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PardNor – PARameters for ingestion Dose models for NORdic areas - Status report for the NKS-B activity 2009

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Abstract

The ECOSYS foodchain model is built into the European standard decision support systems ARGOS and RODOS, which are integrated in the preparedness for radiological events in the Nordic countries. However, a review has revealed that a number of parameters in ECOSYS do not reflect the current state-of-the-art knowledge, and do not adequately represent Nordic conditions. Improved and country/region specific data is required for ECOSYS to give trustworthy results. It is the aim of the PardNor activity to collect new data, and thus enable reliable use of ECOSYS for scenarios involving contamination of Nordic food production areas. In the reported work period of the PardNor activity, examinations have been made of the availability in each of the Nordic countries of soil characterisation data that could be used as a basis for a refined and location-specific approach for estimation of soil-to-plant transfer of contaminants. Large national gridded soil type databases were found to be available for most of the Nordic countries. In addition, for many of these countries, also a number of more detailed soil parameter values, such as local concentrations of various exchangeable ions, cation exchange capacity and soil pH are available on national grids. The feasibility of implementing each of two detailed crop uptake models in ECOSYS - The CoupModel and the 'Absalom' model - was investigated. Both models were found to have serious constraints in this context, and it was therefore recommended to apply a simpler soil classification. To this end, a review was made of state-of-the-art transfer factor data for different soil types, and for the Faeroe Islands, where gridded information is not available, a different approach was described. A preliminary study was also included, on using the Radiocaesium Interception Potential (RIP) as a transfer parameter, utilising the very low RIP values caused by the geological conditions in Iceland. Parameters describing the processes of incorporation and excretion by farm animals of ingested contaminants were also examined, and new datasets for transfer parameters and biological half-lives were derived.

Key words

Foodchain modelling, ingestion dose, ECOSYS, transfer factors, radioactive contamination

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PardNor

PARameters for ingestion Dose models for NORdic areas

Status report for the NKS-B activity 2009

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1. Introduction

In compliance with the agreement with NKS, this year's work on the PardNor activity had two main objectives, both directed towards improving the Nordic knowledge platform required to make reliable estimates, using the ECOSYS model, of ingestion doses in the event of a contaminating incident. As the ECOSYS model is implemented in both of the European decision support systems, ARGOS and RODOS, which are used by the Nordic authorities, the work constitutes an important step towards an improved and harmonised Nordic preparedness. The two main tasks this year were:

(i) an improvement of the soil-to-plant transfer factor approach currently applied in ECOSYS and the decision support systems in which this model is integrated. This implies both a revision of the transfer factors, taking into account the host of primarily Chernobyl-related measurement data reported in recent years, and the introduction of a new approach to enable transfer factors to be applied in relation to a soil type classification, as soil textural differences can make a great difference in uptake.

(ii) a revision of the factors applied in ECOSYS in describing animal metabolism functions (biological half-lives and transfer parameters), also here taking into account the newest data.

In addition, the activity has submitted a journal paper for publication in Radiation Protection Dosimetry, on results obtained in the PardNor activity. The working title of this paper is: 'Effect of Nordic diets on ingestion doses estimated with the ECOSYS model'.

2. Soil data available to describe transfer to crops

As a first step towards introducing an improved soil-to-plant transfer approach for ECOSYS, an investigation was made of the Nordic availability and format of a number of parameters of potential use in linking transfer factors to location-specific soil characteristics. Specifically, information was collected on the national status in each of the Nordic countries on the following items:

- Availability of gridded soil classification data (primarily texture classes)
- Availability of more detailed information that could facilitate use of complex models for determining plant uptake on the basis of soil parameters (pH, % C, CEC, specific important ion concentrations)
- Resolution of grid (e.g., # locations sampled per 100 ha, or grid mesh size)
- The owner of the data
- The age of the data

The results of this investigation are reported below:

2.1 Finnish Soil data

Data on Finnish cultivated soils is collected by Viljavuuspalvelu – Soil Analysis Laboratory. The summations of the results have been published at five years intervals, latest for the years 1996–2000 at the home pages of Soil Analysis Laboratory www.Viljavuuspalvelu.fi in Finnish. During 1996–2000, the amount of analysed soil samples was 882 418. Sampling density has been about 59 samples per 1000 hectares of cultivated soils.

The information is given as percentage proportions by 21 subareas and also by municipalities and includes:

- Soil type
  - Moraine (till) soils (sand, fine sand, silt and clay moraine soils)
  - Sand soils (coarse sand and sand)
  - Fine sand and silt soils (fine sand, finer fine sand, silt)
  - Clay soils (sandy clay, silty clay, heavy clay, muddy clay)
  - Organic soils (humus, mud, Corex peat, Sphagnum peat soils)
- The content of organic matter in soil classified in three categories (<3%, 3-5.9%, 6-11.95 and 12-19.9%)
- pH and cation exchange capacity
- The pH values are given also by the four categories of the organic matter content.
- The concentrations (mg/l) of Ca, K, P, Mg, S, Cu, B, Mn, Zn, Fe, Se. This data is given also by soil types, organic matter contents, and pH.

2.2 Swedish soil data

A systematic survey of Swedish cultivated soils regarding humus content and the most important soil chemical characteristics have been summarized in a report from the Department of Soil and Environment at the Swedish University of Agricultural Sciences and the Swedish Environmental Protection Agency (Eriksson & Andersson, 1997). The survey comprises 3100 samples from plough-layer (0-20 cm) and 1700 subsoil samples (40-60 cm), randomly distributed over the acreage of arable land in Sweden. The plough-layer samples were collected during the years 1988-1995, with most of the samples collected 1994-1995. The subsoil data were sampled in 1995. The information in the report is accessible through a website (http://www-umea.slu.se/miljodata/akermark/index.htm), where also a search-function for the database can be found. The results presented are statistics of average levels for different counties and for the whole country, and maps showing geographic variation. Examples are given in Figures 2.1 and 2.2.

The variables analyzed in both plough-layer and subsoil samples were: pH-H_2O and nitric acid-soluble As, Cs, Cd, Cr, Co, Cu, Pb, Mn, Hg, Mo, Ni, Sr, V and Zn. In the plough-layer samples a number of additional variables were analyzed: water- soluble B, aqua regia-soluble Se, ammonium lactate-acetate-soluble P, hydrochloric acid-soluble P, exchangeable Ca, exchangeable Mg, exchangeable K, exchangeable Na, exchangeable acidity, total carbon content, organic C, total nitrogen contents and total sulfur contents. The basic variables were then used to calculate humus content, carbonate content and other ratios.

Also available is a large survey of forest soils in Sweden. These data can be found at http://www-markinfo.slu.se/eng/. Apart from soil chemical properties the data base also includes data on soil type and soil parent material. The data is maintained by the Department of Soil and Environment at the Swedish University of Agricultural Sciences.

Reference:

Eriksson, J. & Andersson, A. (1997). Tillståndet i svensk åkermark, Swedish Environmental Protection Agency Report 4778 [In Swedish].

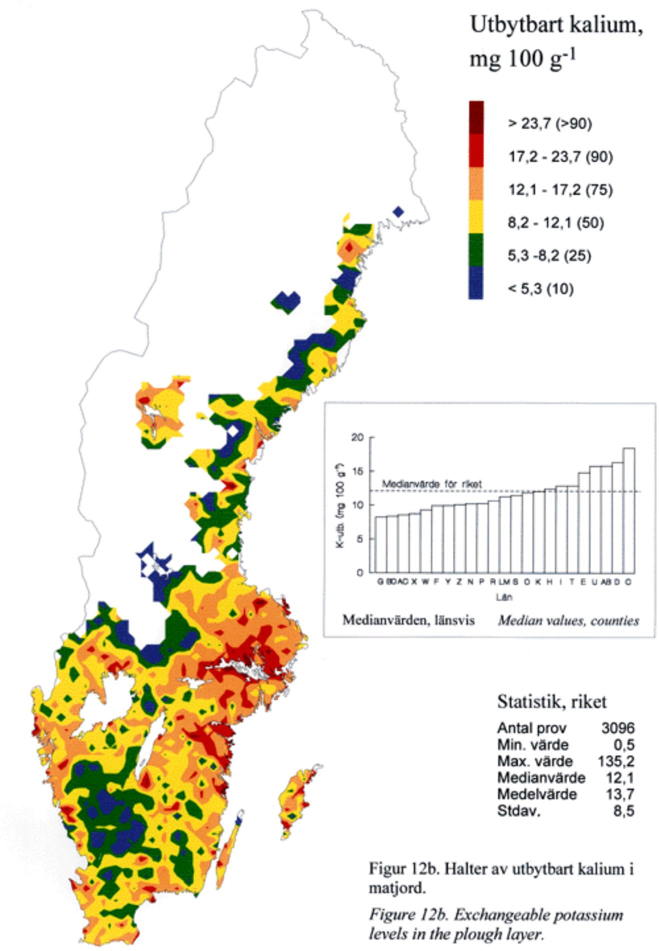

Fig. 2.1. Exchangeable potassium levels in the ploughing layer in different localities in Sweden.

Du har valt att studera följande egenskaper hos matjorden:	*2009-10-04*	
	Humushalt, % av ts	betecknas **Humus** i tabellen
	pH	betecknas **pH** i tabellen
	Utbytbart kalium, % av CECeff	betecknas **K** i tabellen

Värmlands län

	Humus	pH	K
Medel	5.7	5.9	3.4
Std	7.5	0.4	1.6
Antal	130	130	129
Min	1.7	5.0	0.3
Max	75.9	7.4	9.0

Hallands län

	Humus	pH	K
Medel	6.7	6.1	3.2
Std	8.9	0.4	1.6
Antal	143	143	142
Min	0.8	4.9	0.7
Max	76.7	7.4	7.4

Skåne län

	Humus	pH	K
Medel	4.2	6.7	2.7
Std	6.4	0.7	1.6
Antal	558	558	557
Min	1.1	4.8	0.3
Max	85.8	8.3	10.3

Fig. 2.2. Example of output from database search. Search criteria were humus, pH and exchangeable potassium. Requested output were mean, standard deviation, number of samples, minimum value and maximum value. These were requested for the counties Värmland, Halland and Skåne.

2.3 Danish Soil data

In Denmark, a classification of the ploughing layers of soil areas has been published by the Royal Danish Geographical Society (Breuning Madsen et al., 1992). Figure 2.3 shows an example of how the classification of soil types is illustrated. The classification is here based on texture analysis (incl. organic matter) of 36,000 samples from the ploughing and sub layers. For the ploughing layer (0-20 cm) the resolution is 1 sample per 70-90 ha. For sub layers (35-50 cm) the resolution is 1 sample per ca. 600 ha. This investigation covers open areas (e.g., inhabited areas, industrial areas, water bodies and forests) are not included.

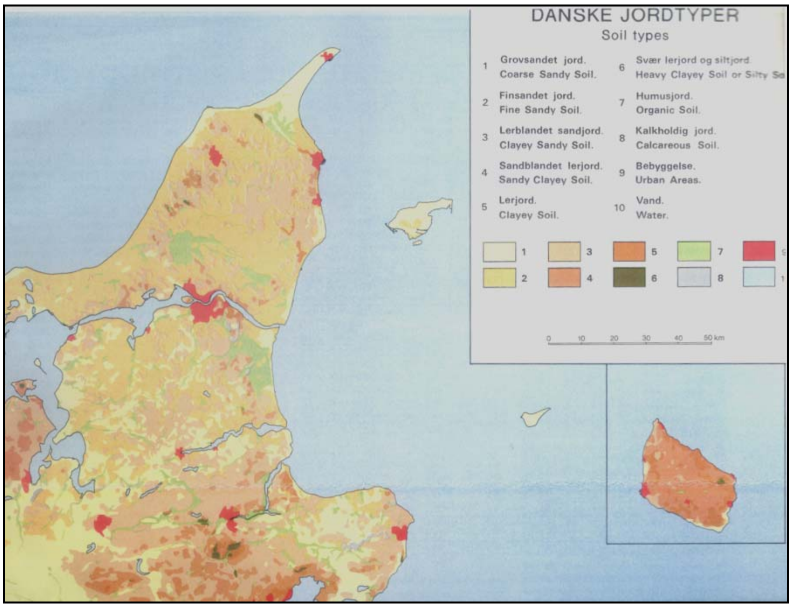

Fig. 2.3. Soil types in Denmark, classified according to texture and application. Excerpt for North-Western Jutland.

The Danish soil profile data base with the widest range of parameter information consists of about 2000 profiles (Breuning Madsen, 2009). About 750 of these lie on a 7 km resolution square net created in 1986 by Landskontoret for Planteavl. This net covers the entire country (Greenland and the Faroes excluded). For practically all of these profiles, information is available on texture, pH, exchangeable ions, % C, and CEC. Heavy metal contents are reported for 300-400 profiles on the net. Net locations in cities are excerpted, but forests are included. If the exact location of a grid point lies in a paved farm area, the point was moved 200 metres to the North, East, South or West. The database lies at the Danish Institute of Plant and Soil Science, Research Centre Foulum (who have the official version) as well as at the Institute of Georgaphy at Copenhagen University. The database on heavy metal concentrations, including zinc, lies at DMU in Silkeborg.

References:

Breuning Madsen, H. (2009). Personal communication. Institute of Geography, Copenhagen University, Denmark.

Breuning Madsen, H., Nørr, A.H. & Aagaard Holst, K. (1992). Atlas over Danmark, Serie 1, Bind 3. Den Danske Jordklassificering, Det Kongelige Geografiske Selskab, København (in Danish).

