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Biosphere Analysis – a Complementary Assessment of Dose Conversion Factors for the Olkiluoto Site

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ABSTRACT

The Olkiluoto site is currently the primary candidate for the final disposal site for spent nuclear fuel from the Olkiluoto and Loviisa NPPs. Safety analysis calculations must be performed to verify the compliance with the long-term safety requirements. The behaviour and distribution of radionuclides in the biosphere is of high importance in these calculations.

The aim of this study was to perform a complementary assessment of dose conversion factors for the Olkiluoto site. Posiva has performed extensive analysis on the different ecosystems. In this work the biosphere analysis model of Fortum Nuclear Services (FNS) is used to give an independent estimate of biosphere dose conversion factors for the Olkiluoto site. The following nuclides are analysed: ^{36}Cl, ^{59}Ni, ^{79}Se, ^{93}Mo, ^{94}Nb, ^{126}Sn, ^{129}I and ^{135}Cs.

The FNS model is an equilibrium compartment model in which a steady annual release of 1 Bq of each radionuclide is distributed in different scenarios. The scenarios are the well scenario, which models a small agricultural ecosystem, the lake scenario which models a larger ecosystem with both agriculture and lake use, and sea and transition scenario, which models the behaviour of the radionuclides in marine environments. The scenarios are described and the transfer equations written for the lake scenario. The parameter values are taken from the FNS biosphere database, which has been used in the Finnish L/ILW waste repository safety analyses since mid 1990's.

The results of the FNS analysis are compared to those presented in Posiva working report 2000-20. The results are of the same order of magnitude for all nuclides except ^{129}I. Since the Posiva and FNS models were independently constructed, the results can be considered as convincing, and the compliance of the results give confidence to the modelling results.

Keywords: biosphere, dose conversion factor, lake, well

Biosfäärianalyysi – varmentava annosmuuntokerroinanalyysi Olkiluodon loppusijoituspaikalle

TIIVISTELMÄ

Olkiluoto on valittu ensisijaiseksi loppusijoituspaikaksi Olkiluodon ja Loviisan ydinvoimalaitosten käytetylle polttoaineelle. Pitkäaikaisturvallisuusvaatimusten täyttymisen osoittamiseksi tulee suorittaa turvallisuusanalyysejä. Radionuklidien käyttäytyminen ja jakautuminen biosfäärissä on tärkeässä osassa näissä analyyseissä.

Tämän tutkimuksen tarkoituksena oli suorittaa varmentava annosmuuntokerroinanalyysi Olkiluodon loppusijoituspaikalle. Posiva on tehnyt laajaa analyysityötä erilaisille ekosysteemeille. Fortum Nuclear Services:n (FNS) biosfäärianalyysimallia sovellettiin riippumattoman arvion laskemiseksi annosmuuntokertoimille Olkiluotoon. Analyysi suoritettiin seuraaville radionuklideille: ^{36}Cl, ^{59}Ni, ^{79}Se, ^{93}Mo, ^{94}Nb, ^{126}Sn, ^{129}I ja ^{135}Cs.

FNS:n biosfäärimalli on kompartmenttilaskentaan perustuva tasapainomalli, jossa kunkin radionuklidin oletetaan vapautuvan tasaisella 1 Bq:n vuosinopeudella erilaisissa skenaarioissa. Analysoidut skenaariot ovat kaivoskenaario, joka mallintaa pientä maanviljelysekosysteemiä, järviskenaario, joka mallintaa suuremman ekosysteemin, jossa harjoitetaan sekä maanviljelystä että järven hyötykäyttöä, ja meri- ja transitioskenaario, joka mallintaa radionuklidien käyttäytymistä merellisissä ekosysteemeissä. Skenaariot kuvataan ja siirtoyhtälöt kirjoitetaan järviskenaariolle. Parametriarvot otetaan FNS:n biosfääritietokannasta, jota on käytetty suomalaisten matalan ja keskiaktiivisen jätteen loppusijoituksen turvallisuusanalyyseissä 1990-luvun alkupuolelta asti.

FNS-analyysin tuloksia verrataan Posivan työraportissa 2000-20 esitettyihin tuloksiin. Tulokset ovat samaa suuruusluokkaa kaikille nuklideille paitsi ^{129}I:lle. Koska Posivan ja FNS:n mallit ovat itsenäisesti ja toisistaan riippumatta rakennettuja, tuloksia voidaan pitää vakuuttavina ja ne antavat luottamusta mallinnustuloksiin.

Avainsanat: biosfääri, annosmuuntokerroin, järvi, kaivo

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ABSTRACT

TIIVISTELMÄ

1 INTRODUCTION

Fortum Nuclear Services (FNS) biosphere model, which has been used in the safety cases for the maintenance- and decommissioning waste repositories in both Olkiluoto and Loviisa Nuclear Power Plants, is modified for Olkiluoto specific conditions to give an alternative look on the dose coefficients to be used in the safety case for the final disposal of the spent nuclear fuel. The compartment models used to describe the migration of radionuclides in the biosphere are essentially the same as the ones used in the performance assessments for the L/ILW waste of the Olkiluoto and Loviisa L/ILW repositories.

The applied nuclide specific calculation parameters are adopted from the FNS Biosphere parameter database (FNS-BIODABA), which has been maintained and utilized in connection to the safety cases and performance assessments for final disposal facilities of low and intermediate level waste carried out by FNS since mid 1990s. The database includes those radionuclides which typically exist in the operational or decommissioning waste of LWR plants. The dose coefficients are calculated for the important long-lived fission products ^{36}Cl, ^{59}Ni, ^{79}Se, ^{93}Mo, ^{94}Nb, ^{126}Sn, ^{129}I and ^{135}Cs.

The biosphere model consists of compartments through which the migration of radionuclides is modelled. In addition to the compartments, food chains are modelled with bioaccumulation and concentration factors. In this dose assessment the chosen dose paths for dose are: external doses from water (swimming, boating), and doses from soils irrigated (beach, kitchen garden and field) with radioactive water. For internal doses, water transfer to plants by root uptake and interception by leaves are considered. Dust from the contaminated ground (kitchen garden) causes inhalation doses. Drinking water, fish, meat, milk, grain, vegetables and root crops were chosen as dose paths for internal doses by ingestion.

In the sea scenario, in which the radioactivity is assumed to be released into the sea close to the Olkiluoto Island, a simplified approach is taken. The sea scenario is treated with less detail due to its insignificance from the point of view radiation exposure. In the L/ILW analyses, for which the model previously has been applied, the margins to dose rate limits or any relevant dose levels have been several orders of magnitude, and thus the sea scenarios are not considered to be significant and therefore the biosphere modelling is focused on the fresh water scenarios.

2 CONSIDERED NUCLIDES AND THEIR RELEVANT DAUGHTERS

Table 2-1 presents the radionuclides to be considered, as well as their half-lives [Browne 1986, LBNL 2004] and dose factors [ST 7.3]. The short-lived daughters ^{90}Y (of ^{90}Sr), ^{93m}Nb (of ^{93}Mo), ^{121}Sn (of ^{121m}Sn), ^{126m}Sb and ^{126}Sb (of ^{126}Sn) have been considered in the dose assessment, assuming that their activity is in equilibrium with that of the mother nuclide. This is justified by their short half-lives and is in practice realised by adding the dose factor of the daughter, multiplied by the yield [Browne and Firestone 1986], onto the value of the mother nuclide.

When choosing the inhalation dose factors, the default absorption type (for unspecified compounds) was chosen following the recommendations in ICRP 71.

Table 2-1. *Considered nuclides and their dose factors.*

Nuclide	Daughter	T½	Yield	Ingestion	Inhalation	
		(a)	%	(Sv/Bq)	Absorption class	(Sv/Bq)
^{36}Cl		3.01E+05		9.30E-10	M*	7.30E-09
^{59}Ni		7.50E+04		6.30E-11	M	1.30E-10
^{79}Se		1.13E+06		2.90E-09	F	1.10E-09
^{93}Mo		3.50E+03		3.10E-09	M	5.90E-10
^{94}Nb		2.00E+04		1.70E-09	M	1.10E-08
^{126}Sn		*1.00E+05*		*4.70E-09*	*M**	*2.80E-08*
	^{126}Sb	*3.40E-02*	*100*	*2.40E-09*	*M*	*2.80E-09*
	^{126m}Sb	*3.62E-05*	*14*	*3.60E-11*	*M*	*1.90E-11*
^{126}Sn incl. daughters		1.00E+05		5.07E-09	M*	2.84E-08
^{129}I		1.57E+07		1.10E-07	F	3.60E-08
^{135}Cs		3.00E+06		2.00E-09	F	6.90E-10

*No default absorption type is given by ICRP71 -> the one with the highest dose rate factor is chosen

3 RADIONUCLIDE MIGRATION IN THE BIOSPHERE

The biosphere analysis follows the rationale for the safety assessment for the final disposal of spent nuclear fuel [YVL 8.4]:

- […] constraints apply to radiation doses which arise to members of the public as a consequence of expected evolution scenarios and which are reasonably predictable with regard to the changes in the environment. Humans are assumed to be exposed to radioactive substances released from the repository, transported to near-surface groundwater bodies and further to watercourses above ground. At least the following potential exposure pathways shall be considered:
    - use of contaminated water as household water
    - use of contaminated water for irrigation of plants and for watering animals
    - use of contaminated watercourses and relictions.

- Changes in the environment to be considered in applying the dose constraints include at least those arising from land uplift. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to be similar to the current ones.

The biosphere model for well and lake scenarios consists of compartments through which the migration of radionuclides is modelled. In addition to the compartments, food chains are modelled with bioaccumulation and concentration factors. As mentioned above, for the sea and transition scenario a simplified approach is taken. The scenarios are described later in the text in Chapter 5 .

3.1 Transfer coefficients and migration between the compartments

Elements migrate between the compartments of the biosphere according to the transfer coefficients (k_{ij}):

$$
\begin{aligned}
k_{ij} &= f_{\mathrm{w}} \frac{\dot{m}_{\mathrm{w}ij}}{m_{\mathrm{w}i}} + f_{\mathrm{s}} \frac{\dot{m}_{\mathrm{s}ij}}{m_{\mathrm{s}i}}, \\
f_{\mathrm{w}} &= \frac{1}{1 + K_{\mathrm{d}i}\sigma}, \\
f_{\mathrm{s}} &= 1 - f_{\mathrm{w}},
\end{aligned}
\tag{1}
$$

where

f_{w}	is the fraction of the element in the soluble phase of compartment *i*,
f_{s}	is the fraction of the element in solid matter,
$K_{\mathrm{d}i}$	is the distribution coefficient in compartment *i* (m^3/kg),
σ	is the solid matter concentration in compartment *i* ($\mathrm{kg_s/m^3{}_w}$),
$\dot{m}_{\mathrm{w}ij}$	is the water flow rate from compartment *i* to *j* (m^3/a),
$\dot{m}_{\mathrm{s}ij}$	is the mass flow rate of solid matter from compartment *i* to *j* (kg/a),

m_{wi} is the volume of water in compartment *i* (m^3),
m_{si} is the mass of solid matter in compartment *i* (kg).

