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Tensit – a novel probabilistic simulation tool for safety assessments

Tests and verifications using biosphere models

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Abstract

This report documents the verification of a new simulation tool for dose assessment put together in a package under the name *Tensit* (Technical Nuclide SImulation Tool). The tool is developed to solve differential equation systems describing transport and decay of radionuclides. It is capable of handling both deterministic and probabilistic simulations. The verifications undertaken shows good results. Exceptions exist only where the reference results are unclear.

Tensit utilise and connects two separate commercial softwares. The equation solving capability is derived from the Matlab/Simulink software environment to which *Tensit* adds a library of interconnectable building blocks. Probabilistic simulations are provided through a statistical software named @Risk that communicates with Matlab/Simulink. More information about these softwares can be found at www.palisade.com and www.mathworks.com.

The underlying intension of developing this new tool has been to make available a cost efficient and easy to use means for advanced dose assessment simulations. The mentioned benefits are gained both through the graphical user interface provided by Simulink and @Risk, and the use of numerical equation solving routines in Matlab.

To verify Tensit's numerical correctness, an implementation was done of the biosphere modules for dose assessments used in the earlier safety assessment project SR 97. Acquired probabilistic results for deterministic as well as probabilistic simulations have been compared with documented values. Additional verification has been made both with another simulation tool named AMBER and also against the international test case from PSACOIN named Level 1B.

This report documents the models used for verification with equations and parameter values so that the results can be recreated. For a background and a more detailed description of the underlying processes in the models, the reader is referred to the original references.

Finally, in the perspective of this report, the choice of using models from SR 97 is for result comparison and does not necessarily imply that they are in preference to any other models for future implementation. No attempt has been done to alter the models. They are however, as presented in this report, a result of interpretation and includes an update of errata.

Sammanfattning

Den här rapporten dokumenterar verifieringen av ett nytt simuleringsverktyg *Tensit* (Technical Nuclide Simulation Tool) för beräkning av stråldoser. Verktyget är utvecklat för att lösa system av differentialekvationer som beskriver transport och sönderfall av radionuklider. Såväl deterministiska som probabilistiska beräkningar kan hanteras. Verifieringen som är gjord visar på bra resultat, men med vissa undantag där oklarheter i referensresultaten finns.

Tensit använder och sammanbinder två separata och kommersiella programvaror. Ekvationslösning fås från mjukvarumiljön Matlab/Simulink till vilken Tensit tillhandahåller ett bibliotek med färdiggjorda byggblock. Probabilistiska simuleringar möjliggörs genom ett statistiskt program @Risk, som kan kommunicera med Matlab/Simulink. Mer information om de här programmen kan återfinnas på www.palisade.com respektive www.mathworks.com.

Den bakomliggande orsaken för utvecklandet av det här nya paketet har varit att tillhanda hålla ett effektivt och användarvänligt verktyg för avancerade stråldosberäkningar. De nämnda fördelarna uppnås genom ett grafiskt användargränssnitt i Simulink samt de inbyggda och vältestade ekvationslösningsalgoritmerna i Matlab.

För att verifiera Tensits numeriska korrekthet implementerades biosfärsmodulerna för stråldosberäkningar beskrivna i rapporten /Bergström m fl, 1999/, som är en del av det större projektet SR 97. De probabilistiska erhållna resultaten har jämförts med de tidigare presenterade. På samma sätt jämfördes deterministiska simuleringar med resultat från samma moduler presenterade i /Karlsson m fl, 2000/. Ytterligare verifiering har gjorts genom jämförelser med både ett annat simuleringsverktyg vid namn AMBER och även mot en beräkningsövning vid namn med PSACOIN Level 1B där resultat från ett flertal internationella grupper jämförts.

Den här rapporten dokumenterar modellerna som har använts för verifiering med ekvationer och parameterdata så att resultaten ska kunna återskapas. För bakgrund och en mer detaljerad beskrivning hänvisas läsaren till originalreferenserna.

Slutligen vill vi påpeka att valet av modeller från SR 97 gjorts med utgångspunkt att jämföra resultat. Det betyder inte att dessa modeller är mer aktuella än några andra för framtida ändamål. Inga försök har gjorts att ändra på modellerna. De är dock en tolkning av originalrapporten och innehåller en uppdatering av feltryck.