2.4 Faroese Soil data

Gridded data does not exist for the Faroe Islands. However, soil data is available for given localities, covering pH, loss on ignition, soluble potassium, sodium, transfer factors and concentration ratios (see Chapter 5 for specific information on transfer parameters for the Faroe Islands).

2.5 Norwegian Soil data

Information regarding Norwegian cultivated soils is available through Bioforsk - Norwegian Institute for Agricultural and Environmental Research (Grønlund, 2009). The data comprises of approximately 50 000 soil samples (0-20 cm) collected during the period 1996-2007. The types of soil specified are:

- Sand (>50 % sand and <12 % clay)
- Silt (>50 % silt and <12 % clay)
- Clay (>12 % clay)
- Organic (>20 % organic matter)

The following parameters are available:

- Organic matter content (%)
- Exchangeable potassium
- pH

In addition, clay content (%) is obtainable for mineral soil samples (i.e. sand, silt and clay). This parameter may be of relevance e.g. in connection with the Absalom model, where clay content (not texture class) is a key parameter (see section 3.2). Unfortunately, the present data are limited to municipality averages and statistical parameters (e.g. number of samples, standard deviations, various percentiles). Higher resolution, however, will be available at a later stage.

There are also mapped information regarding soil texture, organic matter content and other important soil/agricultural parameters from The Norwegian Forest and Landscape Institute (NIJOS) (http://www.skogoglandskap.no/seksjoner/kartkatalog). The map resolution is very high (i.e. farm level), comprising large amounts of data, but not all areas are covered.

References:

Grønlund, A. (2009). Personal communication, Bioforsk Jord og miljø, Ås, Norway.

2.6 Icelandic Soil data

When using soil parameters to assess the transfer of radionuclides from soils to plants and foodstuffs in Iceland, one must also take into consideration that the Icelandic soils are very different from the soils in the other Nordic countries in many respects, including origin and clay minerals. But this means also that the Icelandic soils can be interesting when testing models, provided that the described differences are taken into account.

The parent materials of all Icelandic soils are volcanic in origin, and most of the soils are classified as Andosols, according to the FAO classification (Arnalds, 2004). Soils that form in volcanic tephra (ash) materials are termed Andosols in the World Reference Base (WBR, World Reference Base for Soil Resources, World Soil Resources Reports 84, FAO, Rome) soil classification legend (FAO, 1998). Iceland has the largest area of Andosols in Europe, and may have >5% of all Andosols in the world. The different soil classification is very noticeable on the Soil Atlas of Europe, where the Andosols in Iceland stand out in red (see Fig. 2.4), with small patches visible in France as well (the Massif Central). Other areas with significant amounts of Andosols include south-western coast of Italy, the Kamtchatka Peninsula, the Aleutian Islands and the Rocky Mountains of the USA.

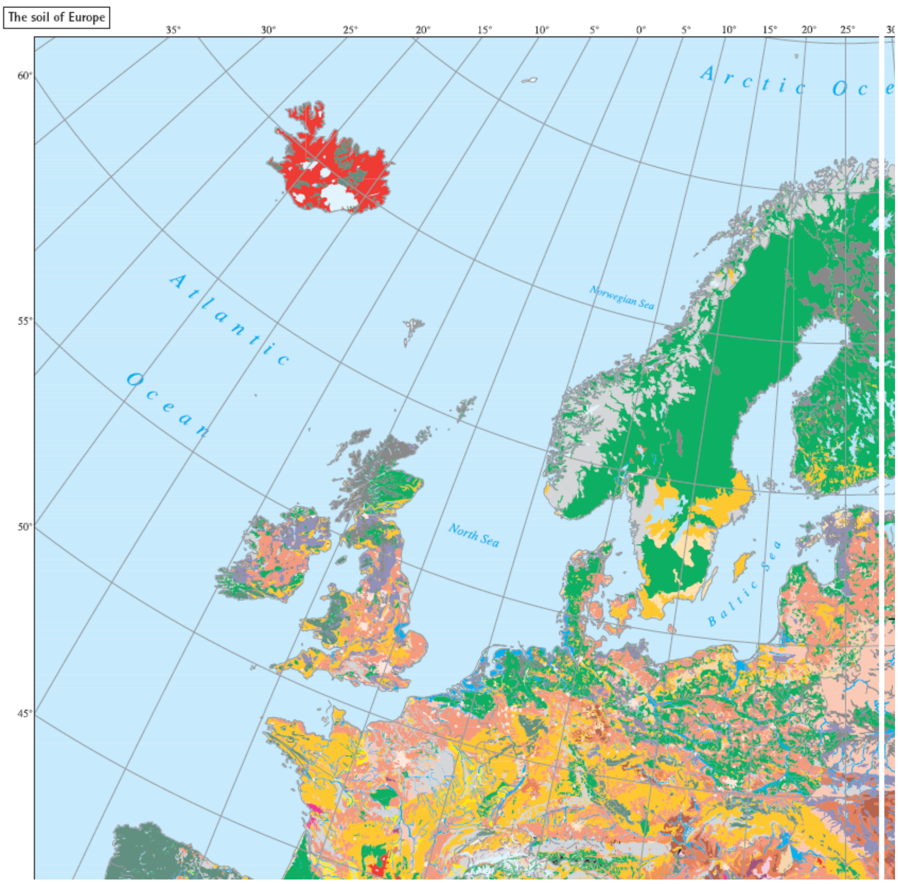

Fig. 2.4. Soils of Europe, part of map (plate 1, p. 42-43) in web version of Soils of Europe (European Commission, 2005).

In recent years the Icelandic soils have been the subject of intensive studies, some being part of international research programmes. The most recent summary can be found in a paper by Arnalds (2008). There has also been a special study on the retention of Cs-137 in Icelandic soils (Sigurgeirsson et al., 2005). This summary is mainly based on these two papers.

Andosols have unique properties, such as very high water retention (even exceeding 100%), rapid infiltration rates, high hydraulic conductivity, carbon accumulation, high P-retention, low bulk density (often < 0.7 g cm-3) and lack of cohesion (Sigurgeirsson et al., 2005). The soils often have a high cation exchange capacity (CEC) which is pH dependent and increases rapidly with pH. These properties are caused by the types of colloids that form in the soils.

Icelandic soils have been divided into soil classes in a classification developed by the Agricultural University of Iceland (Arnalds, 2004) in accordance with recent international classification schemes (see Fig. 2.5). The classes and their basic properties are given in the following table.

Table 2.1. Soil types, their main diagnostic criteria, and classification according to Soil Taxonomy (S.T.) and the WRB (from Arnalds, 2008).

Soil Type	Symbol	Diagn. pr.[1]	Extend (km^2)	%	S.T.[2]	WRB.[3]
Histosols	H	>20% C	1077	1	Histosol	Histosol
Histic Andosols	HA	12-20% C	4700	5	Aquand	Gleyic/Histic Andosol
Gleyic Andosol	GA	<12% C; gley and/or mottles	2600	3	Aquand	Gleyic Andosol
Brown Andosol	BA	<12% C, dry; >6% allophone	14300	14	Cryand	Haplic/Mollic Andosol
Cambic Vitrisol	MV	<1.5% C <6% allophone	17600	17	Cryand	Vitric Andosol/ Arenosol/ Leptosol
Arenic Andosol	SV	Sand	4600	4	Entisol	Leptosol
Leptosol	L	Rock/Scree	7300	7	Gelisol	Cryosol
Cryosol	C	Permafrost	?			
Brown and Gleyic Andosol	BA-GA		27200	26		
Complex	SV-L		4800	5		
Complex	MV-SV		6000	6		
Complex	C-GA		140	0		

1: Simplified diagnostic properties. 2: US Soil Taxonomy equivalent. 3: FAO-WRB equivalent.

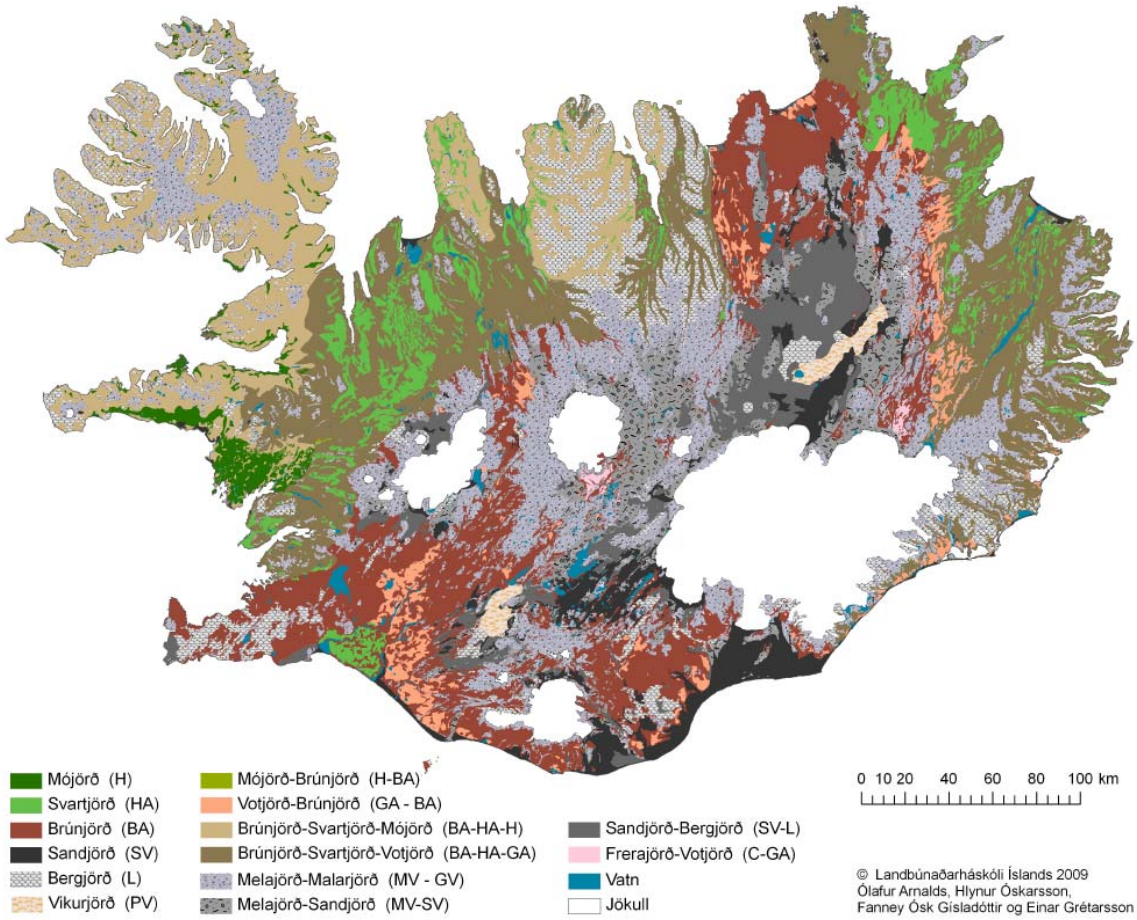

Figure 2.5. Soil map of Iceland (from Arnalds (2008)). The explanatory text is in Icelandic, but the meaning of the abbreviations (H, HA, etc.) is the same as in table 1. Glaciers ("jökull") are shown as white, lakes ("vatn") are shown as blue.

The most common soil types in the largest agricultural area, which is in southern Iceland, are the *Gleyic and Brown Andosols* (GA-BA) and *Brown Andosols* (BA), with *Histic Andosols* (HA) being the dominating type in the south-western part of the region. *Histosol* (H) is the most common type in the western area and Histic Andosol (HA) and *Brown, Histic and Gleyic Andosols* (BA-HA-GA) in the northern areas.

The study on the retention of Cs-137 in Icelandic soils (Sigurgeirsson *et al.*, 2005) showed that the CEC of the soils is high as is common for Andosols. It is mostly related to the organic content of the soil, and also in part to the clay content, especially where the organic content is low. Fallout Cs seemed to be strongly retained by colloidal materials. Cation exchange capacity (CEC) reflects the total amount of active colloidal materials in the soils, both clays and organic matter.

Summary of available soil data from Iceland relevant for PardNor:

- Gridded soil classification data is available
- More information on soil types, structure and soil parameters is available
- In Icelandic agriculture much use is made of semi-natural ecosystems. The soil map of Iceland is relatively detailed and based on remote sensing data, where many types of additional data have been included, such as soil samples from the different soil types previously identified. Thus a grid with a fixed mesh size has not been used.
- The owner of the data is the Agricultural University of Iceland (www.lbhi.is).
- It is not applicable to refer to the age of the data, the time of the latest synthesis of data would be more appropriate. The map referred to here was produced in 2008 and recent data was taken into account.

References:

Arnalds, Ólafur (2004). Volcanic soils of Iceland. *Catena* (56). p. 3-10.

Arnalds, Ólafur (2008). Soils of Iceland. *Jökull* (58), p. 409–421.

European Commission (2005). *Soil Atlas of Europe*. Office for Official Publications of the European Communities, L-2995 Luxembourg, 128 pp. Web version accessed 9.12.2009 at http://eusoils.jrc.ec.europa.eu/projects/soil_atlas/index.html

FAO (1998). *World Reference Base for Soil Resources.* FAO. World Soil Resources Reports 84. 99 pp.

Sigurgeirsson, Magnús Á.; Arnalds, Ólafur; Pálsson, Sigurður E.; Howard, Brenda J.; Guðnason, Kjartan (2005). Radiocaesium fallout behaviour in volcanic soils in Iceland. *J. Environ. Radioact* (79). p. 39-53.