Here the solid matter concentration in compartment is calculated from

$$\sigma_i = \frac{mw_i}{ms_i} \tag{2}$$

where [σ_i]=kg_s / m_w^3.

The water volumes, solid matter masses, water flow rates and solid mass transfer rates are presented in the subsections 3.2 below. The used abbreviations for the compartments are listed in Table 3-1. The parameter values are given in section 5 .

Table 3-1. *The abbreviations of the compartment names.*

Symbol	**Compartment**
J	Lake
PiS	Surface sediment
PoS	Deep sediment
Kmaa	Garden
Vpel	Field
La1cm	Pasture, 1 cm
La10cm	Pasture, 10 cm
Sink	The sink

3.2 Water volume of the compartments

The water volumes for the compartments are calculated as follows:

$$mw_J = A_J \cdot h_J \tag{3}$$

$$mw_{PiS} = A_J \cdot h_{PiS} \cdot \eta w_{PiS} \tag{4}$$

$$mw_{PoS} = A_J \cdot h_{PoS} \cdot \eta w_{PoS} \tag{5}$$

$$mw_{Kmaa} = A_{Kmaa} \cdot h_{Kmaa} \cdot \frac{mw'_{Kmaa}}{\rho w} \tag{6}$$

$$mw_{Vpel} = A_{Vpel} \cdot h_{Vpel} \cdot \frac{mw'_{Vpel}}{\rho w} \tag{7}$$

$$mw_{La1cm} = A_{La1cm} \cdot h_{La1cm} \cdot \frac{mw'_{La1cm}}{\rho w} \tag{8}$$

$$mw_{La10cm} = A_{La10cm} \cdot h_{La10cm} \cdot \frac{mw'_{La10cm}}{\rho w} \tag{9}$$

3.3 Solid matter mass of the compartments

The solid matter masses of the compartments are calculated as follows:

$$ms_J = A_J \cdot h_J \cdot \eta sw_J \tag{10}$$

$$ms_{PiS} = A_J \cdot h_{PiS} \cdot \rho s_{PiS} \cdot (1 - \eta w_{PiS}) \tag{11}$$

$$ms_{PoS} = A_J \cdot h_{PoS} \cdot \rho s_{PoS} \cdot (1 - \eta w_{PoS}) \tag{12}$$

$$ms_{Kmaa} = A_{Kmaa} \cdot h_{Kmaa} \cdot ms'_{Kmaa} \tag{13}$$

$$ms_{Vpel} = A_{Vpel} \cdot h_{Vpel} \cdot ms'_{Vpel} \tag{14}$$

$$ms_{La1cm} = A_{La1cm} \cdot h_{La1cm} \cdot ms'_{La1cm} \tag{15}$$

$$ms_{La10cm} = A_{La10cm} \cdot h_{La10cm} \cdot ms'_{La10cm} \tag{16}$$

3.4 Water flow rate between the compartments

The volumetric water flow rates between the compartments are calculated as follows ($\dot{m}w_i^j$ is the flux of water from compartment *i* to compartment *j*):

$$\dot{m}w_J^{PiS} = Qw_{PiS} \cdot mw_{PiS} + \frac{SED_J \cdot A_J \cdot h_J \cdot (1 - RSsw_{PiS})}{h_J \cdot [\eta w_{PiS} \cdot \rho w + (1 - \eta w_{PiS}) \cdot \rho s_{PiS}]} \tag{17}$$

$$\dot{m}w_J^{Kmaa} = A_{Kmaa} \cdot IRR_{Kmaa} \tag{18}$$

$$\dot{m}w_J^{Vpel} = A_{Vpel} \cdot IRR_{Vpel} \tag{19}$$

$$\dot{m}w_J^{La1cm} = A_{La1cm} \cdot IRR_{La1cm} \tag{20}$$

$$\dot{m}w_J^{Sink} = (A_J + VA_J) \cdot PREC_J - VA_J \cdot EVAP_J \tag{21}$$

$$\dot{m}w_{PiS}^{J} = \dot{m}w_J^{PiS} - \dot{m}w_{PiS}^{PoS} \tag{22}$$

$$\dot{m}w_{PiS}^{PoS} = \dot{m}s_{PiS}^{PoS} \cdot \frac{mw'_{PoS}}{ms'_{PoS} \cdot \rho w} \tag{23}$$

$$\dot{m}w_{PoS}^{Sink} = \dot{m}w_{PiS}^{PoS} \tag{24}$$

$$\dot{m}w_{Kmaa}^{J} = 80 \tag{25}$$

$$\dot{m}w_{Kmaa}^{Sink} = A_{Kmaa} \cdot \left(PREC_{Kmaa} - EVAP_{Kmaa} + IRR_{Kmaa}\right) - \dot{m}w_{Kmaa}^{J} \tag{26}$$

$$\dot{m}w_{Vpel}^{J} = 750 \tag{27}$$

$$\dot{m}w_{Vpel}^{Sink} = A_{Vpel} \cdot \left(PREC_{Vpel} - EVAP_{Vpel} + IRR_{Vpel}\right) - \dot{m}w_{Vpel}^{J} \tag{28}$$

$$\dot{m}w_{La1cm}^{J} = 750 \tag{29}$$

$$\dot{m}w_{La1cm}^{La10cm} = A_{La1cm} \cdot \left(PREC_{La1cm} - EVAP_{La1cm} + IRR_{La1cm}\right) - \dot{m}w_{La1cm}^{J} \tag{30}$$

$$\dot{m}w_{La10cm}^{Sink} = 775 \tag{31}$$

3.5 Solid matter flow rate between the compartments

The solid matter flow rates between the compartments are calculated as follows ($\dot{m}s_i^j$ is the flux of solid matter from compartment *i* to compartment *j*):

$$\dot{m}s_J^{PiS} = \frac{SED_J \cdot A_J \cdot ms'_{PiS}}{h_{PiS} \cdot \left[\eta w_{PiS} \cdot \rho w_{PiS} + \left(1 - \eta w_{PiS}\right) \cdot \rho s_{PiS}\right]} \tag{32}$$

$$\dot{m}s_J^{Kmaa} = \dot{m}w_J^{Kmaa} \cdot \eta sw_J \tag{33}$$

$$\dot{m}s_J^{Vpel} = \dot{m}w_J^{Vpel} \cdot \eta sw_J \tag{34}$$

$$\dot{m}s_J^{La1cm} = \dot{m}w_J^{La1cm} \cdot \eta sw_J \tag{35}$$

$$\dot{m}s_J^{Sink} = \dot{m}w_J^{Sink} \cdot \eta sw_J \tag{36}$$

$$\dot{m}s_{PiS}^{J} = RSsw_{PiS} \cdot \dot{m}s_J^{PiS} \tag{37}$$

$$\dot{m}s_{PiS}^{PoS} = \dot{m}s_J^{PiS} - \dot{m}s_{PiS}^{J} \tag{38}$$

$$\dot{m}s_{PoS}^{Sink} = \dot{m}s_{PiS}^{PoS} \tag{39}$$

$$\dot{m}s_{Kmaa}^{J} = A_{Kmaa} \cdot ERS_{Kmaa} \tag{40}$$

$$\dot{m}s_{Kmaa}^{Sink} = 0 \tag{41}$$

$$\dot{m}s_{Vpel}^{J} = A_{Vpel} \cdot ERS_{Vpel} \tag{42}$$

$$\dot{m}s_{Vpel}^{Sink} = 0 \tag{43}$$

$$\dot{m}s_{La1cm}^{J} = A_{La1cm} \cdot ERS_{La1cm} \tag{44}$$

$$\dot{m}s_{La1cm}^{La10cm} = 0 \tag{45}$$

$$\dot{m}s_{La1cm}^{Sink} = 0 \tag{46}$$

$$\dot{m}s_{La10cm}^{Sink} = 0 \tag{47}$$

Based on the transfer coefficients the equilibrium state of the compartment system is calculated. This calculation is done in the MS Excel computing environment. A comparison of the computing environment to a separate independent calculation, which serves for verification, is presented by Siitonen [1998]. The equilibrium computing environment with the equilibrium calculation is chosen due to the fast calculation times enabling more comprehensive uncertainty and sensitivity analysis. The typical time behaviour of the radioactivity release to the biosphere is relatively smooth compared to the characteristic times of the migration on the biosphere, and therefore the equilibrium model overestimates the doses only slightly.

3.6 Distribution factors

Distribution factors which describe the distribution of radionuclides between solid and water phases are defined as follows:

$$K_d = \frac{A_s \,/\, m_s}{A_w \,/\, V_w} \tag{48}$$

where

K_d is the distribution factor between solid material and water (m^3/kg)
A_s ja A_w are activities in the solid and liquid phase (Bq)
m_s is the mass of the solid material (kg)
V_w is the water volume (m^3)

3.7 Removal coefficient from a compartment

The removal coefficient from a compartment is calculated as follows:

$$k_{ix} = \sum_{j=1, j \neq i}^{N} k_{ij} + \lambda + \mu_i \tag{49}$$

where

k_{ij} is the transfer coefficient from compartment i to compartment j (1/a)
λ is the decay constant of a radionuclide (1/a)
μ_i is the removal coefficient from the entire system via compartment i (1/a)

3.8 Amount of radionuclides in the compartment

The amount of a radionuclide in compartment i is:

$$\frac{dn_i}{dt} = \sum_{j=1, j \neq i}^{N} n_j k_{ji} - n_i k_{ix} + s_i \tag{50}$$

Where
$n_i(t)$ is the radionuclide amount (atoms) in compartment i as a function of time
k_{ji} is the transfer coefficient from compartment j to compartment i (1/a)
k_{ix} is the removal coefficient from compartment i (1/a)
s_i is the source in compartment i (atoms/a).

In the equilibrium, the following condition applies:

$$\frac{dn_i}{dt} = 0 \tag{51}$$

Hence the equilibrium amount of radionuclides in each compartment can be calculated. The radiation doses due to different dose paths are proportional to these amounts.

4 DOSE RATE ASSESSMENT

4.1 External doses from contaminated ground and water

Water

The external dose caused by staying on contaminated water (swimming, diving, boating) is obtained as follows:

$$\dot{H}_{\mathrm{w}}(t) = C_{\mathrm{w}}(t) \cdot E_{\mathrm{s}} \cdot \alpha_{\mathrm{w}} \tag{52}$$

Where

$\dot{H}_{\mathrm{W}}(t)$	is the dose rate from the water (Sv/a)
$C_w(t)$	is the concentration of the nuclide in the lake water (Bq/m^3)
E_{s}	is the exposure time fraction (a/a)
α_{W}	is the dose factor for water immersion (Sv/a)/(Bq/m^3).

This is a conservative approach since the time used for boating is usually far greater than that used for swimming or diving. For boating, the dose rate is in reality one half (or less, for weak emitters) of the above.

Field and kitchen garden

The external dose caused by staying on contaminated ground is obtained as follows:

$$\dot{H}_{\mathrm{s}}(t) = C_{\mathrm{V}}(t) \cdot E_{\mathrm{s}} \cdot \rho_0 / \rho \cdot \alpha_{G,\mathrm{inf}} \tag{53}$$

where

$C_V(t)$	is the concentration of the nuclide in the compartment (Bq/m^3)
ρ	is the soil density of the compartment (kg/m^3)
ρ_0	is the reference soil density for dose factor $\alpha_{\mathrm{G,1cm}}$ (1600 kg/m^3)
$\alpha_{\mathrm{G,\ inf}}$	is the dose factor for the external radiation from ground contaminated to infinite depth (Sv/a)/(Bq/m^3).