Content

1 Introduction

In the post closure safety assessment of a radioactive waste repository, biosphere models are often used to describe how different nuclides are transferred in the occurrence of a leakage from the far zone (i.e. the rock matrix) and, based on the released activity and the effect on man for different nuclides, to estimate the dose to individuals in a given human population. In the safety assessment named SR 97 using biosphere modules documented in /Bergström et al, 1999/, the transport of the different elements through the biosphere was modelled using a compartment-based technique where each compartment represents a particular part of the ecosystem. Depending on the ecosystem, the different pathways as well as the resulting dose may vary considerable. While nuclides entering a well may reach man through drinking water or irrigated vegetables, nuclides that enter a lake may reach man for example through the aquatic food chain. Although the activity concentration in a lake is normally relative low due to dilution in an extensive water mass, the dose may nevertheless be of interest for some nuclides that accumulate in fish.

However, when an ecosystem like a lake undergoes a transformation to land due to land uplift, the deep sediments where nuclides could be buried, may be exposed and contribute to the dose to people living in the area. This type of extended issue was not easily implemented using the stand-alone code used for the SR 97 simulations, and a number of different scenarios could not be tested without extensive code development. From this perspective, a concept that allows easy modification of existing models and at the same time is easy to use and maintain with less external help would be preferable.

One alternative to the stand-alone code would be to use the solving capabilities of the general mathematics software Matlab together with Simulink which provides a graphical interface to Matlab. These two softwares could be used together with the rest of the components in the computational chain and provide a fully graphical interface to all simulation codes from rock matrix to biosphere. Another important and sought after quality is to have the code in a well developed and maintained environment such as Matlab/Simulink so that costs are shared with others. An idea of developing a new simulation tool stemming from this background was aroused. The result has been a newly developed toolbox called Tensit which in this report is described and verified.

To verify Tensit’s numerical correctness, an implementation was done of the biosphere modules for dose assessments presented in /Bergström et al, 1999/, a part of the larger SR 97 project. Acquired probabilistic results have been compared with documented values. In the same manner, deterministic results from the same modules presented in /Karlsson et al, 2000/ have been compared with Tensit’s. Additional verification has been made both with another simulation tool named AMBER and also against the international test case Level 1B from PSACOIN. In essence, this report documents the verifications done to show that the now developed toolkit is computationally sound.

1.1 The Tensit simulation approach

The basic approach of a Tensit simulation will first be outlined. I this scenario we assume that we have given problem formulation of some sort for which we wish to obtain a simulated solution. This is how it is done using Tensit. We would start by setting up a new simulation by creating a new Simulink model and add to it the fundamental TENSIT building block. It defines which radionuclides will be used and also their halftimes. Then we would conceptualise suitable parts of the given problem into new building blocks in Simulink. We might also reuse any previously developed blocks if suitable such exists.

When all blocks needed to solve the problem are in hand and have been interconnected, the model can simulated. This last step, when having a functioning model, is in this document called an implementation.

Up to this point, it has been introduced how a deterministic simulation is realised. If one however wishes to carry out a probabilistic simulation, a few further steps are necessary. The probabilistic data such as e.g. distributions for physical parameters, are entered into @Risk using the spread sheet interface of Excel. The deterministic simulation would then be connected to @Risk through communication which Tensit facilitates. In @Risk properties such as number of realisations and sampling type are entered before the simulation is started. Once started @Risk calls Matlab/Simulink which solves the problem. Statistics are there after calculated and presented.

It is important to remember that Tensit is based on commercial software, Matlab, Simulink and presently @Risk, and that the user needs to acquire these separately.

1.2 Structure of the Tensit toolbox

Tensit may be divided into five supposed levels as in the numbered list below. It starts from the operating system level and ends with concrete implementations.

1.	OS	Windows XP
2.	Software	Simulink, @Risk
3.	Tensit	Structure, syntax, utilities
4.	Building blocks	Simulink blocks
5.	Implementation	e.g. SR 97, SAFE, SR-CAN

The first level represents the operating system which may be of any sort that supports the used software. In the present situation Windows XP is used. The second level represents the commercial software being used. These are Matlab, Simulink and @Risk. The third level is the Tensit level which provides structures, definitions, syntax and utilities for Tensit simulations. The fourth level is the building block level. This level represents the currently available (Simulink) building blocks. These may be earlier documented blocks or such under development that will be documented with results of a new simulation. A block represents a conceptualisation of an object for instance a lake or a process such as diffusion. Building blocks can generally be sorted into families.

The fifth and last level is the implementation level. Implementations are here categorised as a complete simulation with results. This is to distinguish from the fourth level which relates to the building blocks themselves. In a new implementation, earlier developed building blocks from previous implementations can be reused in conjunction with newly developed blocks.