3. Comparison of the CoupModel and the Absalom model

On the basis of the investigation of availability of soil data in the Nordic countries (Section 2), it is seen that both a geographical categorisation with a limited number of soil classes, based on textural analyses, and a number of parameters that might facilitate more detailed analyses of local soil conditions are available for most of the Nordic countries, often on national covering grids. This section is aimed at investigating the possibilities for using two different novel approaches for local transfer factor estimation based on detailed and complex soil parameter calculations - the CoupModel (2009) and the Absalom Model (Absalom et al., 2001).

3.1 CoupModel – overview

The name of the model stems from the fact that it is built upon coupled, numerically solved, differential equations for water and heat flow. The equations are based on conservation of mass and energy, and that flow is a consequence of temperature or water potential gradients. From a basic structure consisting of a soil-profile (variable number of compartments, maximum 100), the model can simulate heat transfer and soil water in bare or vegetation covered soils. Further calculations within the model can then provide data of processes such as snow-melt, interception of precipitation and evapotranspiration, etc.

A number of soil properties are needed for the calculations: water retention curve, hydraulic conductivity curves, heat capacity and latent heat, thermal conductivity etc. Also plant parameters are needed, such as distribution of vertical roots, resistance to flow of water between plant and atmosphere, regulation of water uptake, influence on air streams by the plant above ground and radiation balance. The model contains a database listing important parameter values for a number of sampled sites. Driving variables to the model is meteorological data, e.g. air temperature, precipitation, humidity, wind speed and cloudiness.

A number of “switches” are included making it possible to choose whether one wishes to use e.g. heat flow in the calculations (Figure 3.1). It is also possible to choose output variables (results) and a few examples are given in Figure 3.2. In summary, the model is very comprehensive and has to be carefully set up for each application, but to facilitate the use of the model a user group and an interactive advanced course has been made.

3.2 Absalom model – overview

The Absalom model is tailored to predict the uptake and transfer factor (*TF*, Bq kg^{-1} in plant/Bq kg^{-1} in whole soil) of radiocaesium in plants depending on different soil characteristics. The model determines the bioavailability of radiocaesium from three soil parameters, which are estimated by the model from user input soil characteristics. The user provides soil pH, content of organic material (g g^{-1}), concentration of exchangeable potassium ($cmole_c$ kg^{-1}) and clay content (g g^{-1}). The model then calculates the distribution coefficient of labile caesium (k_{dl}), the concentration of K^+ in soil solution (m_k) and the concentration factor from soil solution to plant (*CF*, Bq kg^{-1}

in plant/Bq dm^{-3} in soil solution). Also the effect of caesium fixation with time is taken into account and the uptake at different times (user input) after a deposition can be simulated in a single run.

The model has been parameterised with uptake data from two trials with ryegrass and bent grass, grown in pots on mineral soils and organic soils, respectively. The model has thereafter been validated against data on uptake of radiocaesium in Barley (with *TF* ranging from 0.001 to 0.1).

3.3 Possible use within PARDNOR

3.3.1. CoupModel

A feature that may be useful in radioecological research and emergency preparedness is the possibility to simulate plant dynamics and turnover of nitrogen and carbon (and not only heat and water conditions). An optional number of plants may be defined, consisting of roots, leaves, stem and grain. Different feedback mechanisms between physical driving forces and plant development can thus be handled by linking abiotic and biotic processes within the model. The transport of a radionuclide has been modelled and the results are reported in an SKB-report (Gärdenäs et al., 2006).

In this simulation the radionuclide is modelled as a state variable in different plant parts and in soil layers (liquid and solid phase). Both passive and active (governed by carbon assimilation) uptake was simulated and the results compared to field studies in a boreal forest. The radionuclide was assumed to enter the system (soil-plant-air) as a constant groundwater flux or as an initial concentration in the soil layers. However, the modelling work was quite extensive and performed, more or less, as a research project.

Using the CoupModel for calculation of transfer factors is probably possible but would demand a considerable effort. A suitable model has to be made, including modelling of the downward migration of deposited radionuclides, in order to calculate the activity concentration in plants (Bq/kg) in relation to the areal activity concentration (Bq/m^2). In that aspect the Absalom model may be better suited for calculation of transfer factors.

3.3.2. Absalom model

In the paper by Absalom *et al.* (2001), the authors discuss the usefulness of the model and claims that the model is an improvement over models that use only single-valued transfer factors. The transfer factors for grass, used in the fitting procedure to determine the parameters, covered nearly five orders of magnitude and resulted in significant fits. The validation of the model predictions with data from barley showed rather large deviations: the overall trend was reproduced but with rather large scatter. Some of the data points are considerably underestimated by the model (three times the residual standard deviation in a plot of log *TF*), which in part may be explained by high content of clay or organic matter. The barley data were also derived from different experimental designs, covering a rather large range of time periods.

The possibilities of finding the data needed for running the model are good and the transparency of the model makes it rather easy to modify. However, the fact that the predicted transfer factors are given only for caesium and only for a generic plant species, not covering the needed range of crops, makes it difficult to include the Absalom model within ECOSYS.

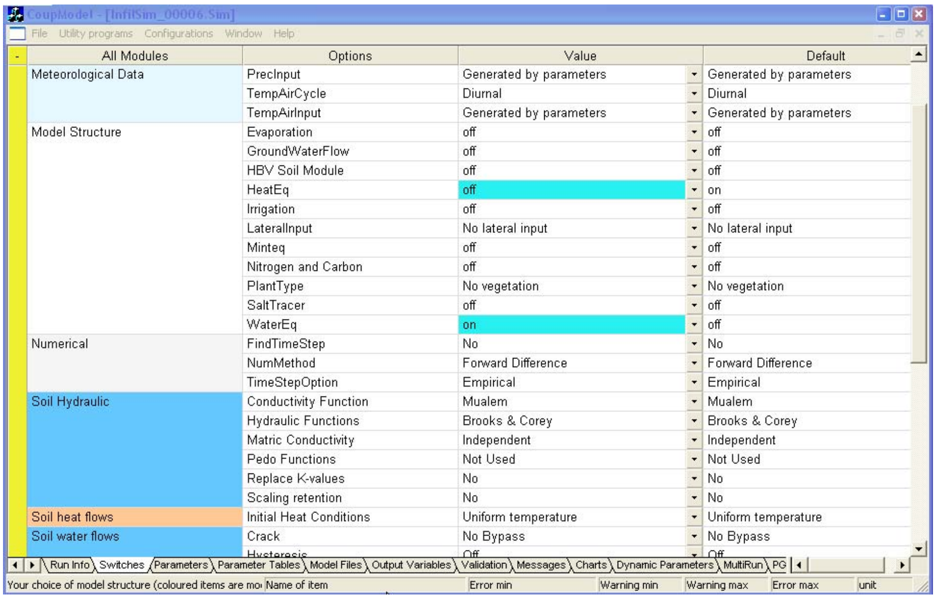

Figure 3.1. Switches in CoupModel that determine which features of the model that will be utilized in a simulation.

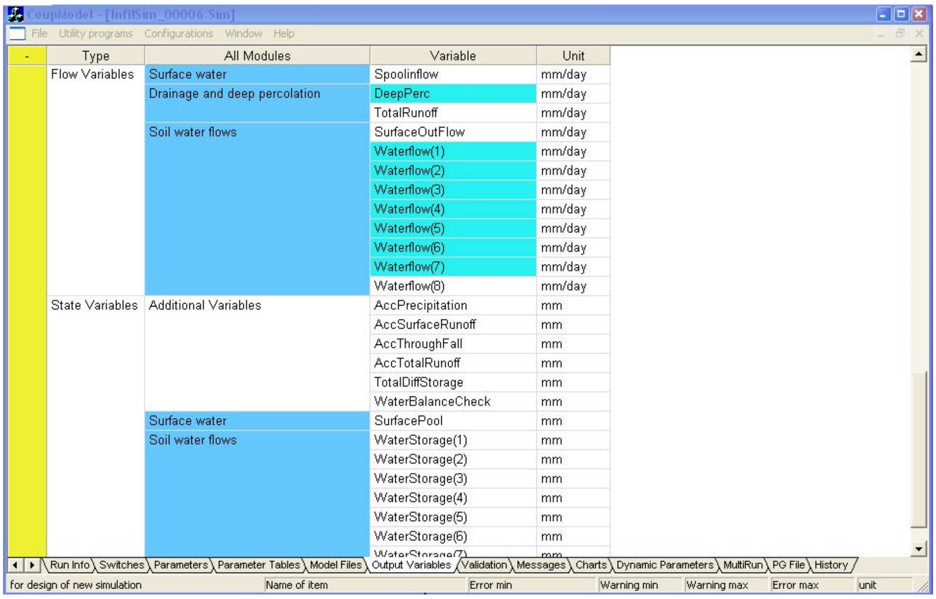

Figure 3.2. Output variables of CoupModel. The number of compartments in the soil profile has been set to eight.

References:

Absalom, J. P., Young, S. D., Crout, N. M. J., Sanchez, A., Wright, S. M., Smolders, E., Nisbet, A. F. & Gillett, A. G. (2001). Predicting the transfer of radiocaesium from organic soils to plants using soil characteristics, Journal of Environmental Radioactivity, 52, pp 31-43.

CoupModel Web Home Page (2009) http://www.lwr.kth.se/vara%20datorprogram/CoupModel/index.htm.

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4. Transfer factors from soil to plants

This section describes an effort made to introduce a series of new transfer factor measurement data to improve the current ECOSYS database. The focus in this study is on radiocaesium, which would be likely to be the main radionuclide of concern in connection with a new major nuclear power plant release, and is also a radionuclide of major concern in connection with conceivable malicious contamination acts (e.g., spraying from an aeroplane). The improvement is twofold: the data currently in the database are old, as the model was created in the late 1980's, and the parameterisation reflects little of the many data, particularly on radiocaesium, that have arisen after the Chernobyl accident; also, the model currently does not distinguish between different soil types, which is known to be a great problem that could lead to very wrong estimates and errors in prioritisation of intervention in different areas after an emergency situation. The new database builds in the state-of-the-art knowledge on radiocaesium transfer and enables the distinction between different soil types. The activity group recommends a simple soil classification according to categories like sand, loam, clay and organic soils (for which reliable measurement data generally exist for important crops), as other, more complex approaches (see Section 3) do not seem feasible. Also, this type of categorisation fits well in line with the expansions in the database structure and graphical user interface foreseen by the ARGOS system developers.

The soil-to-plant transfer factor (TF) describes the transfer of radionuclides from soil to plant when uptake by plant roots is the only process affecting transfer. The transfer factors usually describe radionuclide transfer to edible parts of crops. The transfer factors in the ECOSYS model are defined as the ratio of the activity concentration in plant (fresh mass) and the activity concentration in soil (dry mass) under equilibrium conditions. The values applied in ECOSYS for Excel are representative for intensive farm management in Germany (Health Physics 64 (1993), p. 238).

One parameter that has been suggested for use for quantifying the transfer of radiocaesium from soil is the Radiocaesium Interception Potential (RIP). It is an intrinsic soil parameter that can be determined in standardized experimental conditions. It was decided to include a study on transfer of radiocaesium from soil to vegitation and food in Iceland, since the geological conditions described in Section 2.6 should lead to the RIP values being very low. The preliminary results are described in Section 4.4.

4.1 Soil-to-plant transfer factors in the IAEA TECDOC 1616

Several members of the PardNor activity group have over the later years participated in the IAEA EMRAS work group to produce an updated handbook to replace the now obsolete IAEA-TRS-364 report from 1994. In the new IAEA Handbook (IAEA, 2009), which reports on a very comprehensive and new transfer factor study, soil-to-plant transfer is called concentration ratio (F_v) and is defined as the ratio of the activity concentration of radionuclide in the plant (Bq kg^{-1} dm) to that in the soil (Bq kg^{-1} dm). Soil-to-plant transfer factors are given for four soil groups: sand, loam, clay and organic and/or an average for all soil types. Soils were included in the organic group, if the organic matter content was ≥ 20 %. In the sand group, the sand fraction was ≥ 65 % and the clay fraction ≤ 18 %. In the clay group, the clay fraction was ≥ 35 %, and the loam group included the rest of cases. As mentioned above, the study reported here focuses on radiocaesium, although also improved data for other, often less important, radionuclides is available from the new IAEA handbook and could also be included in ECOSYS (and thereby in the ARGOS and RODOS DSS).

Soil-to-fruit transfer factors (F_v) are reported relating to fresh weight, i.e. as the ratio of the activity concentration of radionuclide in the fruit (Bq kg^{-1} fresh weight) to that in the soil (Bq kg^{-1} dry weight). Data on fruit is reported in three groups: woody trees, both deciduous and evergreen ones, shrubs and herbaceous plants. Data reported under the heading woody trees include apple, pear, peach, apricot, grapevine, olive and orange. The group shrubs includes gooseberry, blackcurrant, red raspberry and red current, whereas the group herbaceous plants include strawberry, melon, watermelon and rhubarb. Values of F_v cover two orders of magnitude, from 10^{-4} to 10^{-2}. F_v values for fruits of woody trees range from $8.6x10^{-4}$ to $8.0x10^{-2}$, for fruits of shrubs from $6.9x10^{-4}$ to $5.7x10^{-3}$ and for fruits from herbaceous plants from $4.1x10^{-4}$ to $8.9x10^{-3}$. The variation in F_v values reflects primarily differences in soil characteristics rather than differences among plants. The highest values are for light textured or organic soils.