Beach

The external dose from staying at the beach has been estimated by assuming the beach to carry the same activity as the sediments of the lake. Therefore, the beach dose path has been divided into two parts - Beach 1 (surface sediment) and Beach 2 (deep). The beach is assumed to be formed of the sediment layers by extraction of excessive water (final composition of soil as in field, $\rho=1500$ kg/ m^3). To simplify calculations, the upper sediment layer is then "compressed" a bit further - the total activity of the upper sediment layer is assumed to be evenly distributed in a 1-cm-thick soil layer. The soil density is then >1600 kg/cm^3, and literature values for "external radiation from ground

($\rho = 1600$ kg/ m^3) contaminated to a depth of 1 cm" can be applied directly with mild conservatism.

The external dose caused by the upper sedimentation layer on a beach (Beach1) is obtained as follows:

$$\dot{H}_{\mathrm{b1}}(t) = C_{\mathrm{B1,1cm}}(t) \cdot E_{\mathrm{s}} \cdot \alpha_{G,1cm} \tag{54}$$

$C_{\mathrm{B1,1cm}}(t)$	is the concentration of the nuclide in the compartment, when the compartment thickness is assumed to be 1 cm (Bq/m^3)
$\alpha_{\mathrm{G,\,1cm}}$	is the dose factor for the external radiation from ground contaminated to a depth of 1 cm (Sv/a)/(Bq/m^3).

The external dose caused by the lower sedimentation layer on a beach (Beach2) is obtained as follows:

$$\dot{H}_{\mathrm{b2}}(t) = C_{\mathrm{B2}}(t) \cdot E_{\mathrm{s}} \cdot (\alpha_{G,\mathrm{inf}} \cdot \rho_0 / \rho - \alpha_{G,1cm}) \tag{55}$$

where

$C_{\mathrm{B2}}(t)$	is the concentration of the nuclide in the compartment after transformation to soil (Bq/m^3)
ρ	is the final soil density of the compartment (kg/m^3)

4.2 Internal dose paths

Drinking water

Dose rate from drinking water can be calculated as follows:

$$\dot{H}_{\mathrm{dw}}(t) = C_{\mathrm{w}}(t) \cdot W \cdot \alpha \tag{56}$$

where

W	is the annual drinking water consumption of an individual (m^3/a),
α	is the ingestion dose factor (Sv/Bq).

Fish

Dose rate from fish ingestion:

$$\dot{H}_{\mathrm{f}}(t) = C_{\mathrm{w}}(t) \cdot F \cdot c_{\mathrm{f}} \cdot \alpha \tag{57}$$

where

F	is the annual fish consumption of an individual (kg/a),
c_{f}	is the concentration factor of the nuclide into fish (m^3/kg).

<u>Grain</u>

The dose path through grain ingestion is assumed to consist of two parts:
a) soil - grain - man (enrichment through the root)
b) soil - man (resuspension of soil onto the grain).

Dose rates:

$$\begin{aligned} a)\quad & \dot{H}_{\mathrm{g1}}(t) = C_{\mathrm{s}}(t)\cdot G\cdot c_{\mathrm{g}}\cdot\alpha \\ b)\quad & \dot{H}_{\mathrm{g2}}(t) = C_{\mathrm{s}}(t)\cdot G\cdot p_{\mathrm{g}}\cdot\alpha \end{aligned} \tag{58}$$

where

$C_{\mathrm{s}}(t)$	is the concentration of the nuclide in the soil (Bq/kg)
G	is the annual grain ingestion of an individual (kg/a)
c_{g}	is the concentration factor of the nuclide into grain (kg/kg)
p_{g}	is the resuspension factor, or the fraction of soil in the grain (kg/kg)

<u>Vegetables</u>

For vegetables, of which the surficial parts are eaten, doses can be calculated in the same way as for grain:

$$\begin{aligned} a)\quad & \dot{H}_{\mathrm{v1}}(t) = C_{\mathrm{s}}(t)\cdot V\cdot c_{\mathrm{v}}\cdot\alpha \\ b)\quad & \dot{H}_{\mathrm{v2}}(t) = C_{\mathrm{s}}(t)\cdot V\cdot p_{\mathrm{v}}\cdot\alpha \end{aligned} \tag{59}$$

where

V	is the annual vegetable ingestion of an individual (kg/a)
c_{v}	is the concentration factor of the nuclide into vegetables (kg/kg)
p_{v}	is the resuspension factor onto vegetables (kg/kg)

<u>Root crop</u>

The dose rate caused by root crops is also calculated according to the same rationale:

$$\begin{aligned} a)\quad & \dot{H}_{\mathrm{r1}}(t) = C_{\mathrm{s}}(t)\cdot R\cdot c_{\mathrm{r}}\cdot\alpha \\ b)\quad & \dot{H}_{\mathrm{r2}}(t) = C_{\mathrm{s}}(t)\cdot R\cdot p_{\mathrm{r}}\cdot\alpha \end{aligned} \tag{60}$$

where

R	is the annual root crop ingestion of an individual (kg/a),
c_{r}	is the concentration factor of the nuclide into root crop (kg/kg),
p_{r}	is the resuspension factor onto root crop (kg/kg).

<u>Milk</u>

The milk dose path is assumed to consist of three parts:
a) soil - pasturage - cattle - milk - man (The pasturage taken by the cattle)
b) soil - cattle - milk - man (The soil taken by the cattle)

c) water - cattle - milk - man

The corresponding dose rates:

$$
\begin{aligned}
&a) \quad \dot{H}_{\mathrm{m1}}(t) = C_{\mathrm{s}}(t) \cdot M \cdot c_{\mathrm{p}} \cdot P_{\mathrm{n}} \cdot c_{\mathrm{m}} \cdot \alpha \\
&b) \quad \dot{H}_{\mathrm{m2}}(t) = C_{\mathrm{s}}(t) \cdot M \cdot P_{\mathrm{n}} \cdot p_{\mathrm{p}} \cdot c_{\mathrm{m}} \cdot \alpha \\
&c) \quad \dot{H}_{\mathrm{m3}}(t) = C_{\mathrm{w}}(t) \cdot M \cdot W_{\mathrm{n}} \cdot c_{\mathrm{m}} \cdot \alpha
\end{aligned}
\tag{61}
$$

where

M	is the annual milk intake of an individual (dm^3/a),
c_{p}	is the concentration factor of the nuclide into pasturage (kg/kg),
P_{n}	is the cow's daily intake of pasturage (kg/d),
c_{m}	is the concentration factor of the nuclide into milk (d/dm^3),
p_{p}	is the resuspension factor onto pasturage (kg/kg),
W_{n}	is the cow's daily intake of water (dm^3/d).

Meat

Also the dose rate from meat ingestion can be divided into three parts:

$$
\begin{aligned}
&a) \quad \dot{H}_{\mathrm{n1}}(t) = C_{\mathrm{s}}(t) \cdot N \cdot c_{\mathrm{p}} \cdot P_{\mathrm{n}} \cdot c_{\mathrm{n}} \cdot \alpha \\
&b) \quad \dot{H}_{\mathrm{n2}}(t) = C_{\mathrm{s}}(t) \cdot N \cdot P_{\mathrm{n}} \cdot p_{\mathrm{p}} \cdot c_{\mathrm{n}} \cdot \alpha \\
&c) \quad \dot{H}_{\mathrm{n3}}(t) = C_{\mathrm{w}}(t) \cdot N \cdot W_{\mathrm{n}} \cdot c_{\mathrm{n}} \cdot \alpha
\end{aligned}
\tag{62}
$$

where

N	is the annual intake of meat by the individual (kg/a),
c_{n}	is the concentration factor of the nuclide into meat (d/kg).

Inhalation

The dose caused by airborne dust through inhalation is obtained from:

$$
\dot{H}_{\mathrm{d}}(t) = C_{\mathrm{s}}(t) \cdot E_{\mathrm{d}} \cdot I \cdot \alpha_{\mathrm{d}} \cdot d
\tag{63}
$$

where

E_{d}	is the exposure time fraction (a/a),
I	is the inhalation rate (m^3/a),
α_{d}	is the dose factor for inhalation of the nuclide (Sv/Bq),
d	is the amount of airborne dust (kg/m^3).

4.2.1 Interception

In addition to the root uptake (cf. previous section), activity is transferred to plants also due to interception through plant leaves, when irrigated with well or lake water. The interception dose factor is calculated with the method and parameters of [Bergström *et al.* 1999, Karlsson *et al.* 2001, and Bergström and Barkefors 2004], Irrigation is described as summation of retention at each occasion. For vegetables the concentration of radionuclides in plants due to retention is

$$C_{pv}(t) = Nr_i \, \frac{LAI_v \cdot StoCap \cdot Kret \cdot C_w(t)}{Y_p}, \tag{64}$$

where

$C_{pv}(t)$	is the concentration of radionuclides in vegetables due to retention (Bq/kg)
Nr_i	is the number of interception events per year
LAI	is the Leaf area index (m^2/m^2)
$StoCap$	is the water storage capacity in vegetation due to the interception (m^3/m^2)
$Kret$	element dependent retention factor (-)
$C_w(t)$	concentration in water (Bq/m^3)
Y_P	yield values (kg/m^2).

For root crops the expression is multiplied with an element dependent translocation factor.

$$C_{pr}(t) = TL \cdot Nr_i \cdot LAI_r \cdot StoCap \cdot Kret \cdot C_w(t), \tag{65}$$

where

$C_{pr}(t)$	is the concentration of radionuclides in root crops due to retention (Bq/kg)
TL	is element dependent translocation factor.

Table 4-1. *Applied parameter values for interception calculation [Karlsson* et al. *2001].*

Parameter		**Unit**	**Best estimate**
Nr_i		-	4
LAI_v		m^2/m^2	5
LAI_r		m^2/m^2	4
StoCap		m^3/m^2	$3 \cdot 10^{-4}$
Yield		kg/m^2	2
Kret	Anions	-	0.5
	Cs	-	1.0
	Cations	-	2.0

The applied parameters are presented in Table 4-1 and Table 4-2. The best estimate values by Karlsson *et al.* [2001] were chosen for this analysis. In [Eurajoki et al. 2006] sensitivity study was made comparing the dose rates from interception calculated with the best estimate and maximum parameter values in Karlsson *et al.* [2001]. The worst case scenario increased the dose rate from interception by a factor of 2…3 for all nuclides.

Table 4-2. *Applied (best estimate) translocation factor values [Karlsson* et al. *2001]*

Nuclide	**TL (m^2/kg)**	**Nuclide**	**TL (m^2/kg)**
^{36}Cl	0.1	^{94}Nb	0.2
^{59}Ni	0.01	^{126}Sn	0.1
^{79}Se	0.1	^{129}I	0.1
^{90}Sr	0.4	^{135}Cs	0.2
^{93}Mo	0.1		

Grain
The grain fields are irrigated with the lake water. The dose path can be calculated as follows: interception → leafs → grain → man.