2 Tensit and its nomenclature

Tensit contains a set of building blocks defined in Simulink. A simple example model built up with Tensit blocks is shown in Figure 2-1.

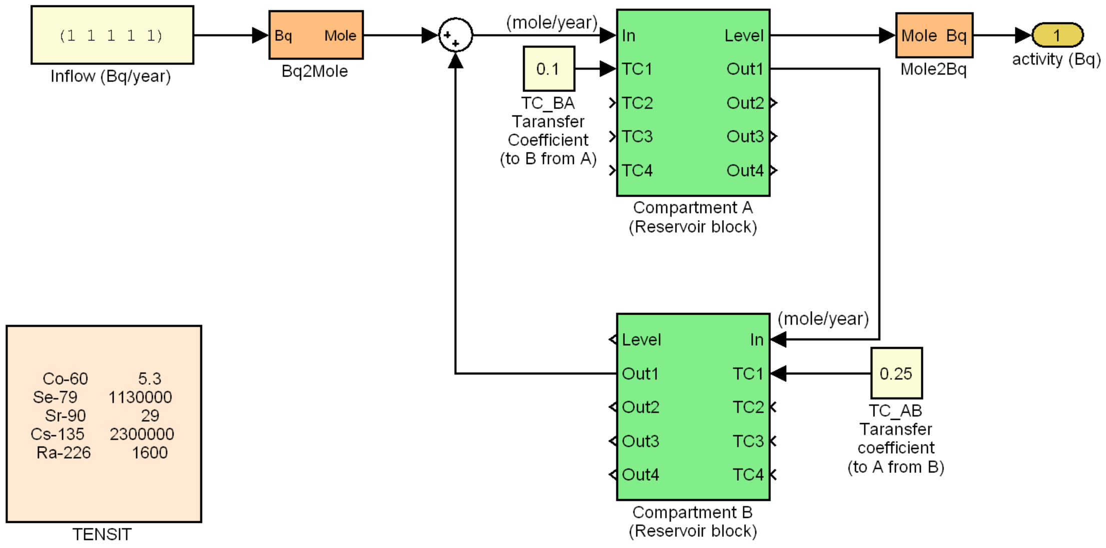


Figure 2-1. *Example model with two compartments built up with Tensit building blocks.*

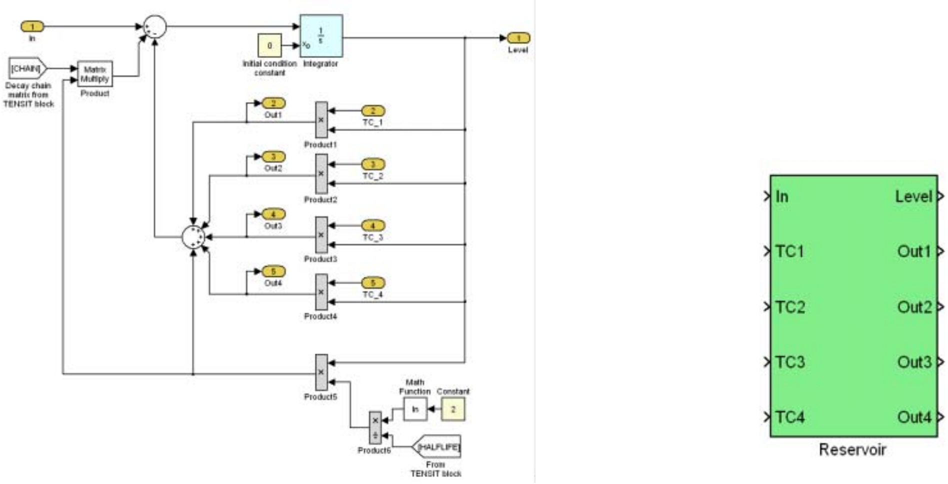
This model consist of two compartments corresponding to the system of differential equations

$$\begin{aligned} \frac{dA}{dt} &= inflow + TC_{AB} \cdot B - TC_{BA} \cdot A \\ \frac{dB}{dt} &= TC_{BA} \cdot A - TC_{AB} \cdot B \end{aligned} \qquad (1)$$

A total of five nuclides are in this case simulated simultaneously. The nuclide names are specified in the *TENSIT* block together with their respective half-lives (in years). There is an inflow to the system with a constant rate of one becquerel per year for each nuclide. Presently all internal calculations are performed in moles instead of becquerel to facilitate mixed simulations of both decaying and non decaying materials. The flux of is thus converted to moles per year by the *Bq2Mole* block. There are two compartment blocks A and B. Each has a constant block attached to it specifying the rate of outflow, here referenced to as transfer constant TC. The notation TC_{AB} entitles transfer to A from B. The outflow is a typical donor controlled process given by the compartment level multiplied by the transfer constant. Finally in this example, compartment *A* has a conversion block connected to its *level* out port so that the integrated activity in the block is obtained.