The radiocaesium transfer factors soil-plant for plant types used in ECOSYS Excel are given in Table 4.1. The corresponding values given in the IAEA TECDOC 1616 for the same plant groups calculated in the same units are also given in Table 4.1.

Table 4.1. Radiocaesium transfer factors (concentration ratios, F_v) soil-plant in the ECOSYS model and IAEA Handbook

ECOSYS Excel		IAEA Handbook				
Plant group	Bq kg^{-1} fw/ Bq kg^{-1} dw	**Plant group**	**Soil type**	Bq kg^{-1} dw/ Bq kg^{-1} dw	Dry matter content, %	Bq kg^{-1} fw/ Bq kg^{-1} dw [b]
Grass intensive	0.05	Grasses (stems and shoots)	All	0.063	20	0.013
		″	Sand	0.084		0.017
		″	Loam	0.048		0.0096
		″	Clay	0.012		0.0024
		″	Organic	0.28		0.056
Grass extensive	1	Pasture (stems and shoots)	All	0.25	20	0.050
		″	Sand	0.29		0.058
		″	Loam	0.19		0.038
		″	Clay	0.18		0.036
		″	Organic	0.76		0.15
Maize	0.02	Maize (stems and shoots)	All	0.073	19	0.014
		″	Sand	0.1		0.019
		″	Loam	0.015		0.0029
		″	Clay	0.022		0.0042
		″	Organic	0.14		0.027
Corn cobs	0.01	Maize (grain)	All	0.033	85	0.028
		″	Sand	0.049		0.042
		″	Loam	0.016		0.014
		″	Clay	0.012		0.010
Potatoes	0.01	Tubers	All	0.056	21	0.012
		″	Sand	0.093		0.020
		″	Loam	0.035		0.0074
		″	Clay	0.025		0.0053
		″	Organic	0.058		0.012
Beet	0.005	See Root crops (roots)	All	0.042	22	0.0092
Beet leaves	0.03	Root crops (leaves)	All	0.035	-[b]	
		″	Sand	0.11		
		″	Clay	0.026		
Cereals [c] (barley, wheat, oats, rye)	0.02	Cereals (grain)	All	0.029	87–88	0.025
		″	Sand	0.039		0.034
		″	Loam	0.02		0.017
		″	Clay	0.011		0.0096
		″	Organic	0.043		0.037

Leafy vegetables	0.02	Leafy vegetables (leaves)	All	0.06	8–12	0.0048–0.0072
		″	Sand	0.12		0.0096–0.014
		″	Loam	0.074		0.0059–0.0089
		″	Clay	0.018		0.0014–0.0022
		″	Organic	0.0225		0.0018–0.0027
Root vegetables	0.01	Root crops (roots)	All	0.042	9–16	0.0038–0.0067
		″	Sand	0.062		0.0056–0.0099
		″	Loam	0.03		0.0027–0.0048
		″	Clay	0.024		0.0022–0.0038
		″	Organic	0.059		0.0053–0.0094
Fruit vegetables	0.01	Non-leafy vegetables	All	0.021	5–6	0.0011
		″	Sand	0.035		0.0018
		″	Loam	0.033		0.0017
		″	Clay	0.0091		0.0005
Fruit	0.02	Woody trees	All			0.0058
		″	Sand			0.015
		″	Loam			0.0035
		″	Clay			0.0011
		″	Organic			0.037
Berries	0.02	Shrubs	All			0.0021
		″	Loam			0.0038
		″	Clay			0.0022

[a] Calculated using the dry matter content given in the IAEA TECDOC 1616. For fruit and berries the values are given in the handbook as fruit fresh weight per soil dry weight.
[b] Not known.
[c] In ECOSYS Excel values for cereals are given separately for each cereal type (winter barley, spring barley, winter wheat, spring wheat, rye and oats) and are similar for all cereal types, 0.02.

The values of transfer factors for cereals, potato and berries are nearly equal in ECOSYS and the IAEA TECDOC 1616, but for the other plants they are of different magnitudes, some of those differing by an order of magnitude. The transfer factors are greatly dependant on the soil types, the highest values are on organic soils and on mineral soils, and the rate of uptake largely decreases with increasing clay content. Some of the plant groups in the IAEA TECDOC 1616 include plants not grown in the Nordic countries. The group cereals includes all the cereal types (barley, oats, rye, wheat), which are separated in the ECOSYS model. According to the IAEA TECDOC 1616 and Panov et al (2009) the variation in transfer factors of the different grain crops is insignificant, so they are combined into one group.

4.2. Nordic soil–plant transfer factor data

The Nordic transfer factor data is for most part reported in units Bq kg^{-1} plant per Bq m^{-2}, and the connection between Bq kg^{-1} soil and deposition Bq m^{-2} has not been given (Eriksson, 1994, Eriksson et al, 1994, Rosén et al, 1996, Kostiainen et al, 2002). Converting the Nordic data to the units used in the ECOSYS model is laborious and more information is needed besides the reported data.

In Finland the transfer factors have generally been calculated using areal ^{137}Cs deposition data based on mobile survey measurements of environmental gamma radiation in 1986-87. The data on cereal grains showed differences between transfer factors of different cereal types, the transfer factors of oats and rye being higher and showing greater variation than those of barley and wheat (Kostiainen, Rantavaara, 2003).
The Finnish data available in the units Bq kg^{-1} plant (dry weight) per Bq kg^{-1} soil (dry weight) is given for the years 1986-89 in Table 2 (Paasikallio et al, 1994). The values in Table 4.2 represent transfer factors for the southern part of Finland. The mean transfer factors for the northern sites were significantly higher than those for the southern sites.

Table 4.2. Concentration ratios for ^{137}Cs in plants (Bq kg^{-1} dm) to soil (Bq kg^{-1} dm) by soil groups.

Plant group	**Soil type**	**Transfer factor (southern Finland)**			
		1986	**1987**	**1988**	**1989**
Leafy vegetables[1]	Clay and silt	0.033-0.113	0.037-0.049	0.040-0.102	0.051-0.103
	Coarse mineral	0.121-0.262	0.053-0.099	0.094-0.156	0.107-0.158
	Organic	0.103-0.108	0.010-0.026	0.008-0.163	0.044-0.122
Root vegetables[2]	Clay and silt	0.021	0.015	0.028	0.027
	Coarse mineral	0.102	0.038	0.074	0.044
	Organic	0.020	0.009	0.027	0.019
Potato	Clay and silt	0.044	0.023	0.070	0.019
	Coarse mineral	0.093	0.060	0.083	0.069
	Organic	0.011	0.008	0.015	0.018
Cereals[3]	Clay and silt	0.033	0.012	0.008	0.006
	Coarse mineral	0.051	0.018	0.018	0.013
	Organic	0.009	-	0.005	0.004
Berries					
blackcurrant		7.92	1.26	0.24	0.03
strawberry		3.14	0.29	0.12	0.02
Fruit (apple)		0.70	-	0.09	0.05

[1] Lettuce and cabbage.
[2] Carrot.
[3] Wheat and barley.

The transfer factor for leafy vegetables fluctuated between the years, and that for root vegetables (carrot), potato and especially cereals decreased gradually after 1986. The highest values of transfer factors in this study were found on coarse mineral soils. The transfer factors given in the IAEA 1616 and in this study are of the same order of magnitude in most plant groups taking into account the different soil group division and species inside the plant groups.

4.3 Use of IAEA 1616 transfer factors in ECOSYS model

Radionuclide transfer from soil to plants depends on numerous factors, e.g. physicochemical properties of radionuclides, type of crop, soil properties, crop management practices (fertilization, irrigation, ploughing, liming), time after fallout. For ^{137}Cs, the transfer factors to farm crops for high fertility soils are typically two orders of magnitude lower than for low-fertility soils. In the IAEA 1616 the transfer factors are reported for different soil types. The use of soil dependant transfer factors in the ECOSYS model would improve substantially the dose assessments. The IAEA 1616 transfer factor data could give more realistic results than the original transfer factor data representative for Germany unless national data is available. For converting the units to those used in the ECOSYS model, the dry matter contents of different plants are found in the IAEA 1616.

References:

Eriksson Å. (1994). A database model for calculations of the transfer of ^{90}Sr and ^{137}Cs in complex agricultural environments. Report SLU-REK-76, Department of Radioecology, Swedish University of Agricultural Sciences, Uppsala.

Eriksson Å, Lönsjö H, Karlström F. (1994). Beräknade effekter av radioaktivt nedfall på jordbruksproduktionen i Sverige. Report SLU-REK-73, Department of Radioecology, Swedish University of Agricultural Sciences, Uppsala.

IAEA. (2009) Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessments, IAEA TECDOC-1616. International Atomic Energy Agency, Vienna, Austria, ISBN 978-92-0-104509-6.

Kostiainen E, Hänninen R, Rosén K, Haak E, Eriksson Å, Nielsen SP, Keith-Roach M, Salbu B (2002). Transfer Factors for Nuclear Emergency Preparedness. NKS-78. Pitney Bowes Management Services Denmark A/S.

Kostiainen E, Rantavaara A. (2001). Transfer of ^{137}Cs and ^{90}Sr from Finnish soils to cereal grains. In: Bréchignac F (ed.). Radioprotection. Proceedings Volume I of the International Congress: The Radioecology – Ecotoxicology of Continental and Estuarine Environments ECORAD 2001, Aix-en-Provence, France, 3-7 September, 2001. Radioprotection – colloques 2002; 37 (C1): CI-509-514.

Paasikallio A, Rantavaara A, Sippola J. (1994). The transfer of cesium-137 and strontium-90 from soil to food crops after the Chernobyl accident. The Science of the Total Environment 155, 109-124.

Panov AV, Aleksakhin RM, Prudnikov PV, Novikov AA, Muzalevskaya AA. (2009). Influence of rehabilitation measures on the ^{137}Cs uptake by crops from soils contaminated during the Chernobyl accident. Eurasian Soil Science, Vol.42, No.4, pp. 445-457.

Rosén K. (1996). Field studies on the behaviour of radiocaesium in agricultural environments after the Chernobyl accident. Report SLU-REK-78, Department of Radioecology, Swedish University of Agricultural Sciences, Uppsala.

4.4. Radiocaesium interception potential (RIP) as a basis for soil-to-plant transfer categorisation

Various soil parameters influence the transfer of radionuclides from soil to plants. For radiocaesium, the Radiocaesium Interception Potential (RIP) is of special interest, being an intrinsic soil parameter that can be determined in standardized experimental conditions (Cremers *et al*., 1988).

In a recent paper, Vandebroek *et al.* (2009) presented results from an analysis of 88 samples of soils from all over the globe. The RIP (μmol ·g^{-1}) can be defined as:

$$RIP = K_C \cdot [FES] = K_{D\,s}^{Cs} \cdot [K^+]$$

where [FES] is the capacity of Frayed Edge Sites with high adsorption selectivity for Cs^+, K_C is the ^{137}Cs-K selectivity coefficient on these sites, $K_{D\,s}^{Cs}$ is the ^{137}Cs solid – liquid distribution coefficient and $[K^+]$ is the concentration of K in solution.

The spread of values within the main soil groups can be seen in Figure 4.1 below.

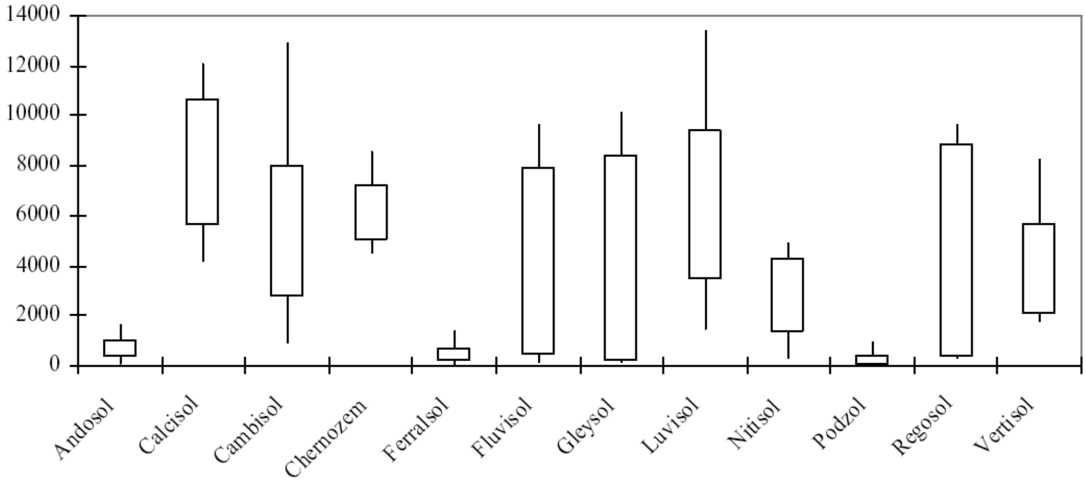

Fig.4.1. Confidence interval and optima of RIP [μmol · g^{-1}] for major reference soil groups (from Vandebroek *et al*., 2009).

According to these results, classification according to soil groups is clearly not good for predicting RIP values. There are however 3 soil groups which gave results that are significantly lower than the others, the *Andosols*, *Ferralsols* and the *Podzols*. As explained in section 2.6 of this report, Iceland is unique in Europe with *Andosols* being the dominating agricultal soil types. It was thus concluded within PardNor that it would be worthwhile to investigate if measurements would confirm the RIP values in Iceland to be (very) low and then if this was thus reflected in a high transfer of radiocaesium from soil to plants and foodstuffs.