Dose rates:

$$\dot{H}_{gi}(t) = C_{pv}(t) \cdot G \cdot \alpha \tag{66}$$

Vegetables
It is assumed that for the irrigation of vegetables the water from the well and from the lake is used. Both dose paths can be calculated as follows: interception → leafs → vegetables → man.

Dose rates:

$$\dot{H}_{vi}(t) = C_{pv}(t) \cdot V \cdot \alpha \tag{67}$$

Root crops
It is assumed that for the irrigation of vegetables the water from the well and from the lake is used. The dose path can be calculated as follows: interception → leafs → root crops → man.

Dose rates:

$$\dot{H}_{ri}(t) = C_{pr}(t) \cdot R \cdot \alpha \tag{68}$$

Milk
The cows ingest pasturage for food. The pasturage is irrigated with lake water. The dose paths can be calculated as follows: interception → leafs → pasturage → cattle → milk → man.

Dose rates:

$$\dot{H}_{mi}(t) = C_{pv}(t) \cdot M \cdot c_m \cdot P_n \cdot \alpha \qquad (69)$$

<u>Meat</u>

The cows ingest pasturage for food. The dose path can be calculated as follows: interception → leafs → pasturage → cattle → meat → man

Dose rates:

$$\dot{H}_{ni}(t) = C_{pv}(t) \cdot N \cdot c_n \cdot P_n \cdot \alpha \qquad (70)$$

For the dose rates from drinking water, fish and inhalation the interception has no effect. Calculations do not consider weathering, which in radioecology includes all processes like growth, grazing and effects of wind and rain, which reduce the concentration of radionuclides on vegetation. According to Bergström and Barkefors [2004], including the weathering the values would decrease about a third.

The total individual dose *D* (Sv) from a nuclide is the sum of doses from all individual dose paths. A combination of the biosphere migration and the dose calculation gives the dependence of the dose rate on the radionuclide concentration ((Sv/a) /(Bq/dm^3)) of well water or on the radionuclide release to the lake (Sv/a, Bq).

5 BIOSPHERE SCENARIOS

The main environmental scenarios are studied: Sea scenario, transition scenario, lake scenario and well scenario. The well scenarios are supposed to last over the entire considered period of time. If the global sea level does not start rising due to climate change, the land uplift will start changing the local environment. The bays on both sides of the Olkiluoto Island will develop into lakes and wetland, see Figure 5-1. The IPCC Report 2007 [IPCC 2007] presents some climate scenarios in which the global sea level will start rising. The rise may be enough to cancel the effects on land uplift, and the environment may then remain in its current state.

The scenarios analysed here may be thought to occur consecutively: first is the sea scenario (0 a ... 1000 a), then a transition (1000 a ... 1500 a) and finally a lake scenario (1500 a ... 7000 a) if the land uplift proceeds as expected [Rantataro 2001].

A lake will form at the westside of the Ulkopää cape within 1000 years if the land uplift rate stays at the present 6 mm / year rate [Eronen et al. 1995, Rantataro 2001, Broed 2007]. This lake is used in the lake scenario.

For the lake its largest area is used. In time, the lake will become smaller, because of the sedimentation and swamp formation. However, because the catchment area stays approximately the same, the turnover rate of the lake increases, and the effect of these two to some extent compensate each other.

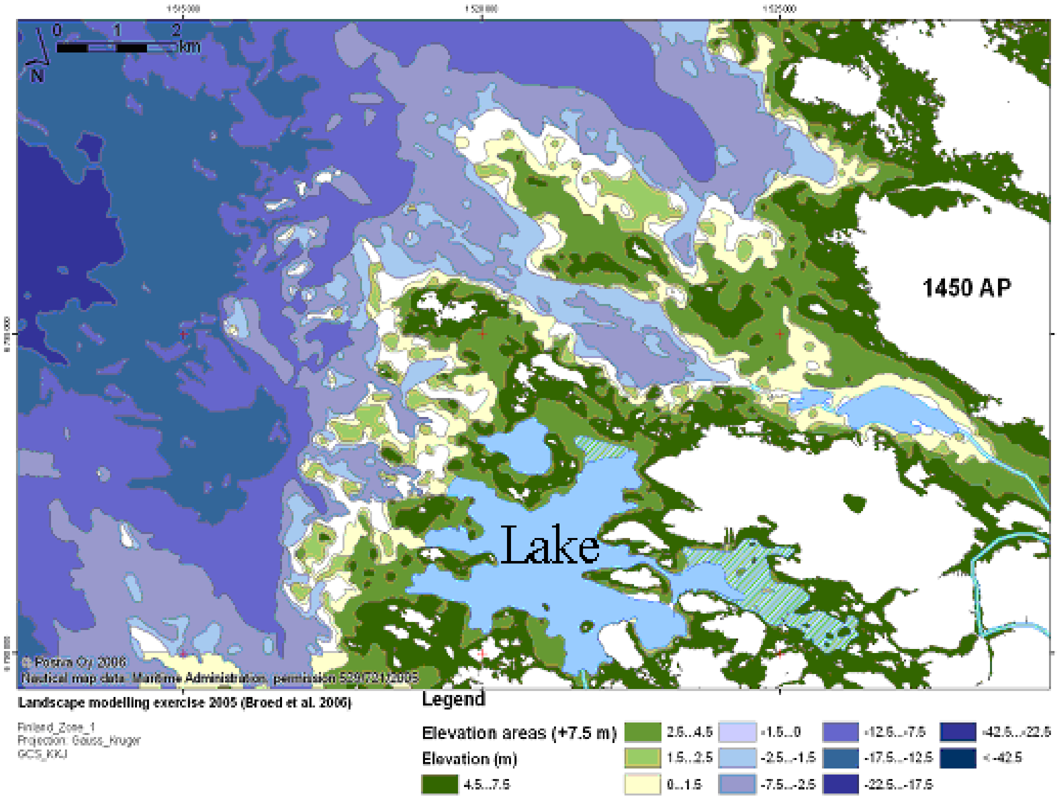

Figure 5-1. *Lake formed near the Olkiluoto Island. (modified from Broed [2007]).*

The flow diagrams of radionuclides and related dose paths for each scenario are presented in Figure 5-2, Figure 5-3 and Figure 5-4.

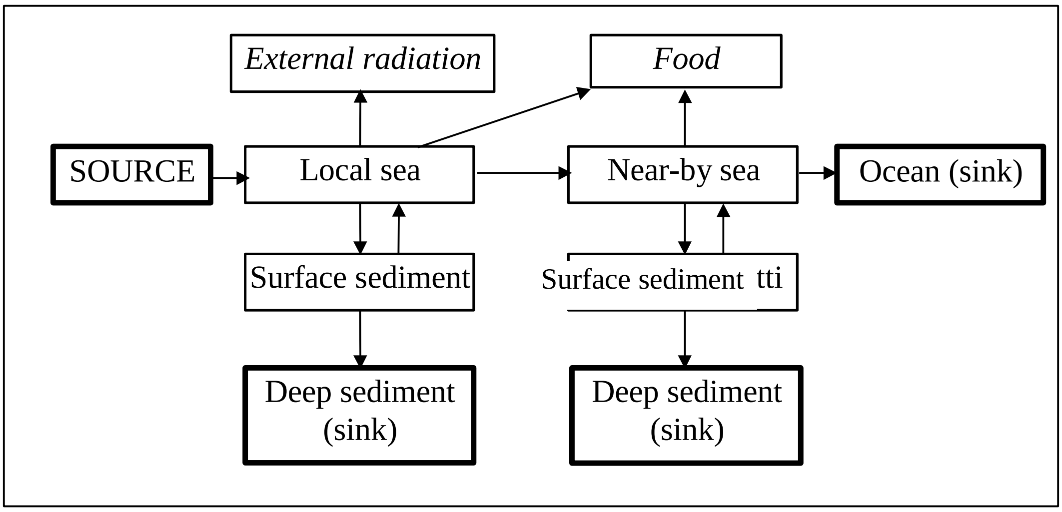

Figure 5-2. *Flow diagram and dose paths of sea and transition scenarios.*

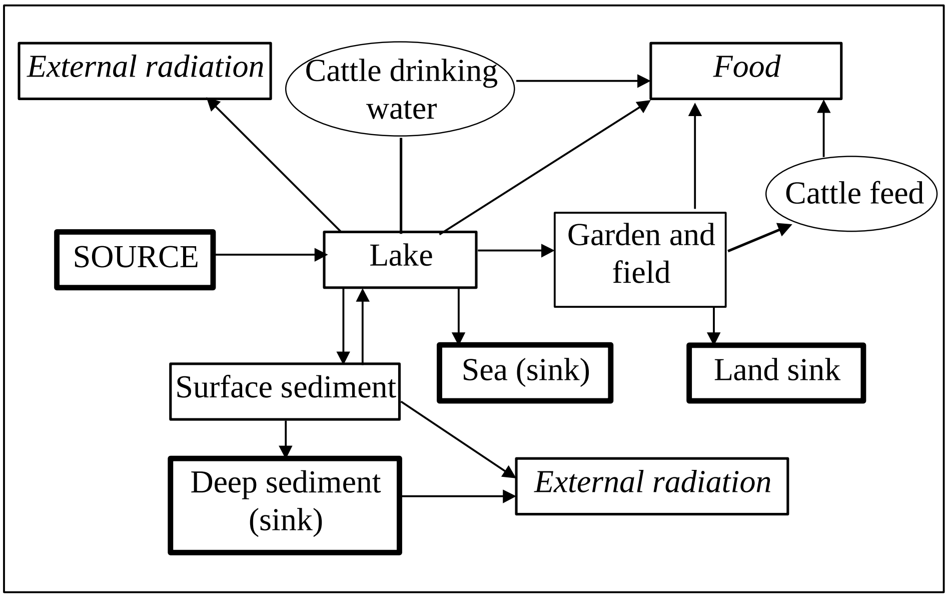

Figure 5-3. *Flow diagram and dose paths of the lake scenario.*

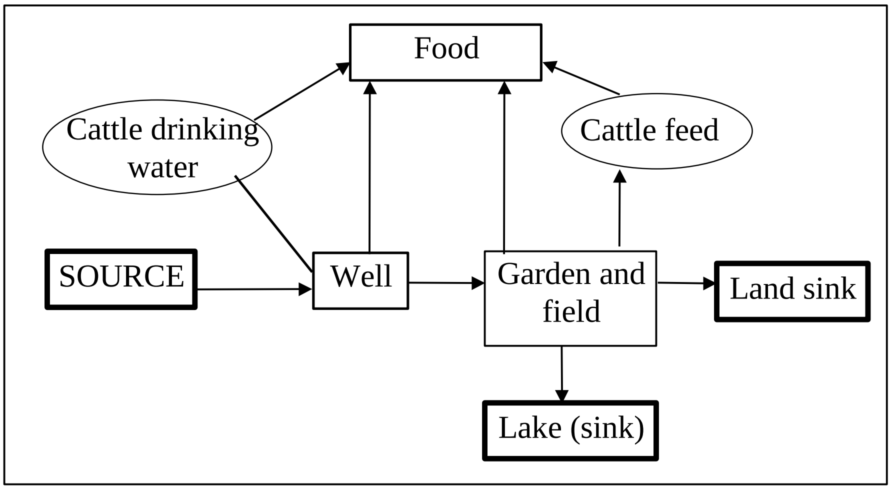

Figure 5-4. *Flow diagram and dose paths of the well scenario.*

5.1 Sea and transition scenarios

In the performance assessment for the final disposal of the operational waste of the Olkiluoto NPP [Vieno and Suolanen 1991] the sea scenario was observed to result in negligible doses due to an efficient dilution in the sea. Dose factors for the sea scenario were several orders of magnitude smaller than the transition scenario dose factors, which are several orders of magnitude smaller than the dose factors for lake and well scenarios. Due to this it is thought to be sufficient to analyse only the transition scenario, using a simplified approach. The method used in calculating the dose factors for the transition scenario is described in detail in Chapter 0.