2.1 Key feature – the Reservoir block

In the Matlab/Simulink model, all compartments have been built up by one single element as the component of lowest order to which transfer coefficients and pathways for material fluxes are connected. This is the *Reservoir* block. It is designed to function as a compartment building block in compartment models. It is essentially an integrator summing up the inflow and handling the radioactive decay. It also provides means to specify outflow from the compartment trough transfer coefficients.



a b

Figure 2-2. *An interior (a) and exterior (b) view of the Reservoir block. In the top part of interior view, the integrator sub block is found. Immediately below is four parallel output channels defined. Further down to the right is the amount of decay products calculated. Up in the top left area arrives the inflow to the block and just below is distribution of branching decay calculated.*

The *Reservoir* has one in port named *in* for inflow which is integrated over time. It uses four parallel channels for outflow. The outflow is controlled by four in ports specifying transfer coefficients TC_1 – TC_4. The output from ports Out_1 – Out_4 is a material flux defined by the product of the respective transfer coefficient and the level of each nuclide in the compartment.

The *Reservoir* block is designed to work with moles. All inputs are therefore expected to be in this unit. Also the outputs as well as all internal calculations are in the same unit. There are two later described converting blocks named *Bq2Mole* and *Mole2Bq* available in the Tensit to help make conversions from activity to moles, and vice versa easier.

The simulation time unit, normally years, is specified in the Tensit block trough the entered halflife times for simulated nuclides.

Inflow and transfer constants used in connection with the Reservoir block use the same time units as the general simulation time unit which is set in the TENSIT block and is described in the following sub section.

2.2 Chain decay and the TENSIT block

In the *Reservoir* block, chain decay is modelled using a source/sink term $TC = \lambda = \ln(2)/T_{1/2}$ to encounter for material lost and produced through radioactive decay. The matrix representation of this process is

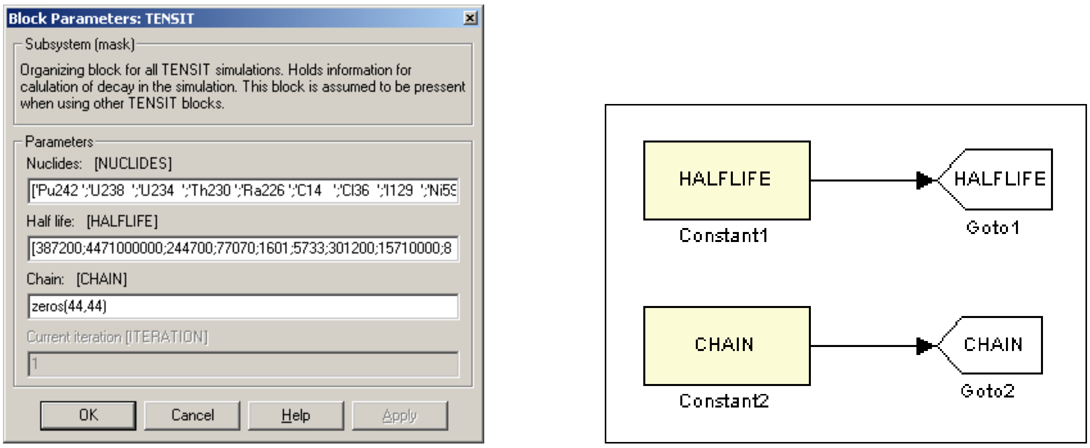
$$\begin{Bmatrix} \frac{dy_1}{dt} \\ \cdot \\ \cdot \\ \cdot \\ \frac{dy_n}{dt} \end{Bmatrix} = \begin{bmatrix} a_{1,1} & \cdot & \cdot & \cdot & a_{1,n} \\ & \cdot & & & \cdot \\ & & \cdot & & \cdot \\ & & & \cdot & \cdot \\ & & & & a_{n,n} \end{bmatrix} \begin{Bmatrix} y_1\lambda_1 \\ \cdot \\ \cdot \\ \cdot \\ y_n\lambda_n \end{Bmatrix} - \begin{Bmatrix} y_1\lambda_1 \\ \cdot \\ \cdot \\ \cdot \\ y_n\lambda_n \end{Bmatrix} \qquad (2)$$

In this equation system the current amount of radionuclide i is denoted y_i. The total number of present radionuclides is n. The matrix components $a_{i,j}$ represents the fraction of decay from the mother nuclide i that yields the daughter nuclide j. This formulation enables the possibility of using branching decay chains defined as separate components in the matrix a.