Previous investigations have indicated low retention of Cs in Icelandic soils. A preliminary study was undertaken in cooperation with Brenda J. Howard (Centre for Ecology and Hydrology) and Miquel Vidal (University of Barcelona). Soil samples were collected from the main agricultural region in the south, another region in the west and two regions in the north (Eyjafjörður and Skagafjörður). First RIP results were in a similar range 20 – 1800 as those reported for Andosols by Vandebroek et al. (2009) and T_{ag} values for milk have been found to be of the order 10^{-3} m^2 kg^{-1}. In the next step more samples were collected in the 4 regions and these were analysed this year by Miquel Vidal for RIP and more parameters that could help to explain observed differences in transfer coefficients from soil-to-milk (T_{ag} values).

The RIP alone should not be expected to explain variability in T_{ag} values (Vidal, 2009). The solid-liquid distribution coefficient, $K_{D\,s}^{Cs}$, (along with the estimation of sorption reversibility) is the key parameter governing the radionuclide mobility from soils to other (environmental) compartments and as explained earlier, the RIP is a product of this parameter and the concentration of K^+ in the solution. The results so far have low RIP values as expected by the geological conditions described in Section 2.6. But the results have so far not shown a clear relationship between T_{ag} and RIP or the K_D. The study will be continued in 2010, with the aim to explain better the role of RIP and other soil parameters and classifications in creating variability in transfer coefficients, such as T_{ag} values.

References:

Cremers A., A. Elsen, P. De Preter and A. Maes, 1988. Quantitative analysis of radiocesium retention in soils. Nature, 335:247-249.

Vandebroek L., Van Hees M., Delvaux B., Spaargaren O., Thiry Y. (2009). Acid extraction as a predictive tool of Radiocaesium Interception Potential (RIP) in a worldwide scale. *Radioprotection*, vol. 44, (no 5), p. 635–638.

Vidal, M. 2009. Personal communication.

5. Transfer of ^{137}Cs in Faroese terrestrial environment 1990-2005

5.1. Introduction

As mentioned in Section 2.4, gridded soil characterisation data does not exist for the Faroe Islands, which could enable application of soil-type-specific transfer factors, as reported in Chapter 4, on an ARGOS square grid. Nevertheless, relevant soil data exists for given localities, and an effort has been made over many years to determine location-specific transfer parameters for radiocaesium.

Activity concentration of ^{137}Cs in soil, mixed grass and lamb meat has been monitored in semi-natural pastures in the Faroe Islands since 1990 (see Figure 5.1). The monitoring is motivated by the fact that lamb meat is an important food component for the local people.

The report presents results for the years 1990-2005. Aggregated transfer factors and concentration ratios in the lamb food chain have been calculated. Observed concentration ratios are compared to values in the international literature and to values in the ECOSYS model used by the NKS PARDNOR working group.

Fig. 5.1. Map of the Faroe Islands showing selected sites for the study

Table 5.1. GPS stations used since August 2004 (for Hvalvík though since August 2006).

GPS nr	Pasture name	Sample plot 0.25 m^2	Height m a.s.l	Latitude (N)	Longitude (W)
8	Skáli	A	41	62°08.823'	006°46.434'
9	Skáli	B	45	62°08.835'	006°46.465'
11	Skáli	C	61	62°08.795'	006°46.450'
14	Skáli	D	52	62°08.808'	006°46.434'
15	Velbastaður	A	156	62°00.113'	006°53.506'
16	Velbastaður	B	179	62°00.124'	006°53.501'
17	Velbastaður	C	179	62°00.116'	006°53.536'
18	Velbastaður	D	175	62°00.100'	006°53.574'
20	Sandur	A	304	61°53.052'	006°50.693'
21	Sandur	B	302	61°53.059'	006°50.720'
22	Sandur	C	302	61°53.075'	006°50.710'
23	Sandur	D	301	61°53.083'	006°50.763'
24	Norðoyri	A	167	62°11.629'	006°30.985'
25	Norðoyri	B	168	62°11.576'	006°30.934'
26	Norðoyri	C	163	62°11.569'	006°30.940'
27	Norðoyri	D	159	62°11.584'	006°30.961'
30	Hvalvík	A	(102 ??)	62°11.959'	007°04.858'
31	Hvalvík	B	50	62°11.899'	007°04.836'
32	Hvalvík	C	55	62°11.892'	007°04.879'
33	Hvalvík	D	55	62°11.870'	007°04.908'

5.2. Materials and methods

Soil, grass and lamb meat have been sampled in semi-natural pastures since 1990. The selected sampling sites are shown in Figure 5.1. Soil and grass were sampled in late July and early August, while lamb meat (neck muscle) was collected at the time of slaughter in October when the lambs were about 6 months old.

Four plots with the width of 0.25 m^2 were used for grass and soil sampling in each pasture. Three soil cores, 5.7 cm in diameter and 10 cm in depth, were collected from each plot. GPS positions have been attached to some of the sampling stations (Table 5.1).

Soil characteristics are presented in Table 5.2. The low pH and high loss on ignition are conditions that favour high uptake of radiocesium.

Table 5.2. Soil characteristics for the top 10 cm soil layer. Average for the eight years 1990-97 ± 1 SE. (Adapted from Joensen, 1999)

	Bøur	Velbastað	Hvalvík	Skáli	Funnings-fjørður	Norðoyri	Sandur	Hvalba	Sumba
pH	4.9 ± 0.05	5.1 ± 0.11	4.8 ± 0.09	4.9 ± 0.06	4.8 ± 0.07	4.7 ± 0.10	4.8 ± 0.11	5.1 ± 0.07	4.9 ± 0.07
K, mg/100g	63.2 ± 8.0	60.0 ± 6.3	51.4 ± 7.4	67.8 ± 8.6	45.5 ± 6.0	64.3 ± 5.9	56.5 ± 5.0	77.2 ± 8.0	65.8 ± 6.8
Na, mg/100g	39.3 ± 4.0	39.8 ± 4.3	31.3 ± 5.1	34.2 ± 4.2	31.9 ± 3.4	43.8 ± 4.9	39.5 ± 2.8	108.7 ± 15.6	58.5 ± 5.9
Loss on ignition, %	52 ± 4.1	30 ± 3.1	67 ± 3.8	56 ± 3.6	51 ± 3.1	67 ± 4.0	52 ± 4.4	63 ± 2.7	56 ± 5.2

The main pathway of ^{137}Cs to the terrestrial environment is by precipitation. Precipitation data are available near some of the selected sites (Table 5.3). There is a factor of nearly 4 between the lowest and highest precipitation rate in Table 5.3.

The geographic variability in the soil parameters and the precipitation rate (Tables 5.2 and 5.3) imply variation of the ^{137}Cs activity concentration of in soil, mixed grass and lamb meat (Figures 5.2-5.4).

Table 5.3. Precipitation rate in mm per year. (Ref: Cappelen and Laursen, 1998).

Bøur (1988-97)	Hvalvík (1988-97)	Norðoyri (1961-90)	Sandur (1961-90)	Sumba (1961-90)
1555	3261	2710	1193	884

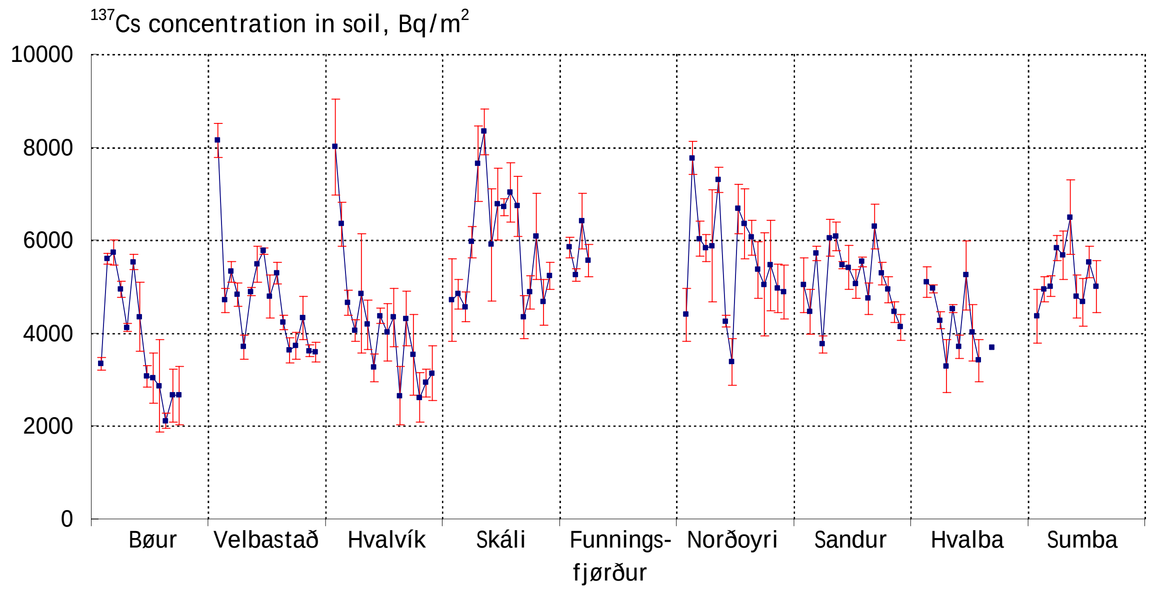

Fig. 5.2. ^{137}Cs (Bq/m^2) in upper 10cm soil since 1990. Annual average ± 1 SE. The first data for Hvalba are from 1991.

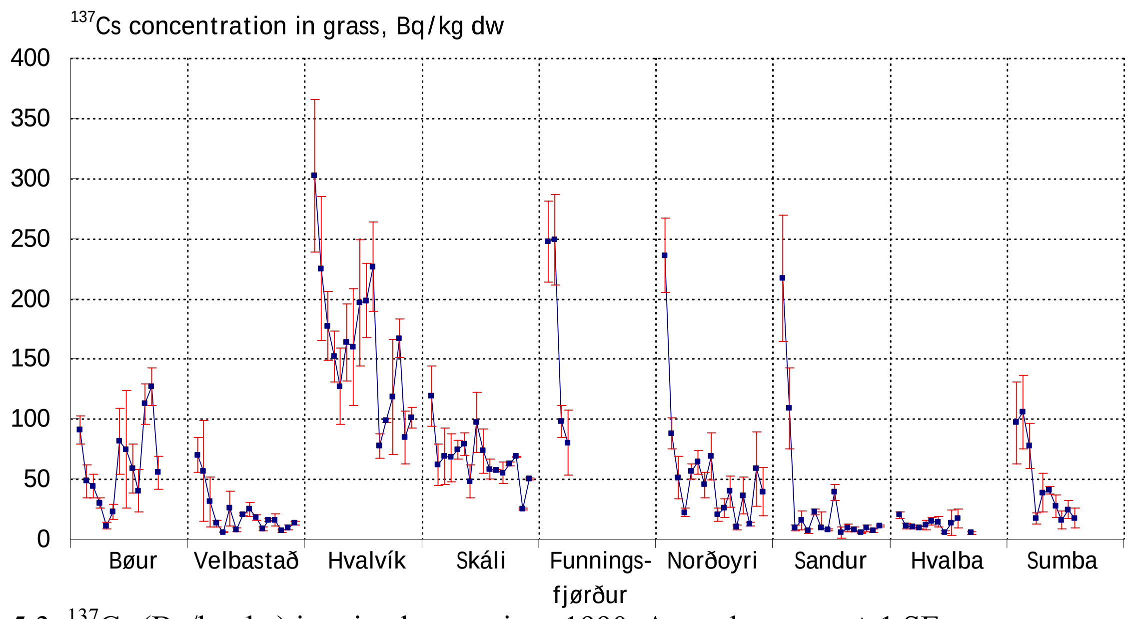

Fig. 5.3. ^{137}Cs (Bq/kg dw) in mixed grass since 1990. Annual average ± 1 SE.

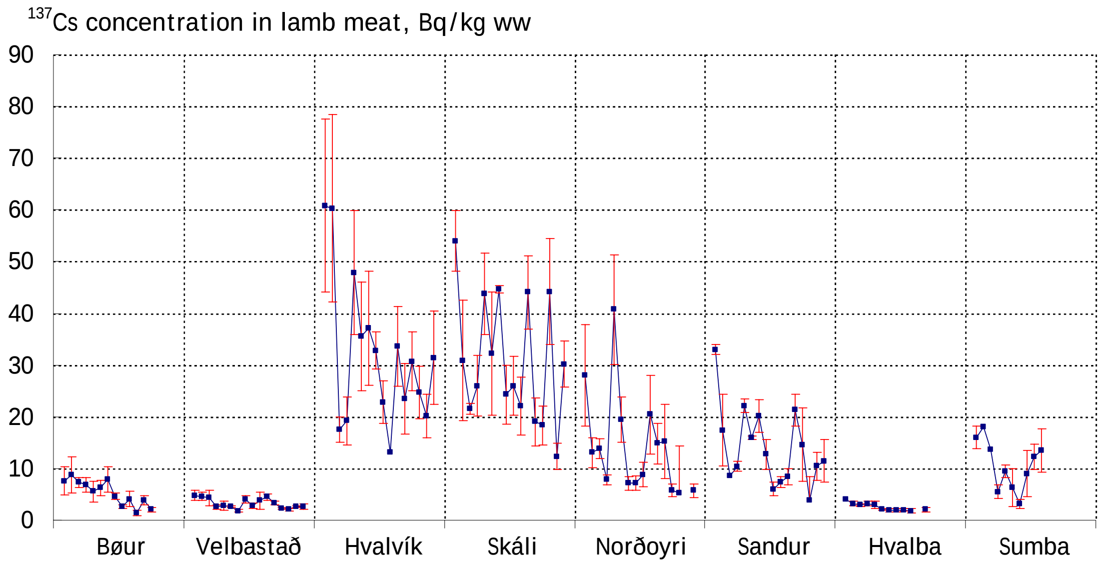

Fig. 5.4. ^{137}Cs (Bq/kg ww) in lamb meat since 1990. Annual average ± 1 SE.