5.2 Model parameters for well and lake scenarios

5.2.1 FNS Biosphere Parameter Database FNS-BIODABA

Fortum Nuclear Services Ltd (FNS) has carried out safety cases and performance assessments for final disposal facilities of low and intermediate level waste since mid 1990s, the first being the FSAR performance assessment for the Loviisa L/ILW repository. Since that FNS has carried out safety cases for both the Loviisa and Olkiluoto L/ILW repositories, and the analyses have covered also the planned final disposal concepts for the decommissioning plans of Loviisa and Olkiluoto NPPs. Throughout these analyses FNS has maintained and developed a biosphere parameter database (FNS-BIODABA), which has been updated and revised on a regular basis taking into account the available literature data. The database includes those radionuclides which typically exist in the operational or decommissioning waste of LWR plants. The database description [Eurajoki 2009] gives a brief overview of the scope of the database and the rationale according to which the database is maintained, as well as a literature list, which has been reviewed for parameter selection in the foundation and maintenance of the database from 1990s until present.

In the selection of the parameter values for the FNS-BIODABA a multi-target approach has been adopted. Derived from the regulatory requirements, there is a target not to underestimate the radiation dose resulting as a consequence of the radioactive waste disposal. Therefore the values are selected in a conservative way, but also with an attempt to avoid excessive conservatism. Hence it may be formulated that the target in the parameter selection has been a reasonably conservative value for each parameter. Another crucial target was to utilise more recent or otherwise more representing information available, since it is believed to better reflect the state-of-the art knowledge. As the values are based on literature surveys, some of them are not directly derivable back to any particular sources, but represent an average weighted with the targets above.

The values are not adopted directly from one of these sources, but a synthesis of the literature is made. The aim has been to apply the most recent knowledge, but at the same time reaching a conservative value for individual doses, which in some cases (for example niobium) means choosing a higher value than the most recently published. As explained above, overconservativeness is still aimed to be avoided.

In the literature surveys, the most significant elements have been especially emphasized, and also the mutual physical and chemical reasonability has been accounted for, e.g. regarding the chemical forms of the considered elements. Especially for some rarer elements, for which the literature data is sparse, the chemical relationships between the elements have been considered.

As the database is updated on a regular basis, an approach has been selected to separately document the parameters always, when applied in the calculation of dose-conversion factors. This principle is followed also in this document, and therefore the single parameter values may easily be considered and the relevance evaluated.

5.2.2 Distribution coefficients

The distribution coefficients for the considered elements in different surroundings are shown in Table 5-1. The distribution coefficients were selected in a conservative way to obtain the maximum for individual doses, but also with an attempt to utilise the most recent information available.

Fish has been recognised as the most significant dose path in sea and lake scenarios in previous assessments for Loviisa and Olkiluoto L/ILW repository sites, so it may be considered conservative to select a small value for the distribution coefficient of lake water. A low distribution coefficient results in slow deposition into the sediment layers, which act as activity sinks. Only one distribution factor has been applied for both the waterborne solid matter and the sediments in each water system.

In agricultural soils, a high distribution factor gives a long retention time, thus increasing the potential for individual doses through vegetation.

Table 5-1. *The distribution coefficients (K_d-values, m^3/kg) used in the analysis.*

Element	Lake	Agricultural soil
^{36}Cl	0.001	0.01
^{59}Ni	1	5
^{79}Se	2.2	0.032
^{93}Mo	0.001	1
^{94}Nb	10	2
^{126}Sn	22.4	0.22
^{129}I	0.1	0.1
^{135}Cs	1	10

5.2.3 Compartments

Table 5-2, Table 5-3 and Table 5-4 contain the parameters related to the modelling of migration between compartments. The choice of parameters has been made by comparing the values presented in several sources [Vieno and Suolanen 1991, Jumppanen 2001, Jumppanen 2002, Karlsson et al. 2001, Mattila 2003, Kirkkala 2005, Broed 2007, Turkki 2006, Mattila et al. 2006] and applied in previous safety assessments carried out by FNS. The well discharge values 1 m^3 for the use of a normal family, and 20 m^3 for agricultural use have been used.

Table 5-2. *Parameters related to the water system compartments.*

Lake	
area	6.94 km^2
depth	5.8 m
solid matter concentration	0.01 kg/m^3
sedimentation	1 $kg/m^2a \approx 0.9$ mm/a
water turnover (into the Gulf of Bothnia)	0.007 $km^3/a \approx 0.18/a$
runoff land area	21.8 km^2
Local sea area	
area	0.9 km^2
depth	4.5 m
solid matter concentration	0.009 kg/m^3
water turnover (into the Gulf of Bothnia)	0.0082 $km^3/a \approx 2/a$
Well	
irrigation	20 m^3/d
drinking water	1 m^3/d

Table 5-3. *Parameters related to the sediment compartments.*

	Surface sediment, 0-5 cm	Deep sediment, 5-35 cm
Density of solid matter, kg/m^3	2800	2800
Volume fraction of water, %	90	72
Water mass, kg/m^2	45	216
Solid matter mass, kg/m^2	14	235
Resuspension of solid matter into water, % of sedimentation	10	0
Water turnover rate, 1/a	1	0

Table 5-4. *Parameters related to the land compartments.*

Agricultural land, for crops and other vegetables	
area of field (grain)	10 000 m^2
area of kitchen garden (vegetables)	1000 m^2
thickness of utilised layer	0.3 m
density	1500 kg/m^3
water mass	380 kg/m^3
solid matter mass	1120 kg/m^3
rain yield	0.55 m/a (evaporation 0.41 m/a)
irrigation of field	0.05 m/a
irrigation of kitchen garden	0.1 m/a
surface runoff, kitchen garden -> lake	0.08 m/a
surface runoff, field -> lake	0.075 m/a
erosion	0.25 kg/m^2
Pasture	
As field but divided into layers: 0-1 cm, 1-10 cm, over 10 cm	

The areas of the field and the kitchen garden have been selected in such a way that they would sufficiently cover the consumption of grain and vegetables of one family. In dose calculations, the area only affects external doses. The patch is assumed to be fully mixed within the depth of use, except for the pasture, which is divided into layers having different inventories of radionuclides. Both the field and the pasture are assumed to be irrigated in some degree, although that is not the current practice in Finnish agriculture.

5.2.4 External exposure

Dose rate coefficients for water immersion are applied to calculate the external dose from the lake. Dose rate coefficients for exposure to soil contaminated to an infinite depth are applied to calculate the external dose from the field and kitchen garden. The activity concentration in the soil is calculated from compartment area and thickness, and the total activity of the compartment.

The beach is assumed to be formed of the sediment layer of the lake by extraction of excessive water (final composition of soil as in field). The upper sediment would thus become 1.25 cm thick, but to be able to utilize standard dose rate coefficients from literature (for soil contaminated to a depth of 1 cm, density 1600 kg/m^3), the total activity of the compartment is (conservatively) assumed to be evenly distributed in a 1 cm-thick soil layer. The calculated thickness for the lower sediment layer after water extraction would be 19.3 cm. This thickness is applied to calculate the activity concentration, after which dose rate coefficients for soil contaminated to infinite depth are applied.

All the external dose rate coefficients are presented in Table 5-5. They apply for infinite areas, and therefore overestimate the dose rate somewhat in the case of gamma-emitting nuclides. For beta emitters the dose rate on a fairly large limited area is very close as for infinite areas, because of the short range of beta radiation. The parameter values applied in the calculation of the external dose rate are summarized in Table 5-6.

Table 5-5. *External dose rate coefficients [Eckerman and Ryman 1993].*

Nuclide	Included daughter nuclides	Water immersion (Sv/a / Bq/m^3)	Soil contam. to a depth of 1 cm (Sv/a / Bq/m^3)*	Soil contam. to a an infinite depth (Sv/a / Bq/m^3)*
^{36}Cl		1.41E-12	1.11E-13	4.04E-13
^{59}Ni		0.00E+00	0.00E+00	0.00E+00
^{79}Se		1.87E-14	1.82E-15	3.14E-15
^{93}Mo		1.87E-12	1.00E-13	9.97E-14
^{94}Nb		5.27E-09	3.11E-10	1.63E-09
^{126}Sn	^{126}Sb, ^{126m}Sb	6.61E-09	3.97E-10	2.00E-09
^{129}I		2.81E-11	1.88E-12	2.19E-12
^{135}Cs		3.47E-14	3.31E-15	6.46E-15

* ρ_{soil}=1600kg/m^3

Table 5-6. *Parameters related to external dose rates.*

Exposure time fraction on land	
Beach	$E_{e,b}$ = 0.114 (≈1000 h/a)
Field	$E_{e,f}$ = 0.034 (≈ 300 h/a)
Kitchen garden	$E_{e,k}$ = 0.027 (≈ 240 h/a)
Soil density	P = 1500 kg/m^3
Exposure time fraction on lake water	E_w = 0.114 (≈1000 h/a)

5.2.5 Internal exposure

Table 5-7 presents parameters related to the exposure of the individual to internal dose paths.

Table 5-7. *Parameters related to the calculation of internal doses.*

Ingestion rates of man	
Drinking water	$W = 0.6\ \mathrm{m^3/a}$
Fish	$F = 25$ kg/a
Grain	$G = 100$ kg/a
Vegetables	$V = 50$ kg/a
Root crop	$R = 100$ kg/a
Milk	$M = 0.5\ \mathrm{m^3/a}$
Meat	$N = 75$ kg/a
Ingestion rates of domestic animals (cows)	
Pasturage	$P_N = 50$ kg/d
Water	$W_N = 100$ l/d
The factors of soil in food (resuspension factors)	
Grain	$p_g = 0.0001$ kg/kg
Vegetables	$p_v = 0.001$ kg/kg
Root crop	$p_r = 0.001$ kg/kg
Pasturage	$p_p = 0.04$ kg/kg
Inhalation dose path	
Exposure time fraction on dust	$E_i = 0.027$ (≈ 240 h/a)
Inhalation rate	$I = 9000\ \mathrm{m^3/a}$
Mass of airborne dust	$d = 2 \cdot 10^{-5}\ \mathrm{kg/m^3}$

The selection of concentration factors into fish, vegetation, meat and milk are based on the literature reviewed for the FNS-BIODABA (cf. section 5.2). The applied values are shown in Table 5-8 and Table 5-9.