If one wish to distinguish the resulting daughter nuclides with respect to their mother nuclide while using decay chains, only one mother nuclide should be simulated at the time. Otherwise the daughter nuclides will be mixed without any possibility to distinguish their respective source or mother nuclide.

Using *Tensit*, chain decay is defined in a block named *TENSIT,* Figure 2-1 and Figure 2-3. This block holds the required information for chain decay, i.e. half-life and branching data in the form of the matrix a in Equation (2), for an arbitrary number of nuclide types. When chain decay is not included in the simulation, all elements in this matrix are simply set to zero. The *TENSIT* block holds and passes the nuclide information on to other building blocks depending such as the *Reservoir* block where it is used in calculations. It also holds name labels for the simulated species so that different species are easily identifiable. An additional variable holds the current realisation number which is used in probabilistic simulations.

An important feature of the *TENSIT* block is that it can simultaneously simulate an arbitrary number of nuclides by treating signals as vectors.



Block Parameters: TENSIT

Subsystem (mask)

Organizing block for all TENSIT simulations. Holds information for calulation of decay in the simulation. This block is assumed to be pressent when using other TENSIT blocks.

Parameters

Nuclides: [NUCLIDES]

`['Pu242 ';'U238  ';'U234  ';'Th230 ';'Ra226 ';'C14   ';'Cl36  ';'I129  ';'Ni5`

Half life: [HALFLIFE]

`[387200;4471000000;244700;77070;1601;5733;301200;15710000;8`

Chain: [CHAIN]

`zeros(44,44)`

Current iteration [ITERATION]

`1`

Figure 2-3. *Left: Mask dialog screenshot from the TENSIT block. Here data for the simulated nuclides are entered. Right: Inside view of the TENSIT block. This is a very simple block with the only purpose of making the halflife and decay chain globally available in the model using Goto blocks.*

2.3 Simulation of non-decaying materials

With Tensit it is possible to simulate non-decaying materials together with decaying materials at the same time. This is done by setting the half-life in the TENSIT block to the Matlab infinity constant, *inf,* for the non-decaying material.

To prevent mistakes with non decaying materials, an error message will be displayed if trying to make an implausible conversion of activity into moles for a stable material. One way to set up a mixed simulation with both decaying and non decaying materials is displayed in Figure 2-4. Another way is to give all input directly in moles.

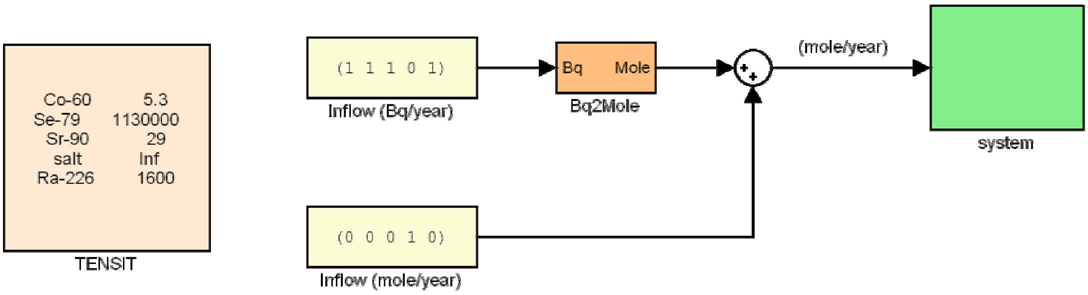


Figure 2-4. *Simulation of both decaying and non-decaying nuclides. An activity inflow for the decaying nuclides are after a conversion to moles added to a complementary inflow source given directly in moles for the non-decaying material.*

2.4 Conversion building blocks

The *Bq2mole* block converts activity in Bq into moles. Note that it assumes the simulation time unit to be in years. An inside view of this block can be seen in Figure 19-1. As mentioned earlier regarding the TENSIT block, halflives for non radioactivly decaying materials are infinite. In order to prevent arithmetic errors, the infinite halftime is in this block temporarily set to zero. Non radioactive materials are further expected to have no, or zero, input activity in Bq. If that is not the case, the simulation is stopped due to inconsistent input data.