5.3. Behaviour of ^{137}Cs in the food chain of lamb

The ^{137}Cs activity in soil, mixed grass and lamb meat has decreased at most sites from 1990 to 2005, although not monotonically (Figures 5.2-5.4). The highest values occurred at the site with the highest precipitation rate, Hvalvík (Table 5.3).

The effective ecological half-life of ^{137}Cs could in some cases be estimated by a one-component exponential decay function (Table 5.4), with the ranges 11.4-21.7 years for deposition (3 sites), 3.6-16.5 years for grass (6 sites) and 5.1-9.9 for lamb meat (2 sites).

Table 5.4. Effective ecological half-life in years, based on measurements 1990-2005. All time series do, however, not cover the same time period. Numbers in brackets represent R^2 from a linear regression between time and natural logarithm of ^{137}Cs concentration in the samples. No estimates are given when R^2<0.300.

	Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
Grass Bq/kg dw	- (0.027)	8.1 (0.329)	12.8 (0.437)	16.5 (0.357)	7.8 (0.302)	5.0 (0.384)	- (0.005)	3.6 (0.667)
Meat Bq/kg ww	5.1 (0.668)	- (0.194)	- (0.162)	- (0.148)	- (0.295)	- (0.202)	9.9 (0.781)	- (0.069)
Soil Bq/m^2	11.4 (0.528)	21.7 (0.462)	13.9 (0.636)	- (0.005)	- (0.044)	- (0.015)	- (0.253)	- (0.035)

5.4. Aggregated transfer factors and concentration ratios for ^{137}Cs

Soil-to-grass and soil-to-meat T_{ag}'s are presented in Figures 5.5 and 5.6, respectively. Soil-to-grass and grass-to-meat concentration ratios, CR, are presented in Figures 5.7 and 5.8, respectively.

The soil-to-grass T_{ag}'s and CR's are calculated for every 0.25 m^2 sampling plot. The T_{ag}'s for soil-to-meat transfer are calculated as the ratio between activity concentration in the single lamb meat samples and the average activity deposition in soil at the particular pasture. The CR's for grass-to-meat transfer are similarly calculated as ratio between activity concentration in the single lamb meat samples and the average activity concentration in grass at the particular pasture.

At most sites, there is no clear trend with time in the observed transfer parameters. There is a significant variation in the values within and between sites.

The highest soil-to-grass and soil-to-meat transfer parameters were generally observed in Hvalvík, while the lowest values occurred in Hvalba (Figures 5.5 - 5.7). This may partly be related to the soil characteristics at the two sites (Table 5.2). The observed pH and K-content are higher in Hvalba than in Hvalvík.

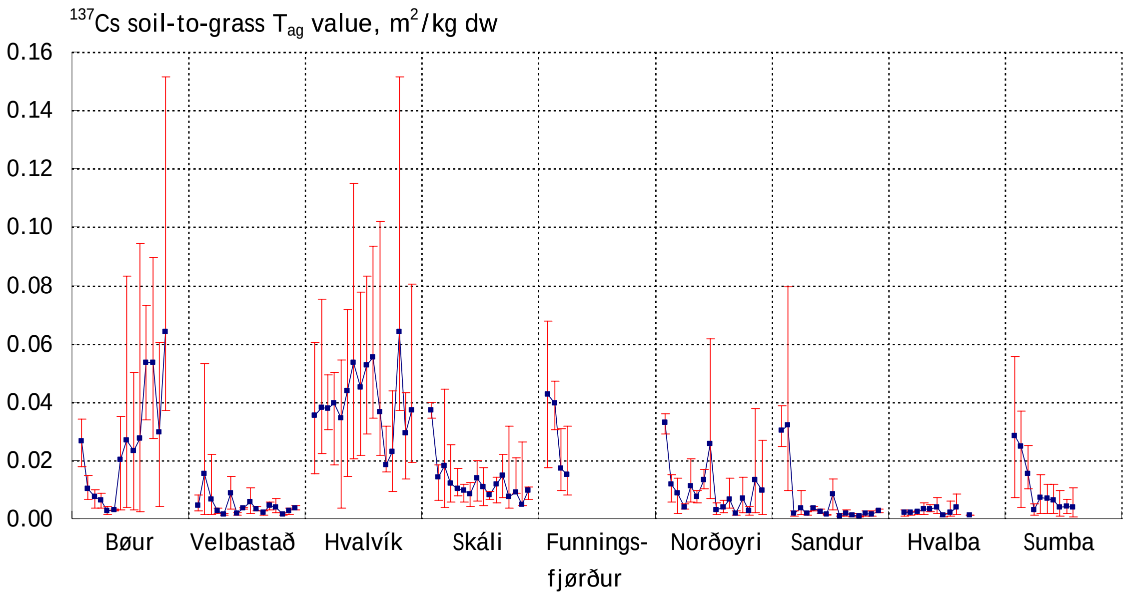

Fig. 5.5. Soil-to-grass transfer factor of ^{137}Cs (m^2/kg dw). Annual average and ranges since 1990. The first data for Hvalba are from 1991.

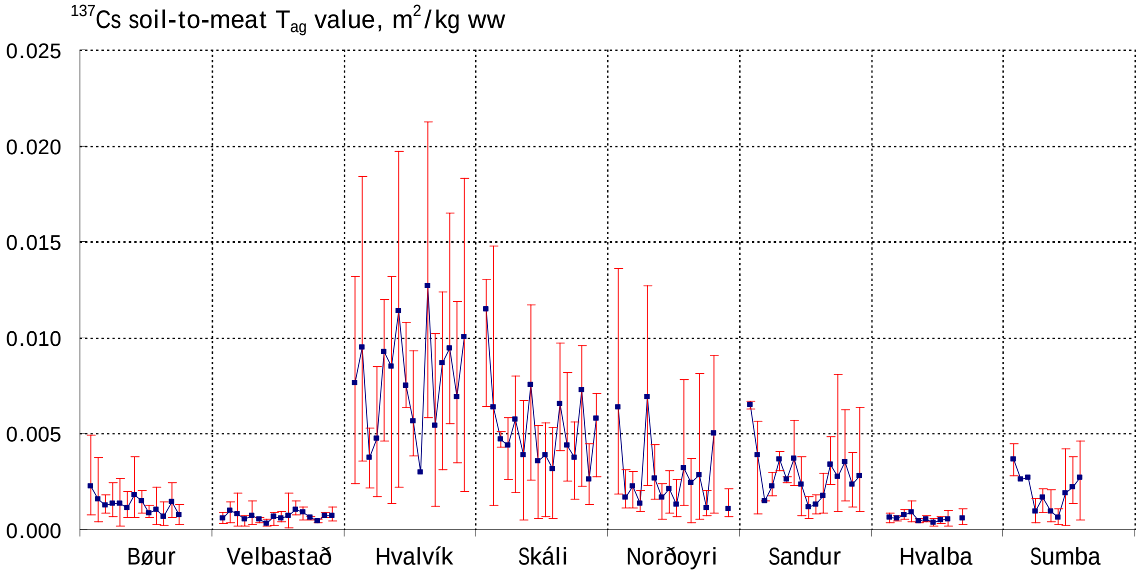

Fig. 5.6. Soil-to-meat aggregated transfer factor of ^{137}Cs (m^2/kg ww). Annual average and ranges since 1990. The first data for Hvalba are from 1991.

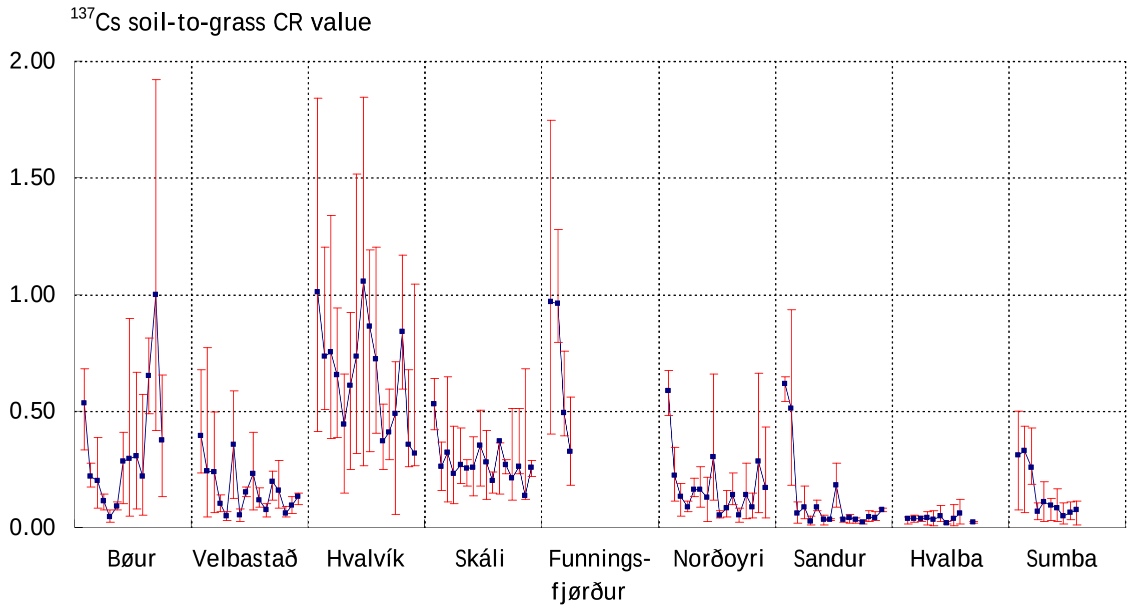

Fig. 5.7. Grass/soil concentration ratio for ^{137}Cs. Annual average and ranges since 1990. The first data for Hvalba are from 1991.

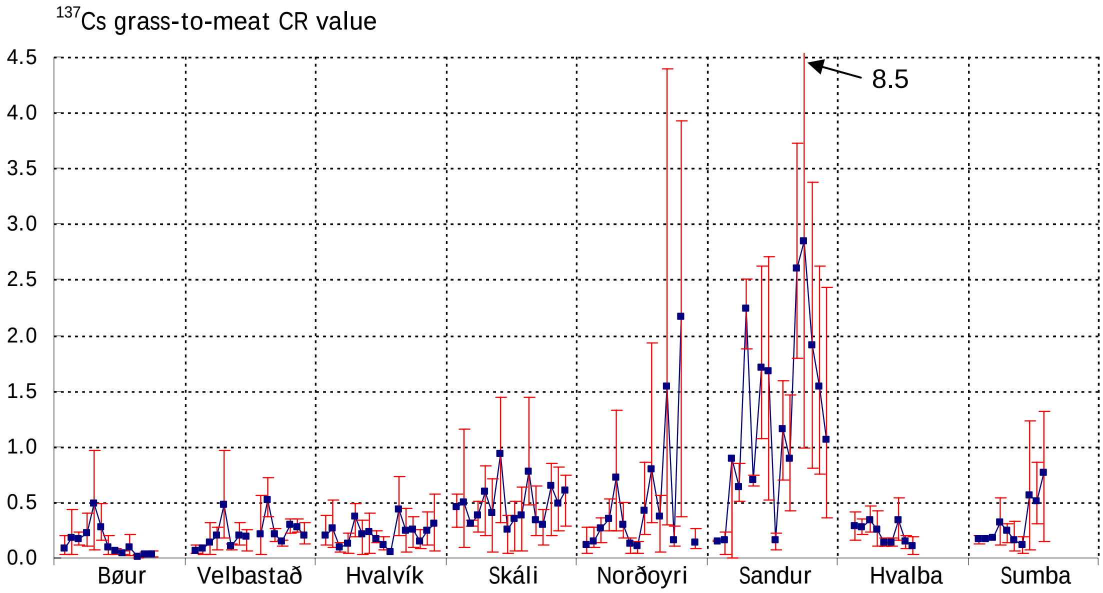

Fig. 5.8. Meat/grass concentration ratio for ^{137}Cs. Annual average and ranges since 1990. The first data for Hvalba are from 1991.

Soil-to-grass annual average T_{ag} values were below 0.02 m^2/kg dw in most cases, although the annual averages vary by more than an order of magnitude across the country. The highest value observed for a 0.25 m^2 plot was 0.15 m^2/kg dw, and the lowest was $0.5 \cdot 10^{-3}$ m^2/kg dw.

Soil-to-meat annual average T_{ag} values were generally below $0.4 \cdot 10^{-2}$ m^2/kg dw. The highest annual average was $1.3 \cdot 10^{-2}$ m^2/kg dw.

The grass/soil annual average concentration ratio was typically below 0.4, although values above 1.0 were observed as well. The highest value observed for a 0.25 m^2 plot was 1.9, and the lowest was $0.7 \cdot 10^{-2}$.

The meat/grass concentration ratios were generally below 0.5. The site Sandur and partly Norðoyri, however, are outliers in the context, as the values were generally above 0.6. The high values may express that the grass samples don't represent the food selected by the lambs used for meat sampling.

5.5. Parameter review

Howard *et.al.* (2009) present transfer coefficients for radiocesium to sheep meat. The estimates of the transfer coefficients are presented as measured fresh weight activity concentration in meat divided by the daily intake of radionuclide. An extensive part of the compilation by Howard *et.al.* (2009) derives from Russian language literature. The (arithmetic) mean ± 1 SD was 0.27±0.26 d kg^{-1}. They also report a geometric mean ± 1 GSD of 0.19±2.2 d kg^{-1}. The range was $5.3 \cdot 10^{-2}$ – 1.3 d kg^{-1}. These parameter values are also reported in IAEA (2009).