Table 5-8. *Concentration factors into fish in the lake, c_f, $\mathrm{dm^3/kg}$.*

Nuclide	Lake
^{36}Cl	50
^{59}Ni	1000
^{79}Se	3160
^{93}Mo	10
^{94}Nb	300
^{126}Sn	9500
^{129}I	200
^{135}Cs	10000

Table 5-9. *Concentration factors into foodstuff.*

Element	Grain c_g ($kg_{d.w.soil}$ / $kg_{w.w.\ grain}$)	Vegetable c_v ($kg_{d.w.soil}$ / $kg_{w.w.\ veg.}$)	Root crop c_r ($kg_{d.w.soil}$ / $kg_{w.w.\ root}$)	Pasturage c_p ($kg_{d.w.soil}$ / $kg_{d.w.grass}$)	Milk c_m (d/l)	Meat c_l (d/kg)
^{36}Cl	30	16	16	60	0.01	0.01
^{59}Ni	0.03	0.019	0.019	0.2	0.01	0.053
^{79}Se	24.5	2.4	4.9	24.5	0.013	0.017
^{93}Mo	0.12	0.12	0.12	0.6	0.0075	0.008
^{94}Nb	0.0094	0.0094	0.0094	0.047	0.0025	0.28
^{126}Sn	0.63	0.24	0.22	0.45	0.0055	0.0095
^{129}I	0.2	0.2	0.2	0.6	0.01	0.01
^{135}Cs	0.01	0.02	0.02	0.2	0.02	0.03

5.3 Transfer coefficients in the well and lake scenarios

The transfer coefficients of different elements between compartments in lake and well scenarios are presented in Table 5-10.

Table 5-10. *Transfer coefficients in the lake scenario.*

	lake -surface sediment	Surface sediment - lake	Surface sediment - bottom sediment	Bottom sediment - sink	Lake - kitchen garden	Kitchen garden - lake	kitchen garden - sink
^{36}Cl	7.93E-3	7.73E-1	6.95E-3	9.08E-4	2.48E-6	2.37E-2	4.61E-2
^{59}Ni	4.83E-2	4.93E-3	1.52E-2	9.08E-4	2.48E-6	7.92E-4	9.52E-5
^{79}Se	9.72E-2	3.15E-3	1.52E-2	9.08E-4	2.48E-6	8.19E-3	1.49E-2
^{93}Mo	7.93E-3	7.73E-1	6.95E-3	9.08E-4	2.48E-6	9.82E-4	4.76E-4
^{94}Nb	3.79E-1	2.02E-3	1.53E-2	9.08E-4	2.48E-6	8.63E-4	2.38E-4
^{126}Sn	7.54E-1	1.84E-3	1.53E-2	9.08E-4	2.48E-6	1.81E-3	2.13E-3
^{129}I	1.20E-2	3.32E-2	1.49E-2	9.08E-4	2.48E-6	3.11E-3	4.75E-3
^{135}Cs	4.83E-2	4.93E-3	1.52E-2	9.08E-4	2.48E-6	7.68E-4	4.76E-5

Table 5-10 cont.

	lake - field	field - lake	field - sink	lake – pasturage 1cm	pasturage 1cm - lake	Pasturage 1-10cm	Pasturage 10cm - sink	Lake - Gulf of Finland
^{36}Cl	1.24E-5	2.23E-2	3.31E-2	1.24E-5	6.69E-1	9.93E-1	7.44E-2	1.71E-1
^{59}Ni	1.24E-5	7.89E-4	6.84E-5	1.24E-5	2.37E-2	2.05E-3	1.54E-4	1.71E-1
^{79}Se	1.24E-5	7.72E-3	1.07E-2	1.24E-5	2.32E-1	3.21E-1	2.41E-2	1.71E-1
^{93}Mo	1.24E-5	9.67E-4	3.42E-4	1.24E-5	2.90E-2	1.03E-2	7.69E-4	1.71E-1
^{94}Nb	1.24E-5	8.56E-4	1.71E-4	1.24E-5	2.57E-2	5.13E-3	3.84E-4	1.71E-1
^{126}Sn	1.24E-5	1.74E-3	1.53E-3	1.24E-5	5.22E-2	4.58E-2	3.43E-3	1.71E-1
^{129}I	1.24E-5	2.97E-3	3.41E-3	1.24E-5	8.90E-2	1.02E-1	7.66E-3	1.71E-1
^{135}Cs	1.24E-5	7.66E-4	3.42E-5	1.24E-5	2.30E-2	1.03E-3	7.69E-5	1.71E-1

6 DOSE CONVERSION FACTORS

6.1 Lake and well scenarios

The dose conversion factors introduced here are related to the case in which the release rates of radionuclides are constant over a long period of time, i.e. equilibrium coefficients. Table 6-1 shows the dose conversion factors for the lake scenario and Table 6-2 for the well scenario.

The external dose from staying at the beach has been estimated by assuming the beach to carry the same activity as the sediments of the lake. Therefore, the beach dose path has been divided into two parts - Beach 1 (or b1) corresponds to surface sediments, and Beach 2 (or b2) to the deep.

In the lake scenario, the dose paths Lake - Meat and Lake - Milk refer to the activity taken by the cow when drinking lake water. Pasture_1 describes the internal dose from the surface soil at the depth of 0…1 cm, taken by the cow with pasturage. Pasture_{10} refers to the internal dose caused by activity concentrated into the pasturage from the soil layer at the depth of 1…10 cm. Since inhalation dose is almost directly connected to the activity of the kitchen garden (over 99% of the total inhalation doses), it has only been derived for this dose path.

In the well scenario, doses from meat and milk ingestion includes only the dose path via the cow's drinking water. Surface soil intake and pasturage are not considered, since the normal practice in Finland is not to irrigate fields or pastures. The drinking water of the livestock is however considered necessary, and the irrigation of the kitchen garden may be more likely that that of fields and pastures.

The dose conversion factors of the lake and the well scenario have been presented differently because the dose conversion factor for the wells depends on the water uptake of the well. In order to obtain dose conversion factors with the same units [Sv/Bq] as in the lake scenario, Table 6-1, the dose conversion factors for the well scenario, Table 6-2, should be divided by the water uptake of the well. For the well scenario the dose conversion factor depending on concentration and not on the entering activity is still a more natural quantity, since the concentration is calculated in the near- and far-field analysis, and on the other hand the doses are directly proportional to the radioactivity concentration in the water.

Table 6-1. *Dose conversion factors for the lake scenario.*

		^{36}**Cl**		^{59}**Ni**		^{79}**Se**		^{93}**Mo**	
		Sv/Bq	fraction	Sv/Bq	fraction	Sv/Bq	fraction	Sv/Bq	fraction
lake	external	2.3E-20	2.0E-06	0.0E+00	0.0E+00	2.1E-22	3.3E-09	3.1E-20	2.8E-06
	fish	1.7E-16	1.4E-02	1.9E-16	4.5E-01	2.3E-14	3.6E-01	1.1E-16	1.0E-02
	meat	1.0E-17	8.6E-04	3.0E-18	7.1E-03	3.7E-17	5.9E-04	2.7E-17	2.5E-03
	milk	6.8E-17	5.8E-03	3.8E-18	8.9E-03	1.8E-16	2.9E-03	1.7E-16	1.6E-02
beach1	external	1.1E-20	9.3E-07	0.0E+00	0.0E+00	6.3E-20	9.9E-07	9.8E-21	9.0E-07
beach2	external	1.2E-20	1.1E-06	0.0E+00	0.0E+00	4.6E-20	7.2E-07	1.9E-22	1.8E-08
kitchen-garden	external	8.1E-21	6.9E-07	0.0E+00	0.0E+00	1.3E-22	2.0E-09	8.4E-20	7.7E-06
	inhalation	2.1E-20	1.8E-06	2.5E-20	6.0E-05	6.7E-21	1.1E-07	7.5E-20	6.9E-06
	root crop	8.9E-16	7.6E-02	5.0E-18	1.2E-02	1.8E-15	2.8E-02	9.8E-16	9.0E-02
	vegetable	4.5E-16	3.8E-02	2.5E-18	5.9E-03	4.5E-16	7.1E-03	4.9E-16	4.5E-02
field	external	6.4E-21	5.5E-07	0.0E+00	0.0E+00	1.0E-22	1.6E-09	5.8E-20	5.3E-06
	grain	1.1E-15	9.0E-02	3.9E-18	9.2E-03	5.6E-15	8.8E-02	5.3E-16	4.9E-02
pasturage1	meat	5.3E-19	4.5E-05	1.0E-17	2.5E-02	6.0E-18	9.4E-05	6.1E-17	5.6E-03
	milk	3.5E-18	3.0E-04	1.3E-17	3.1E-02	2.9E-17	4.6E-04	3.8E-16	3.5E-02
pasturage10	meat	1.2E-15	1.0E-01	7.3E-17	1.7E-01	5.4E-15	8.5E-02	1.1E-15	1.0E-01
	milk	7.8E-15	6.7E-01	9.2E-17	2.2E-01	2.6E-14	4.1E-01	6.8E-15	6.2E-01
interception	meat	7.6E-18	6.5E-04	9.0E-18	2.1E-02	1.1E-16	1.8E-03	2.0E-17	1.9E-03
	milk	5.1E-17	4.3E-03	1.1E-17	2.7E-02	5.4E-16	8.6E-03	1.3E-16	1.2E-02
	root crop	3.2E-18	2.8E-04	7.3E-20	1.7E-04	2.8E-17	4.3E-04	1.1E-17	1.0E-03
	vegetable	1.0E-17	8.6E-04	2.3E-18	5.4E-03	8.6E-17	1.4E-03	3.4E-17	3.1E-03
	grain	2.0E-17	1.7E-03	4.5E-18	1.1E-02	1.7E-16	2.7E-03	6.8E-17	6.2E-03
TOTAL		**1.2E-14**	**1.0E+00**	**4.2E-16**	**1.0E+00**	**6.3E-14**	**1.0E+00**	**1.1E-14**	**1.0E+00**