Conversion from mole to Bq is done with block *Mole2Bq*. Note that it also assumes the simulation time unit to be in years. An inside view of this block can be seen in Figure 19-2.

2.5 Units

Tensit has no way of checking consistency in the units used in a simulation, it is entirely up the user! The only place units are actually entered is in the text string describing input parameters of Simulink masks. So it is up to the developer specify correct units for all input parameters in masks and of course the user to follow specified units.

Observe that the simulation time unit will be determined by the units used in specifying the decay halflife in the Tensit block for simulated nuclides. It is recommended to be in years. All other units are recommended to be in SI-units for simplicity.

3 Modules

This section describes the biosphere modules from /Bergström et al, 1999/ used to obtain the results documented in coming sections of this report both for the deterministic and probabilistic simulations.

3.1 Irrigation sub-module

The irrigation sub-module, /Bergström et al, 1999/, is used in conjunction with other modules that includes water for irrigation which are lake, well and running water. In Figure 3-1, the module providing the irrigation water is represented by the block *Fresh water*. The irrigation sub-module provides two extra compartments (2–3) to the module containing the water source. These represent soil irrigated by water. Radionuclides are transported with irrigation water to the top soil. Between the top soil and deep soil there is a bidirectional exchange. There is also a return flow of radionuclides back to the fresh water source from both top soil through erosion and from the deep soil trough leakage. Soil removed by weeding in the top soil compartment is transported out of the system.

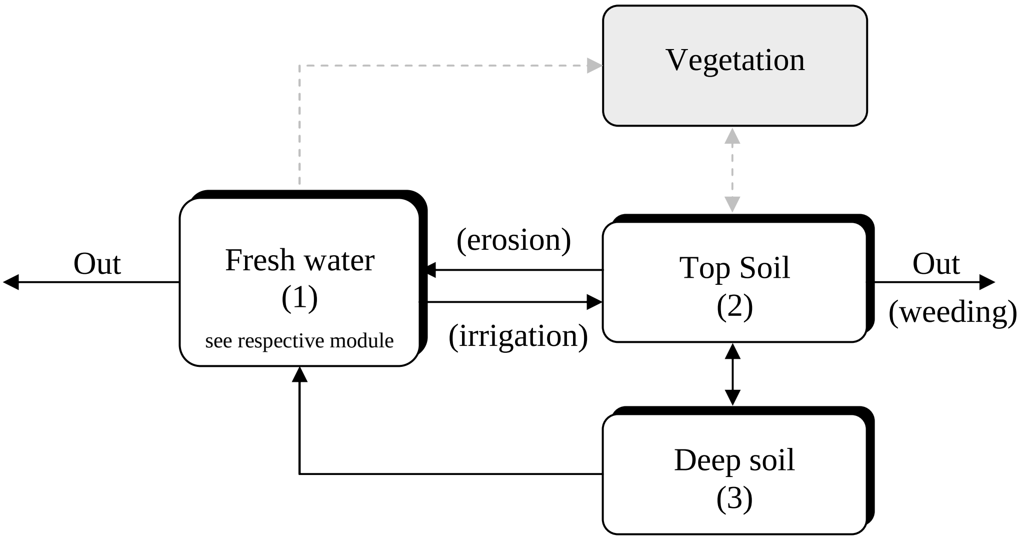


***Figure 3-1.** Compartment system for the sub-module irrigation. Redrawn from /Bergström et al, 1999/.*

The equation system given in /Bergström et al, 1999/ for radionuclide transport in the irrigation sub-module can be written

$$
\begin{aligned}
\frac{dy_1}{dt} &= \dot{y}_{in} + TC_{12}y_2 + TC_{13}y_3 - TC_{01}y_1 - TC_{21}y_1 \\
\frac{dy_2}{dt} &= TC_{21}y_1 - TC_{12}y_2 + TC_{23}y_3 - TC_{32}y_2 \\
\frac{dy_3}{dt} &= TC_{32}y_2 - TC_{13}y_3 - TC_{23}y_3
\end{aligned}
\tag{3}
$$

where the module providing fresh water is treated as a single compartment for simplicity. The activity in each compartment n is denoted y_n. The transfer coefficient TC_{01} corresponds to the nuclides leaving the module containing the fresh water source and TC_{21} radionuclides transported with irrigation water to the top soil. Coefficients TC_{23} and TC_{32} represent exchange between the top soil and the deep soil. The flow back to the fresh water source from the top soil through erosion is given by TC_{12} and from the deep soil trough leakage by TC_{13}. Soil removed by weeding from the top soil and is transported out of the system corresponds to TC_{02}. A detailed description of the included transfer coefficients is given in Table 11-1 and all associated input parameters are listed in Table 3-1. The activity concentration in each compartment is given in Table 13-1.