Howard *et.al.* (2009) use 1.5 kg d^{-1} as estimate for daily intake of dry matter for sheep. Multiplying the reported transfer coefficients by 1.5 kg d^{-1} gives the following estimates for, respectively, geometric means and arithmetic means of the concentration ratios, CR's: 0.29±3.3 and 0.41±0.39, and the range $8.0 \cdot 10^{-2}$ – 2.0.

The estimate of daily intake is clearly a source of uncertainty when estimating transfer coefficients, especially in the case of monitoring or field studies. The new IAEA (2009) report recommends the daily intake of dry matter to be 1.22 kg d^{-1} for adult sheep and 1.0 kg d^{-1} for lamb. This reduces the CR's for sheep meat by around 20% as compared to the values referred to above. The geometric means and arithmetic means of the CR's as derived from Howard *et.al.* (2009) then become 0.23±2.7 and 0.33±0.32, respectively, and the range becomes $6.5 \cdot 10^{-2}$ – 1.6.

Fesenko *et.al.* (2009) have reviewed more than 150 publications in the former USSR on transfer of radionuclides to animal muscle. They use the same definition of the transfer coefficient as Howard *et.al.* (2009). The publications reviewed by Fesenko *et.al.* (2009) cover experiments using chronic administration of intake of radionuclides. The reported transfer coefficients were generally considered to correspond to activity concentration in meat closest to equilibrium. Fesenko et al. (2009) operate with threshold ages for animals, as the transfer of radionuclides depends on the age of the animals. For sheep, adults are considered to be older than 6 months while lambs are considered to be up to 6 months of age. Typical slaughter age for lamb in former USSR was reported to be 3-6 months, and above 12 months for sheep. The mean transfer coefficients in the compiled study were in the range 0.13 – 0.15 d kg^{-1} and 0.27 – 0.51 d kg^{-1} for, respectively, sheep muscle and lamb muscle. Using 1.22 kg d^{-1} and 1.0 kg d^{-1} (IAEA,1994) for the daily dry matter intake by sheep and lamb, respectively, gives the CR mean value ranges 0.16 – 0.18 for sheep and 0.27 – 0.51 for lamb.

Smith *et.al.* (2005) report transfer coefficients and concentration ratios regarding sheep meat and lamb meat. They use a daily dry matter intake of 1.3 kg d^{-1} and 1.1 kg d^{-1} for, respectively, sheep and lamb. The transfer coefficients for meat was $5.8 \cdot 10^{-2}$ d kg^{-1} and 0.49 d kg^{-1} for, respectively, sheep and lamb. The corresponding concentration ratios were 0.075 and 0.54 for, respectively, sheep and lamb. The transfer coefficients and CR's for lamb was thus almost an order of magnitude higher than for adult sheep.

Estimates of transfer parameters in the ECOSYS model (Müller and Pröhl, 1993) is currently considered by the NKS PARDNOR project group. ECOSYS is essentially the food chain module in the European state-of-the-art decision support systems ARGOS and RODOS, used by e.g. some of the Nordic countries. Knowledge of Nordic transfer parameters have still to be implemented in the ECOSYS model, as the default model parameters refer to environmental conditions of Southern Germany.

The ECOSYS model operates with an equilibrium fodder-to-lamb meat transfer "factor" of 0.5 d kg^{-1} for ^{137}Cs under equilibrium conditions (Müller and Pröhl, 1993; Müller and Pröhl, *Ecosys for Excel*).

Müller and Pröhl (1993) define the transfer factor for soil-to-plants as the ratio between activity concentration in plant (fresh weight) and soil (dry weight). They use a default soil-to-grass transfer factor of $5 \cdot 10^{-2}$ and 1.0 for, respectively, intensive and extensive grass in the ECOSYS model. Using 20% as an estimate of dry matter content in fresh grass leads to a corresponding CR equal to 0.25 and 5.0 as defaults in the ECOSYS model (ratio between activity concentration in grass (dry weight) and soil (dry weight)).

5.6. Discussion

Ward and Johnson (1965) invented a diet-to-muscle transfer coefficient for ^{137}Cs as the ratio of the ^{137}Cs activity concentration in boneless meat to the dietary daily intake of ^{137}Cs. Radionuclide transfer in the ecosystem has since then been described in this way. It has, however, been demonstrated in the literature that many factors affect transfer coefficients, e.g. animal age, dry matter intake and dietary source (Howard *et.al.*, 2001).

In later literature, the aggregated transfer factor (T_{ag}) has been widely used.

The best way of estimating transfer of radionuclides in ecosystems is a matter of discussion, and may depend on the particular circumstances. For field studies and monitoring, Beresford *et.al.* (2007) conclude that the concentration ratio (CR) is a robust and potentially generic parameter.

Transfer of ^{137}Cs has been presented both as T_{ag}'s and CR's in the current field study in the Faroe Islands. The observed CR values for grass-to-lamb meat are generally comparable to values found in the literature, although larger values are observed in some cases in the study. The value of 0.5 d kg^{-1} used as default for the transfer factor in the ECOSYS model tends, however, to be relatively high for the Faroe Islands.

The observed CR's for soil-to-grass transfer of ^{137}Cs vary significantly across the Faroe Islands, documenting the need for adjusting the default value when the ECOSYS model is used locally. The grass samples in the study correspond to "extensive grass" in the ECOSYS model, but the observed CR's are significantly lower than the corresponding default ECOSYS value. The adjustments of the ECOSYS parameters need to be related to local soil characteristics.

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6. Incorporation and excretion by animals of ingested contaminants

This chapter gives an account of an investigation to improve the quality of the factors applied in ECOSYS in describing animal metabolism functions (biological half-lives and transfer parameters), also here taking into account the newest data.

In the ECOSYS model, both the biological half-lives and the rate of transfer from feed to animal products are included as parameters when estimating the dose. Several parameters may be used to describe the transfer from feed to animal products. In the ECOSYS model, the transfer coefficient is used.

6.1. Biological half-lives

The biological half-life is defined as the time required in nature for the activity concentration of a given radionuclide in an animal tissue or milk to decline to half of its initial value, excluding physical decay. As noted by Müller & Pröhl (1993), the foundation for the original ECOSYS parameterisation of biological half-lives was very thin, reflecting the lack of specific data in the late 1980's. A total of only eight publications were used in the parameterisation of both biological half-lives and feed-animal product transfer factors, and only a couple of these even mention biological half-lives. The values that were reported here only occasionally seem to reflect actual practical investigations. Even today, although the past two decades have helped considerably in addressing this lack, the reported measured values constitute only a sparse background for parameterisation, and by far the majority of the experiments have been targeted exclusively on radiocaesium (Table 6.1).

As can be seen from the figures in the table, biological half-lives in milk are very short compared to those in the corresponding animal meat. Generally, biological half-lives of Cs, I and Sr in cow milk and goat milk have on the basis of practical work been estimated to be between 0.4 and 3.5 days (Sirotkin et al., 1969; Fabbri et al., 1994; Howard et al., 1993).

Table 6.1. Recorded biological half-lives of radiocaesium in animal products

	Half-life	References
Milk		
Cow milk	3.5 d	Hansen and Andersson, 1994
	1.1 d	Lettner et al., 2007
	1.7 d	Voigt et al., 1989
	0.9-1.0 d	Fabbri et al., 1994
Goat milk	3 d	Hansen and Hove, 1990
Meat		
Cattle (> 1 year)	20-40 d	Voigt et al., 1989
Veal (< 1 year)	25-30 d	Voigt et al., 1989
Sheep (> 6 mo)	9.8 d	Beresford et al., 1998
	35 d	Assimakopoulos et al., 1993
Lamb (< 6 mo)	21 d	Hansen and Hove, 1993; Hove et al., 1994; Hansen et al., 1994
Goat	21 d	Hansen and Hove, 1990
Roe-deer	10-35 d	IAEA, 2009
	10 d	Fielitz, 1992
Reindeer	21 d	Hove et al., 1999
	30 d	Jones et al., 1989
	18-33 d	IAEA, 2009
	30 d	West Valley, 1999
Pig	30-40 d	Voigt et al., 1989;
	30 d	Andersson et al., 1990
Poultry	Leg meat 1.2 d	Pöschl et al., 1997
	Breast meat 2.0 d	
	1.5 d	Avery et al., 1996
	2.2-4.8 d	Amaral et al., 1995
	2.2-4.7 d	Voigt et al., 1993
Game:		
Red grouse	11 d	Moss and Horrill, 1996
Duck	11 d	Warren et al., 2001

Although most of the sources reporting on a given value in the above table are in fairly reasonable agreement, there are a few that fall somewhat out and are on the edge of being conflicting. However, it should be noted that the data that can be deduced from experiments conducted under different conditions and notably over different time-spans should not be expected to be in excellent agreement. It has been claimed that although single values are very often reported for biological half-lives, two- (or more) component exponential functions are in reality better approaches to capture the changes with time (Beresford et al., 1996). This is because part of the contamination is lost rather rapidly through simple turnover, whereas another part of the contamination is lost at a slower rate largely determined by the radionuclide dynamics in major storage organs.

Generally, most contaminants are excreted by animals in urine and faeces. The excretion of contaminants like radiocaesium, that are distributed in muscle tissue, have been reported to be associated with simple metabolic turnover, whereas for instance radiostrontium, that is accumulated in the bones, is released at a rate reflecting the body content status of the metabolic equivalent, calcium (Beresford et al., 1996). It has been observed that small animals seem to have a shorter biological half-life than do larger animals. Coughtrey et al. (1983) derived an empirical expression for the relationship between animal body weight and biological half-life in units of days:

$$T_{½} = \alpha \text{ (animal weight [kg])}^{\beta},$$

in which α and β are constants depending on the radionuclide. Table 6.2 shows values suggested for use in this formula for a range of radionuclides considered by ECOSYS. The values are derived on the background of (often sparse) measurement data.

Table 6.2. Parameters applicable in the above formula for the animal body weight and biological half-life relationship.

Contaminant	α [d]	β	References
Ce	352	0.82	DOE (2002)
Cs	5.2	0.30	Coughtrey et al. (1983)
I	16.7	0.13	Higley et al. (2003)
Pu	1140	0.73	Brown et al. (2003)
Sr	645	0.26	Higley et al. (2003)
Zr	562	0.25	DOE (2002)

If the values for Cs from Table 6.2 are used in the above equation for the biological half-life, assuming a live weight of a cow of 300 kg, the corresponding biological half-life is calculated to be 29 days, compared with the 20-40 days found in the experiment reported in Table 6.1. Similarly, calculated values for other animals can be compared with those in Table 6.1, and the results are shown in Table 6.3. It seems that the equation makes a fairly good and overall convincing representation of biological half-lives for radiocaesium, as body weights can vary considerably, and also for instance physicochemical forms may play a decisive role. Introducing the body weight based equation in ECOSYS would have the advantage that variation in animal species could be taken into account simply by specifying body weight (e.g., some types of cows weigh much more than others). Also shown in this table are values applied in ECOSYS, which are mostly in-line with the new values, but particularly the ECOSYS value for chicken is much too high.

It should also be noted that as some radionuclides are primarily incorporated in other body parts than those that are eaten, the accumulation is not necessarily problematic, if for instance bone, liver and kidney are discarded. Table 6.4 shows biological half-lives of some of the radionuclides considered in ECOSYS in various organs/tissues of sheep (based on Beresford et al., 1998). For comparison, the value for Ce for all animals in ECOSYS is 4000 days, which is too high, and particularly wrong for small animals like chickens. Also the ECOSYS value of 1000 days for 90 % of the Ru in all animals is very far from the measured 42 days.

Table 6.3. Comparison of biological half-life values for radiocaesium reported in literature (Table 6.1) and corresponding values calculated from animal body weight.

Animal	Body weight estimate [kg]	Calculated value [d]	Literature value [d]	ECOSYS value [d]
Cow	300	29	20-40	30-50
Goat	30	14	21	-
Pig	100	21	30-40	35
Duck	3	7	11	-
Lamb	20	13	21	20
Chicken	2	6	1.2-4.7	20
Reindeer	100	21	18-33	-
Roedeer	20	13	10-35	20

Table 6.4. Reported measured biological half-lives of various radioactive contaminants in different tissues of sheep.

Contaminant	Organ/Tissue/Product	Biological half-life [d]
Ce	Bone	2050
Ce	Muscle	69 (40 %), 1350 (60 %)
Cs	Muscle	9.8
I	Milk	1
Pu	Liver	135
Ru	Kidney	3.9 (56 %), 36 (44 %)
Ru	Muscle	42

6.2. Transfer coefficients

Also the coefficients describing the relationship in ECOSYS between radiocontaminant concentrations in meat or milk and the corresponding daily dietary intake are based on the very sparse data that was available when this model was created. For instance where no data was found available to describe the radionuclide transfer to tissues like veal, pork and lambs meat, the transfer was estimated using the value for beef and a correction factor taking into account lower body mass, without given a scientific account of the method. This correction factor was 3 for veal, 5 for pork and 10 for lamb. As also mentioned by Müller & Pröhl (1993) in the ECOSYS description, the parameterisation for many of the radionuclides was based on very little measured data, and a number of not too well founded assumptions were necessitated at the time.