		^{94}**Nb**		^{126}**Sn**		^{129}**I**		^{135}**Cs**	
		Sv/Bq	fraction	Sv/Bq	fraction	Sv/Bq	fraction	Sv/Bq	fraction
lake	external	3.0E-17	2.6E-04	2.2E-17	1.1E-04	4.6E-19	2.1E-06	4.7E-22	6.7E-09
	fish	6.3E-16	5.6E-03	3.5E-14	1.8E-01	7.8E-14	3.6E-01	6.0E-14	8.5E-01
	meat	1.8E-16	1.6E-03	1.1E-17	5.3E-05	1.2E-15	5.3E-03	5.4E-17	7.7E-04
	milk	1.0E-17	9.4E-05	4.1E-17	2.0E-04	7.8E-15	3.6E-02	2.4E-16	3.4E-03
beach1	external	2.2E-14	2.0E-01	3.4E-14	1.7E-01	4.4E-18	2.0E-05	6.3E-20	9.0E-07
beach2	external	8.5E-14	7.7E-01	1.3E-13	6.4E-01	9.1E-19	4.1E-06	5.9E-20	8.4E-07
kitchen-garden	external	6.8E-16	6.1E-03	1.4E-16	7.2E-04	3.8E-19	1.7E-06	9.1E-21	1.3E-07
	inhalation	6.9E-19	6.2E-06	3.1E-19	1.5E-06	9.4E-19	4.3E-06	1.5E-19	2.1E-06
	root crop	2.3E-17	2.0E-04	2.5E-16	1.3E-03	1.2E-14	5.4E-02	1.8E-16	2.6E-03
	vegetable	1.1E-17	1.0E-04	1.4E-16	6.9E-04	5.9E-15	2.7E-02	9.2E-17	1.3E-03
field	external	4.6E-16	4.1E-03	1.1E-16	5.4E-04	3.0E-19	1.3E-06	5.9E-21	8.3E-08
	grain	1.1E-17	1.0E-04	4.3E-16	2.1E-03	7.3E-15	3.3E-02	4.5E-17	6.4E-04
pasturage1	meat	5.1E-16	4.6E-03	9.7E-18	4.8E-05	5.5E-16	2.5E-03	2.0E-16	2.9E-03
	milk	3.0E-17	2.7E-04	3.7E-17	1.9E-04	3.6E-15	1.7E-02	8.9E-16	1.3E-02
pasturage10	meat	8.1E-16	7.3E-03	1.6E-16	8.0E-04	1.2E-14	5.5E-02	1.5E-15	2.1E-02
	milk	4.8E-17	4.3E-04	6.2E-16	3.1E-03	8.1E-14	3.7E-01	6.6E-15	9.4E-02
interception	meat	5.3E-16	4.7E-03	8.0E-18	4.0E-05	8.8E-16	4.0E-03	8.1E-17	1.2E-03
	milk	3.1E-17	2.8E-04	3.1E-17	1.5E-04	5.9E-15	2.7E-02	3.6E-16	5.1E-03
	root crop	1.6E-17	1.4E-04	3.6E-18	1.8E-05	3.8E-16	1.7E-03	2.3E-17	3.3E-04
	vegetable	2.5E-17	2.2E-04	1.1E-17	5.6E-05	1.2E-15	5.3E-03	3.6E-17	5.1E-04
	grain	5.0E-17	4.5E-04	2.2E-17	1.1E-04	2.4E-15	1.1E-02	7.2E-17	1.0E-03
TOTAL		**1.1E-13**	**1.0E+00**	**2.0E-13**	**1.0E+00**	**2.2E-13**	**1.0E+00**	**7.0E-14**	**1.0E+00**

Table 6-2. *Dose conversion factors for the well scenario.*

		^{36}Cl Sv/ (Bq/dm³)	fraction	**^{59}Ni** Sv/ (Bq/dm³)	fraction	**^{79}Se** Sv/ (Bq/dm³)	fraction	**^{93}Mo** Sv/ (Bq/dm³)	fraction
well	drinking water	5.6E-07	5.4E-02	3.8E-08	2.1E-01	1.7E-06	6.3E-02	1.9E-06	1.4E-01
	meat	7.0E-08	6.7E-03	2.5E-08	1.4E-01	3.8E-07	1.4E-02	1.9E-07	1.4E-02
	milk	4.7E-07	4.5E-02	3.2E-08	1.8E-01	1.8E-06	6.6E-02	1.2E-06	8.5E-02
kitchen - garden	external	5.6E-11	5.3E-06	0.0E+00	0.0E+00	1.3E-12	4.7E-08	5.8E-10	4.2E-05
	inhalation	1.5E-10	1.4E-05	2.1E-10	1.2E-03	6.8E-11	2.5E-06	5.2E-10	3.8E-05
	root crop	6.1E-06	5.9E-01	4.2E-08	2.4E-01	1.8E-05	6.5E-01	6.7E-06	4.9E-01
	vegetable	3.1E-06	3.0E-01	2.1E-08	1.2E-01	4.5E-06	1.6E-01	3.4E-06	2.5E-01
interception	root crop	2.2E-08	2.1E-03	6.0E-10	3.4E-03	2.8E-07	1.0E-02	7.4E-08	5.5E-03
	vegetable	7.0E-08	6.7E-03	1.9E-08	1.1E-01	8.7E-07	3.1E-02	2.3E-07	1.7E-02
TOTAL		**1.0E-05**	**1.0E+00**	**1.8E-07**	**1.0E+00**	**2.8E-05**	**1.0E+00**	**1.4E-05**	**1.0E+00**
		^{94}Nb Sv/ (Bq/dm³)	fraction	**^{126}Sn** Sv/ (Bq/dm³)	fraction	**^{129}I** Sv/ (Bq/dm³)	fraction	**^{135}Cs** Sv/ (Bq/dm³)	fraction
well	drinking water	1.0E-06	5.1E-02	3.0E-06	1.3E-01	6.6E-05	2.5E-01	1.2E-06	1.9E-01
	meat	3.6E-06	1.8E-01	3.6E-07	1.5E-02	8.3E-06	3.1E-02	4.5E-07	7.0E-02
	milk	2.1E-07	1.1E-02	1.4E-06	5.9E-02	5.5E-05	2.1E-01	2.0E-06	3.1E-01
kitchen - garden	external	1.4E-05	6.8E-01	4.9E-06	2.1E-01	2.7E-09	1.0E-05	7.6E-11	1.2E-05
	inhalation	1.4E-08	7.0E-04	1.0E-08	4.4E-04	6.6E-09	2.5E-05	1.2E-09	1.9E-04
	root crop	4.6E-07	2.3E-02	8.6E-06	3.7E-01	8.3E-05	3.1E-01	1.5E-06	2.4E-01
	vegetable	2.3E-07	1.2E-02	4.7E-06	2.0E-01	4.2E-05	1.6E-01	7.7E-07	1.2E-01
interception	root crop	3.3E-07	1.6E-02	1.2E-07	5.2E-03	2.6E-06	1.0E-02	1.9E-07	3.0E-02
	vegetable	5.1E-07	2.5E-02	3.8E-07	1.6E-02	8.3E-06	3.1E-02	3.0E-07	4.7E-02
TOTAL		**2.0E-05**	**1.0E+00**	**2.3E-05**	**1.0E+00**	**2.7E-04**	**1.0E+00**	**6.4E-06**	**1.0E+00**

6.2 Sea and transition scenarios

Sea scenario represents the situation, where the surroundings of the Olkiluoto Island remain as present or the sea level rises. Before the lake presented in Figure 5-1 is formed, there will be bay instead of the lake. The area is roughly the same as used by [Suolanen 1986] in the transition scenario. Because the doses from the sea scenario are smaller than from the transition scenario, due to the larger volume and water turnover, the examination of the transition scenario is thought to be sufficient.

The dose conversion factors from the transition scenario are updated with new ingestion rates, concentration factors and dose factors, giving updated dose conversion factors for the nuclides that are also used in the assessment by [Suolanen 1986]. For the nuclides that were not calculated by [Suolanen 1986], the dose conversion factor in the sea scenario is estimated based on the chemical similarity to some nuclide calculated by Suolanen [1986] as well as the ratio between sea and lake scenarios for this reference nuclide. This is a very rough approach, but thought to be sufficient in this matter, especially when considering the insignificance of these scenarios in comparison to the lake scenario. Calculated dose conversion factors are presented in Table 6-3.

Table 6-3. *Transition scenario dose conversion factors.*

Nuclide	Sv/Bq
^{36}Cl	2.74E-18
^{59}Ni	4.63E-17
^{79}Se	1.48E-17
^{93}Mo	1.14E-17
^{94}Nb	1.17E-16
^{126}Sn	2.1E-16
^{129}I	9.49E-15
^{135}Cs	1.13E-15

6.3 Sensitivity and uncertainty of the dose conversion factors

6.3.1 Model

Due to several consecutive phenomena studied in the biosphere analysis, the related uncertainties may accumulate in the results. Therefore the parameter choice is done in a conservative but still relatively reasonable way. It is therefore not expected that there might be a systematic underestimation in the results due to the parameter choices. The deviations should mostly overestimate the results, and possible underestimations should be covered by other related conservatism.

In addition to the parameter choices one may also ask, how the model itself meets the requirement of overestimating the harmful consequences. First of all the main dose path for most radionuclides in the well scenario is actually not "a model" at all, but is calculated simply with the amount of drinking water of man and the dose factors of the radionuclides, i.e. either well defined quantities or quantities that are not to be speculated in an assessment like this, except by mentioning that further development of the metabolic models may results in changes on the dose factors, which in turn have be reflected to the safety case of the final disposal.

Further uncertainties related to the model itself can be crystallized in the following questions:

- Will the forming lake correspond to the one assumed in the analysis, and if not how will this affect the results?
- Could the human habits, including the nutrition differ from the assumed so significantly that it would increase the harmful consequences?

The main parameters describing the lake in the model are its volume and water exchange rate. They are based on data about the sea depth, and should not include large uncertainties. Along with the land-uplift, the size of the lake changes, but the effects of this change should be relatively moderate, especially when considering that the relative contribution of the radiation exposure arising from the lake is low. The drinking water from the well is for most radionuclides the most significant single contributor to the radiation doses also in such case, where lake water is used for agricultural purposes and well water as drinking water for humans and livestock.

Whether human habits change in the future is always an open question, but the fact that agriculture is considered as a part of the human activities in the vicinity of the repository, should be a rather conservative choice. The terrain in Olkiluoto is not very suitable for agriculture.

Dose paths relating to natural products, like berries, mushrooms or game animals are not analysed, but it is noted that the exposure due to them would include factors reducing the exposure, such as the fact that a diet cannot exclusively consist of them as well as the fact the game animals typically use a large area for their diet, and only a fraction of their food would be from the Island.

Therefore assumptions that could lead to significantly more harmful consequences seem to be beyond the reasonable future scenarios and uncertainties in the results of the biosphere assessment are considered not to contradict the targets of a safety case.

6.3.2 Parameters

In the performance assessment for the Loviisa NPP operational waste [Eurajoki *et al.* 2006], the biosphere dose factors were recalculated with the parameters in the SFR-1 performance assessment to assess the validity and to quantify the related uncertainties in the distribution coefficients (K_d) and concentration factors (c). As a general conclusion from this comparison one could observe that the differences between the best-estimate and worst-case values from SFR-1 lead to intervals in the dose coefficients equal to 1…2 orders of magnitude, and the chosen parameter values in that assessment mostly fell within that range. As the distribution coefficients and concentration factors in this work are essentially the same as in [Eurajoki et al. 2006], the same holds true for the values obtained in this report. It is to be noted that the SFR-1 analysis gives also values that lead to more favourable dose coefficients. Hence the target of choosing the parameter values conservatively but still within a reasonable range could be considered met.

6.4 Results for transition, lake and well scenarios

The final biosphere dose factors for all the four scenarios are summarized in Table 6-4. The dose coefficients for the lake scenario are given in terms of radiation dose per activity, whereas for the well scenario in terms of radiation dose per activity concentration. Since the well uptake is between 1 and 20 m^3/d, depending on the well case, one may derive a lower limit for the radiation dose per activity uptaken from a well by dividing the well dose coefficients with the water uptake 7300 m^3/a. This is done in the last column of Table 6-4. The values are still mainly 1 … 3 orders of magnitude higher than the dose coefficients for the lake.