Table 3-1. Input parameters and variable names used in the irrigation sub-module.

Parameter	Variable name in Tensit	Unit
Irrigation water volume	IRRIGATION	$m^3/(m^2 \cdot year)$
Irrigated area	IRRAREA	m^2
Top soil depth	DEPTHTS	m
Top soil porosity	POROSITYTS	1
Deep soil depth	DEPTHDS	m
Deep soil porosity	POROSITYDS	1
Bioturbation	BIOTURBATION	$kg/(m^2 \cdot year)$
Erosion	EROSION	m/year
Soil removal by weeding	WEEDING	$kg/(m^2 \cdot year)$
Runoff	RUNOFF	$m^3/(m^2 \cdot year)$
Soil particle density	DENSITYSOILP	kg/m^3
Distribution factor, concentration of radionuclides on solids compared to dissolved	KD	$m^3/(kg\ d.w.)$

The yearly water volume taken from the external water source supplying irrigation water is the product of parameters IRRIGATION and IRRAREA.

3.2 Running water

The running water module in /Bergström et al, 1999/, Figure 3-2, consists of only one compartment representing a stream. A fraction of the water is assumed to be used for irrigation, and the remaining fraction leaves the system through outflow.

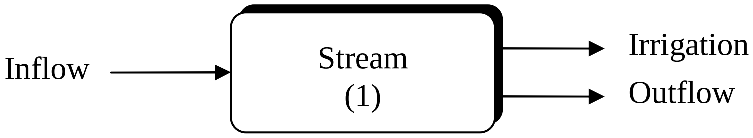


Figure 3-2. *Compartment system for the running water module.*

The differential equation given in /Bergström et al, 1999/ for the running water module can be written

$$\frac{dy_1}{dt} = \dot{y}_{in} - TC_{i1}y_1 - TC_{01}y_1 \tag{4}$$

Nuclides leaving the system trough outflow are represented by coefficient TC_{01} and trough irrigation by TC_{i1}. A detailed description of these transfer coefficients is given in Table 11-2 and all associated input parameters are listed in Table 3-2. The activity concentration in the stream compartment is given in Table 13-1.

The running water module requires three input parameters, presented in Table 3-2.

Table 3-2. Input parameters for the running water module.

Parameter	Variable name	Unit
Irrigation water volume	IRRIGATION	m^3/year
Catchment area	CATCHMENTAREA	m^2
Runoff	RUNOFF	$m^3/(m^2\cdot year)$

3.3 Well

The well module in /Bergström et al, 1999/, Figure 3-3, corresponds in general with the running water module. Some of the water is assumed to be used for irrigation and the remaining water is leaving the well trough outflow.

Figure 3-3. *Compartment system for the well module.*

The differential equation given in /Bergström et al, 1999/ for the well module can be written

$$\frac{dy_1}{dt} = \dot{y}_{in} \text{-} TC_{i1} y_1 \text{-} TC_{01} \qquad (5)$$

A detailed description of the included transfer coefficients are given in Table 11-2 and all associated input parameters are listed in Table 3-3. The activity concentration in the well compartment is given in Table 13-1.

The well module requires two input parameters, presented in Table 3-3.

Table 3-3. Input parameters for the well module.

Parameter	Variable name in Tensit	Unit
Annual irrigation water volume	IRRIGATION	m^3/year
Capacity	CAPACITY	m^3/year

The water in the well module is assumed to be used to irrigate garden plots when connected to the irrigation sub-module.

3.4 Lake

The lake module in /Bergström et al, 1999/ consists of four different compartments, Figure 3-4. The compartments represents the water body, compartment 1, transport sediment, compartment 2, and two compartments for the accumulation, compartment 3, and deep, compartment 4, sediments.