The transfer coefficient is described as the ratio at equilibrium between the contaminant activity concentration in milk or meat and the daily dietary contaminant intake (Ward et al. 1965). The unit for the transfer coefficient is for milk: Fm, d l^{-1} or d kg^{-1}, and for meat: Ff, d kg^{-1}.

To estimate transfer coefficients, the dietary composition of the animal must be quantified. For agricultural animals this varies according to feeding strategies (e.g., whether animals are indoors or grazing), maintenance requirements, agricultural practices and dietary composition and characteristics such as dry matter digestibility.

Typical dietary constituents for agricultural animals vary between and within countries, and with season. The relative proportion of grass, grain and other dietary constituents is important in determining radionuclide intake by agricultural animals, since grassy vegetation tends to be more highly contaminated. It is therefore most appropriate to consult data from animal nutrition reviews relevant to the region and farming system being considered to derive dietary intake information (IAEA 2009).

Table 6.5 shows an overview of measured transfer coefficients for contaminants considered in ECOSYS to various types of animal food products. The values are here compared with the original values in the ECOSYS system, and discrepancies by more than a factor of respectively 2 and 5 are highlighted by different shading codes. The shown values based on measurements are geometric means, and the numbers in brackets reflect the number of underlying studies. The measured values originate from the above-mentioned comprehensive new IAEA handbook study, in which several PardNor experts participate (IAEA, 2009; Howard et al., 2009). As can be seen, there are rather many significant discrepancies, also for the contaminants traditionally perceived as being of greatest importance in connection with airborne contamination of agricultural areas following a large nuclear power plant accident (e.g., Cs, Sr, I, Ru).

Table 6.5. Estimated values of transfer coefficients based on the new IAEA handbook review (geometric means with number of studies in brackets), compared with ECOSYS defaults.

		Goat's milk, d/l	Cow's milk, d/l	Beef, d/kg	Veal, d/kg	Pork, d/kg	Lamb, d/kg	Poultry, d/kg	Eggs, d/kg
Ba	IAEA	1.1E-2(3)	1.6E-4(15)	1.4E-4 (2)		-	-	1.9E-2(2)	8.7E-1(1)
	ECO.	5.0E-3	5.0E-4	2.0E-4	6.0E-4	1.0E-3	2E-3	2.0E-2	9.0E-1
Cs	IAEA	1.2E-1(28)	4.6E-3(288)	2.2E-2 (58)	4.0E-1*	2.0E-1(22)	1.9E-1(41)	2.7E0(13)	4.0E-1(11)
	ECO.	6.0E-2	3.0E-3	2.0E-2	3.5E-1	4.0E-1	5.0E-1	4.5E0	3.0E-1
Ce	IAEA	4.0E-5(1)	2.0E-5(6)	-		-	2.5E-4(1)	-	3.1E-3(1)
	ECO.	2.0E-4	2.0E-5	8.0E-4	2.0E-3	4.0E-3	8.0E-3	2.0E-2	5.0E-3
I	IAEA	2.2E-1(24)	5.4E-3(104)	6.7E-3 (5)		4.1E-2(2)	3.0E-2(1)	8.7E-3(3)	2.4E0(4)
	ECO.	5E-1	3.0E-3	1.0E-3	3.0E-3	3.0E-3	2.0E-2	1E-1	2.8E0
Mn	IAEA	1.0E-3(1)	4.1E-5(4)	6.0E-4(2)		5.3E-3(1)	9.0E-3(1)	1.9E-3(2)	4.2E-2(3)
	ECO.	1.0E-3	1.0E-4	5.0E-4	2.0E-3	4.0E-3	5.0E-3	5.0E-2	7.0E-2
Mo	IAEA	8.2E-3(4)	1.1E-3(7)	1.0E-3(1)		-	-	1.8E-1(1)	6.4E-1(3)
	ECO.	1.0E-2	1.0E-3	1.0E-3	3.0E-3	3.0E-3	1.0E-2	1.0E0	1.0E0
Nb	IAEA	6.4E-6(1)	4.1E-7(1)	2.6E-7(1)		-	-	3.0E-4(1)	1.0E-3(1)
	ECO.	6.0E-6	4.0E-7	3.0E-7	1.0E-6	2.0E-6	3.0E-6	3.0E-4	1.0E-3
Pu	IAEA	-	1.0E-5(1)	6.0E-5(5)		-	5.3E-5(2)	-	1.2E-3(2)
	ECO.	4.0E-4	6.0E-5	1.1E-6	2.0E-4	3.0E-4	7.0E-4	2.0E-4	7.0E-3
Ru	IAEA	-	9.4E-6(6)	3.7E-3(3)		3.0E-3(1)	2.1E-3(2)	-	4.0E-3(1)
	ECO.	1.0E-3	1.0E-4	3.3E-3	2.0E-3	5.0E-3	1E-2	7.0E-3	6.0E-3
Sr	IAEA	1.6E-2(21)	1.3E-3(154)	1.3E-3(35)		2.5E-3(12)	1.5E-3(25)	2.0E-2(7)	4.9E-1(9)
	ECO.	1.4E-2	2.0E-3	3.0E-4	2.0E-3	2.0E-3	3.0E-3	4.0E-2	2.0E-1
Te	IAEA	4.4E-3(1)	3.4E-4(11)	7.0E-3(1)		-	-	6.0E-1(1)	5.1E0(1)
	ECO.	4.0E-3	5.0E-4	7.0E-3	2.0E-2	3.0E-2	7.0E-2	6.0E-1	5.0E0
Zn	IAEA	6.4E-2(1)	2.7E-3(8)	1.6E-1(6)		1.7E-1(2)	4.5E-2(6)	4.7E-1(3)	1.4E0(4)
	ECO.	3.0E-2	3.0E-3	2.0E-2	6.0E-2	1.0E-1	2.0E-1	6.5E0	2.5E0
Zr	IAEA	5.5E-6(1)	3.6E-6(6)	1.2E-6(1)		-	-	6.0E-5(1)	2.0E-4(1)
	ECO.	6.0E-6	6.0E-7	1.0E-6	3.0E-6	5.0E-6	1.0E-5	6.0E-5	2.0E-4

* Value taken from Voigt et al., 1989

At least a factor of 2 off   At least a factor of 5 off

Animal products harvested from free ranging animals (roedeer, game) or semi domesticated animals (reindeer) may have a more pronounced effect of seasonality in the radiocaesium activity concentration than completely domesticated animals. The increased effect of seasonality in free ranging animals is likely due to (Fielitz et al 2009):

- Changed availability of major feed components over the year. For example reindeer that mainly feed on lichen during the winter and on pasture during the summer.
- Changed availability of fungi during the summer period. Both roedeer, reindeer and wild boar are known to select fungi when available.

Because wild and free ranging animals utilize large areas and have a variable diet it is more appropriate to describe the transfer from feed to meat using the aggregated transfer T_{ag} (Table 6.6).

Table 6.6. Aggregated transfer factors for wild or free ranging animals

	Mean	Range ($m^2\ kg^{-1}$)	Ref
Roedeer		$2.0\ 10^{-3} – 5.0\ 10^{-2}$ (January-June) $2.0\ 10^{-3} – 8.0\ 10^{-2}$ (July - Dec)	Fielitz et al 2009
Reindeer		0.78-0.84 Chernobyl fallout Jan - April 0.15 -0.36 weapons fallout Jan -April	Ahman et al 2001

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7. Summary and conclusions

This year's work on the PardNor activity was targeted on the following investigations:

(i) Revision of ECOSYS soil-to-plant contaminant transfer factors and characterisation in relation to soil type classification.

(ii) Revision of ECOSYS parameters for description of animal metabolism (uptake and excretion of contaminants)

An overall objective was to enable integration of state-of-the-art knowledge and data in the ECOSYS model, which was parameterised about 20 years ago.

A clear weakness of the current ECOSYS crop uptake model is that soil type is not properly taken into account. Differences in soil type might imply large differences in crop contaminant uptake. Transfer factors thus need to be incorporated for different crops, radionuclides and soil types. The transfer factors could either be specified for a limited number of distinct Nordic soil types (e.g., 4, as outlined in the ARGOS database editor), or by entering a formula for transfer factor as a function of soil parameters.

To investigate the feasibility of classifying Nordic soils according to a number of distinct soil types, an examination was made of the availability in each of the Nordic countries of gridded data that could facilitate simple classification (Chapter 2). The classification would need to be made according to soil types for which transfer parameter data was available. For many of the Nordic countries, a soil classification had been made, on the basis of textural analysis of soil samples on a detailed grid. National grids have different resolution. For instance, in Finland, the sampling density is ca. 59 samples per 1000 hectares, whereas the grid with highest resolution in Denmark has about 14 samples per 1000 hectares, and in Sweden, some 3100 samples have been taken randomly over the entire country. For the Faroes, soil data is only available for a limited number of localities.

The alternative option, to describe transfer factors by a mathematical expression or complex model, taking into account various soil parameters, was investigated and reported in Chapter 3. This would require information on at least key data like pH, exchangeable cation content and capacity, as well as organic content. Such data was found to be available at different resolution in different countries, from various national databases. The applicability and potential for integration in ECOSYS of two different models, the CoupModel and the Absalom model, was examined. The CoupModel was found to have the useful feature that it can take into account plant dynamics, carbon and nitrogen turnover, and heat and water characteristics in the given area. However, this model is highly complex, and its integration and validation in the ECOSYS, ARGOS or RODOS system would be a highly demanding task, which might well still not lead to a very suitable model, due to insufficient local characterisation and data availability. Here, the alternative Absalom model might be more useful, as it requires only data that is available on high resolution in most Nordic countries, and is comparatively easier to overview. However, since the model is only applicable in its current form for calculation of caesium uptake, and does not cover the range of crops of relevance to ECOSYS and the decision support systems in which ECOSYS is integrated, the Absalom Model is not well suited for integration either.

The activity work group therefore recommends that future versions of ECOSYS make use of a soil type distinction in four or five categories, for which reliable measured transfer data is available. As illustrated in Chapter 4, which gives a new and updated account of soil-to-plant transfer factor data, distinction could conveniently be made between sand, loam, clay and organic soils. The data tables in this chapter are concentrated on transfer of radiocaesium, but a new (and as yet unpublished) review in which several members of the PardNor activity group are involved, gives a sufficient background for re-parameterisation with up-to-date data of all radionuclides considered in ECOSYS. As Table 4.1 clearly shows, the distinguishing between data for different soil types will make a highly important improvement of the ECOSYS model, as transfer factors for the same radionuclide and crop sometimes vary by more than an order of magnitude according to soil type. A preliminary study was carried out in Iceland to investigate to what degree the Radiocaesium Interception Potential (RIP) could be used as a basis for soil-to-plant transfer categorisation. The special geological conditions in Iceland described in Section 2 means that the expected values of RIP should be low. This was confirmed by measurements, but variability in the measured RIP values did not show a clear correlation with e.g. measured T_{ag} values for milk.

Chapter 5 gives an account of the transfer of radiocaesium in the Faroese terrestrial environment over a 15 years long period. Of particular concern in this country, where most types of food are imported, is the lamb meat uptake chain. The concentration ratios found for the grass-to-meat transfer are high compared with those currently applied by default in the ECOSYS model. Also this study underlines the necessity of relating ECOSYS transfer parameters to local soil characteristics, as grass uptake is very different in different soil areas.

Chapter 6 gives an account of recent values for animal metabolism parameters. The background for describing these in the original ECOSYS model was very sparse, but since then, a number of new investigations have shed light on these matters. Although the focus is, particularly for biological half-lives, also in these new investigations on radiocaesium, also values for other radionuclides are included in this review. A simple empirical formula for describing the biological half-life of any animal as a function of its body weight was tested against measurement data and deemed quite suitable. Transfer coefficients (incorporation in animals of ingested contamination) were described on the basis of new data, and the new values were compared with the original ECOSYS default parameters. In many cases, these deviated by more than a factor of 5, and in some cases even by more than an order of magnitude.

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Abstract

The ECOSYS foodchain model is built into the European standard decision support systems ARGOS and RODOS, which are integrated in the preparedness for radiological events in the Nordic countries. However, a review has revealed that a number of parameters in ECOSYS do not reflect the current state-of-the-art knowledge, and do not adequately represent Nordic conditions. Improved and country/region specific data is required for ECOSYS to give trustworthy results. It is the aim of the PardNor activity to collect new data, and thus enable reliable use of ECOSYS for scenarios involving contamination of Nordic food production areas. In the reported work period of the PardNor activity, examinations have been made of the availability in each of the Nordic countries of soil characterisation data that could be used as a basis for a refined and location-specific approach for estimation of soil-to-plant transfer of contaminants. Large national gridded soil type databases were found to be available for most of the Nordic countries. In addition, for many of these countries, also a number of more detailed soil parameter values, such as local concentrations of various exchangeable ions, cation exchange capacity and soil pH are available on national grids. The feasibility of implementing each of two detailed crop uptake models in ECOSYS - The CoupModel and the 'Absalom' model - was investigated. Both models were found to have serious constraints in this context, and it was therefore recommended to apply a simpler soil classification. To this end, a review was made of state-of-the-art transfer factor data for different soil types, and for the Faeroe Islands, where gridded information is not available, a different approach was described. A preliminary study was also included, on using the Radiocaesium Interception Potential (RIP) as a transfer parameter, utilising the very low RIP values caused by the geological conditions in Iceland. Parameters describing the processes of incorporation and excretion by farm animals of ingested contaminants were also examined, and new datasets for transfer parameters and biological half-lives were derived.

Key words: Foodchain modelling, ingestion dose, ECOSYS, transfer factors, radioactive contamination

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