Table 6-4. *Biosphere dose factors.*

Nuclide	Transition	Lake	Well	
	Sv/Bq	Sv/Bq	Sv / a Bq/dm³	Sv/Bq for well 20m^3/d
^{36}Cl	2.74E-18	1.17E-14	1.04E-05	1.42E-12
^{59}Ni	2.21E-15	4.23E-16	1.77E-07	2.42E-14
^{79}Se	1.48E-17	6.35E-14	2.78E-05	3.80E-12
^{93}Mo	1.14E-17	1.13E-14	1.42E-05	1.94E-12
^{94}Nb	1.17E-16	1.11E-13	2.01E-05	2.76E-12
^{126}Sn	2.1E-16	2E-13	2.35E-05	3.22E-12
^{129}I	9.49E-15	2.21E-13	0.000265	3.63E-11
^{135}Cs	1.13E-15	7.03E-14	6.44E-06	8.82E-13

7 COMPARISON OF THE BIOSPHERE DOSE COEFFICIENTS TO POSIVA DOSE COEFFICIENTS

The biosphere dose conversion factors calculated in this work can be compared to the EDFs reported in *Posiva* (2000). Figure 7-1 and Table 7-1 present a comparison of the EDFs for the lake scenario, and Figure 7-2 and Table 7-2 provide a comparison in a similar fashion for the well scenario.

The results compare well and most of the results match within the same order of magnitude for both models. The lake-scenario does not reveal any systematic differences between the two models. The results from the Posiva model are more scattered, which can be accounted to the more detailed model used and to the inclusion of transient effects, whereas the FNS model only assesses the equilibrium state of a somewhat simpler model and hence does not reflect details in the time scales of the nuclide releases.

For the well-scenario the FNS results are on average slightly higher than the results provided by Posiva, although the opposite holds true for ^{59}Ni and ^{129}I. The highest systematic discrepancy is evident for ^{129}I, for which the EDF reported by Posiva differ from FNS results approximately by a factor of 11 in the lake-scenario and by a factor of 2 in the well-scenario. In general, the differences in the description of the lake result in some deviations between the Posiva and FNS models. Among the element-specific parameters, the selected distribution factors in the agricultural soil explain the larger discrepancy in case of Iodine in comparison to other elements.

As the reference (Posiva) values for Mo-93 originate not in the same report with the rest of the radionuclides, they are not comparable in the same way with other results. Partially the differences can be explained by different dilution factors in the biosphere water compartments.

Since the two models (Posiva and FNS) were constructed independently, the results can be considered convincing and to support the reliability of one another. The comparison also gives an idea about the related uncertainties in the dose-conversion factors. The difference between two independent analyses being less than one order of magnitude in most cases as well as the fact that it may be partially explained by the assumptions of the ecosystem, such as the lake characteristics, indicate a fairly consistent conception of the behaviour of the analysed radionuclides, if they end up in the well or lake water. The models may also serve for identifying those parameters to which the dose-conversion factors, or even the eventual radiation doses are most sensitive to. Alternatively, by introducing the parameter-related uncertainties into the models, their effect on the final results may be studied.

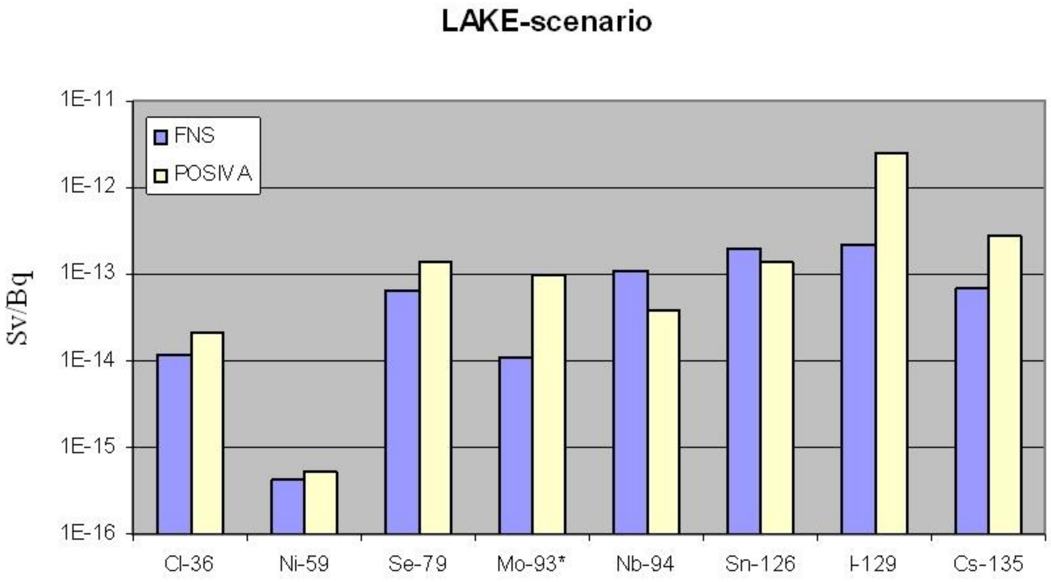

Figure 7-1. *Comparison of the EDFs for the lake-scenario. The Posiva results are reported in Posiva (2000), apart from* ^{93}*Mo which is taken from the lake scenario of the KBS-3H –model (marked with asterisk).*

Table 7-1. *Comparison of the EDFs for the Lake-scenario. The Posiva results are reported in Posiva (2000), apart from* ^{93}*Mo which is taken from the lake scenario of the KBS-3H –model (marked with asterisk).*

Nuclide	***FNS***	***Posiva***	***Ratio***
	Sv/Bq	Sv/Bq	*Posiva/FNS*
^{36}Cl	1.2e-14	2.1e-14	1.8
^{59}Ni	4.2e-16	5.4e-16	1.3
^{79}Se	6.4e-14	1.4e-13	2.2
^{93}Mo	1.1e-14	1.0e-13 (*)	9.1 (*)
^{94}Nb	1.1e-13	3.8e-14	0.3
^{126}Sn	2.0e-13	1.4e-13	0.7
^{129}I	2.2e-13	2.5e-12	11.4
^{135}Cs	7.0e-14	2.8e-13	4

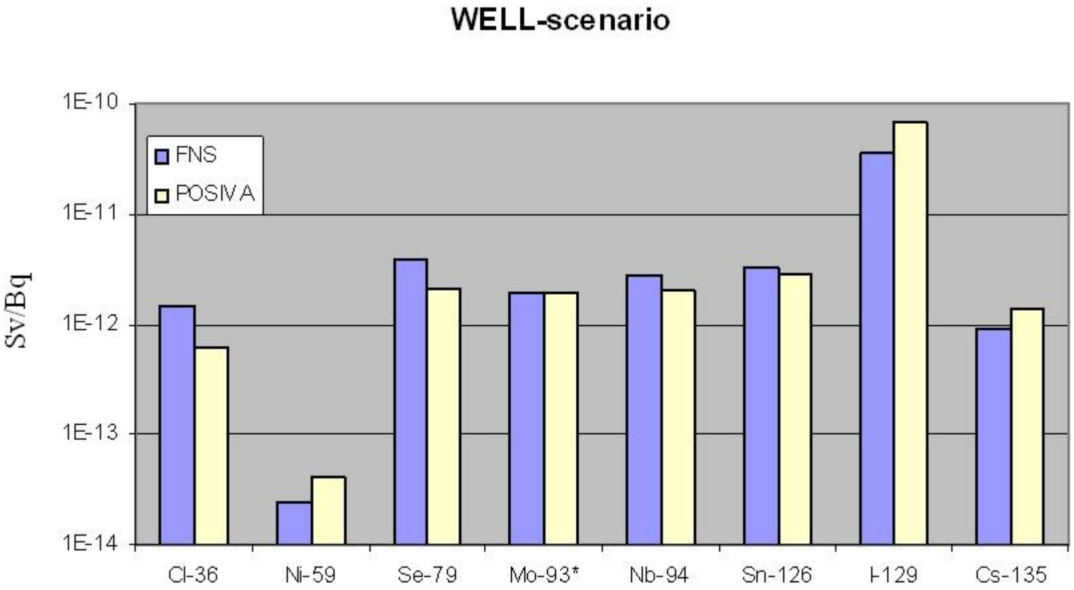

Figure 7-2. *Comparison of the EDFs for the Well-scenario. The Posiva results are reported in Posiva (2000), apart from ^{93}Mo which is taken from the agricultural scenario of the KBS-3H –model (marked with asterisk).*

Table 7-2. *Comparison of the EDFs for the Well-scenario. The Posiva results are reported in Posiva (2000), apart from ^{93}Mo which is taken from the agricultural scenario of the KBS-3H –model (marked with asterisk).*

Nuclide	***FNS*** Sv/Bq	***Posiva*** Sv/Bq	***Ratio*** *Posiva/FNS*
^{36}Cl	1.4e-12	6.1e-13	0.4
^{59}Ni	2.4e-14	4.1e-14	1.7
^{79}Se	3.8e-12	2.1e-12	0.6
^{93}Mo	1.9e-12	1.9e-12 (*)	1.0 (*)
^{94}Nb	2.8e-12	2.0e-12	0.7
^{126}Sn	3.2e-12	2.9e-12	0.9
^{129}I	3.6e-11	6.9e-11	1.9
^{135}Cs	8.8e-13	1.4e-12	1.6

8 SUMMARY AND CONCLUSIONS

In this study a complementary assessment of dose conversion factors for the Olkiluoto site is made based on the biosphere model and parameter database, which Fortum Nuclear Services Ltd (FNS) has applied for the long-term safety assessments of Loviisa and Olkiluoto L/ILW repositories. The aim is to give an independent estimate of biosphere dose conversion factors for the Olkiluoto site. The following nuclides are analysed: ^{36}Cl, ^{59}Ni, ^{59}Ni, ^{79}Se, ^{93}Mo, ^{94}Nb, ^{126}Sn, ^{129}I and ^{135}Cs.

The FNS model is an equilibrium compartment model in which a steady unit annual release of each radionuclide is distributed in different scenarios. The scenarios are the well scenario, which models a small agricultural ecosystem, the lake scenario which models a larger ecosystem with both agriculture and lake use, and sea and transition scenario, which models the behaviour of the radionuclides in marine environments. The scenarios are described and the transfer equations written for the lake scenario. Both internal and external exposures are included in the model.

Food chains are modelled with bioaccumulation and concentration factors and water transfer to plants is modeled to occur by root uptake and interception by leaves. The dose paths considered are: external doses from water (swimming, boating), and doses from soils irrigated (beach, kitchen garden and field) with radioactive water. Dust from the contaminated ground (kitchen garden) causes inhalation doses. Drinking water, fish, meat, milk, grain, vegetables and root crops were chosen as dose paths for internal doses by ingestion. The parameter values are taken from the FNS biosphere parameter database (FNS-BIODABA), which has been used and maintained parallel with the Finnish L/ILW waste repository safety analyses since mid 1990's.

The results of this study, i.e. the dose conversion factors for unit activity release to sea or lake and for unit concentration in a well are summarized in Table 6-4. The results are also compared to those presented in Posiva working report 2000-20. They are of the same order of magnitude for all nuclides except ^{129}I, for which the difference originates mainly in the selected distribution factors in the agricultural soil. Since the Posiva and FNS models were independently constructed, the results can be considered as convincing, and the compliance of the results give confidence to the modelling results.

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