosystems: A status report for the NKS-B activity 2006
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ISBN	978-87-7893-250-1
Date	March 2009
Project	NKS-B / ECODOSES
No. of pages	44
No. of tables	18
No. of illustrations	44
No. of references	49

Abstract

The overall aim of the NKS-B EcoDoses activity is to improve the prediction of doses to humans from consumption of radioactively contaminated food. For this purpose, various published and unpublished datasets have been compiled and applied in developing refined parameterisation for existing food dose models. The ECOSYS model developed in Germany after the Chernobyl accident has been applied as the basis for the investigations. This model can be operated both with discrete releases adequately representing a nuclear power plant accident, and with continuous or multiple releases, as observed in the nuclear weapons testing period. The modelling has revealed that it is essential to ensure that case-specific values are applied for a range of parameters, adequately reflecting the actual conditions with respect to geology, season, climate and demography. In connection with this year's work on the activity, sensitivity studies have been conducted with the ECOSYS model, in which the influence on ingestion dose estimates of a number of parameters has been evaluated in relation to Faroese conditions. The importance of applying location specific data to estimate dose is pinpointed, and it is also concluded that dose predictions for a small and distinct area like the Faroese, where not all of the many parameters required to run ECOSYS optimally have been adequately assessed in recent years, can be associated with considerable uncertainty. A Finnish study has been made in relation to modelling of radiocaesium behaviour in lakes. This study was carried out using a compartmental model that is included as a module in the DETRA dose assessment tool. A total of nine different input parameters (distribution coefficients, run-off from the catchment, erosion from the catchment, sedimentation rate in the lakes, lake water exchange rate, and biological half-lives in four fish species) were varied, and particularly distribution coefficients and lake water exchange rates were demonstrated to have high influence on doses. The model showed reliable performance when compared with Chernobyl data. Also a study of consumption habits and leaf area indices in Denmark has been made and the new datasets exhibit significant differences compared to the ECOSYS default values. ECOSYS model runs highlight the importance of these findings for dose estimates. Also the influence of local deviations in weathering half-lives, feeding regimes, aerosol particle sizes and deposition velocities have been studied.

Key words: Nuclear weapons fallout, deposition modelling, food-chain modelling, ecological half-lives radiological sensitivity, Chernobyl accident

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