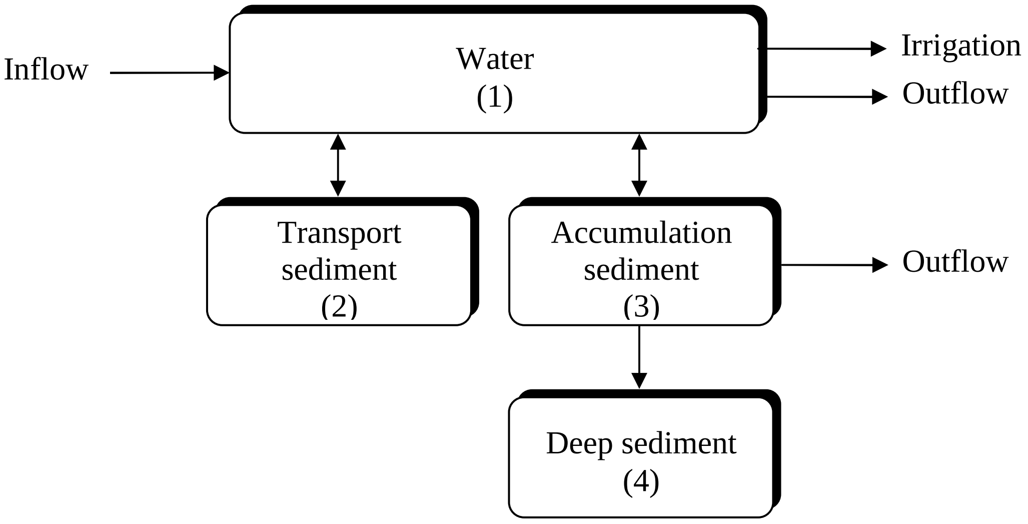


Figure 3-4. *Compartment system for the Lake module. Redrawn from /Bergström et al, 1999/ with added irrigation arrow.*

The equation system given in /Bergström et al, 1999/ modelling the radionuclide transport in the lake module can be written

$$
\begin{aligned}
\frac{dy_1}{dt} &= \dot{y}_{in} + TC_{12}y_2 - TC_{01}y_1 - TC_{21}y_1 \\
\frac{dy_2}{dt} &= TC_{21}y_1 + TC_{23}y_3 - TC_{02}y_2 - TC_{12}y_2 - TC_{32}y_2 \\
\frac{dy_3}{dt} &= TC_{32}y_2 - TC_{23}y_3 - TC_{43}y_3 \\
\frac{dy_4}{dt} &= TC_{43}y_3
\end{aligned}
\tag{6}
$$

With TC_{01} and TC_{03} representing radionuclides leaving the lake, TC_{21} and TC_{31} tranportation from water to sediment through gravitational settling. Resuspension from sediments to water is controlled by TC_{12} and TC_{13}. The build up of deep sediment is represented by TC_{43}. A detailed description of these transfer coefficients is given in Table 11-4 and all associated input parameters are listed in Table 3-4. The activity concentration in the compartments of interest for dose calculations is given in Table 13-1.

The lake module requires 14 input parameters, presented in Table 3-4.

Table 3-4. Input parameters for the lake module.

Parameter	Variable name in Tensit	Unit
Annual irrigation water volume	IRRIGATION	m^3/year
Catchment area	CATCHAREA	m^2
Run off	RUNOFF	m/year
Lake area	AREA	m^2
Mean depth	MEANDEPTH	m
Gross sediment rate	SEDRATE	$kg/(m^2 \cdot year)$
Suspended matter	SUSP	kg/m^3
Fraction transportation bottoms	FRAC	1
Max depth	MAXDEPTH	m
Primary production	PRIMEPROD	$kg/(m^2 \cdot year)$
Fraction primary production reaching sediment	FSED	1
Mass of top sediment per area in accumulation bottoms	MSED	kg/m^2
Empirical factor	K	1
Distribution factor, concentration of radionuclides on solids compared to dissolved	KD	m^3/kg

3.5 Peat bog

The peat module in /Bergström et al, 1999/ consists of two separate compartments, one for radionuclides sorbed in water, compartment 1, and one compartment for radionuclides in the solid (particulate) phase, compartment 2. The nuclides enter and leave the system through the water compartment.

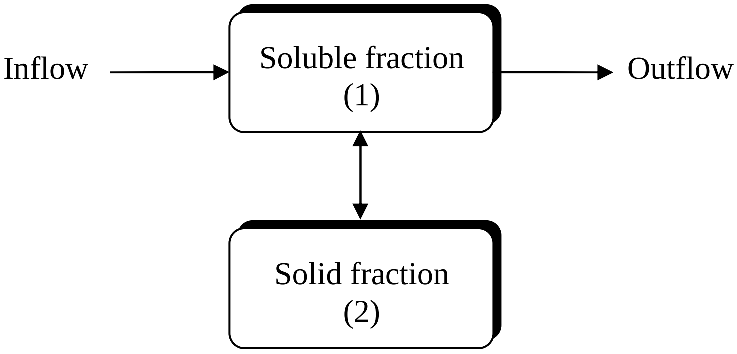


Figure 3-5. Compartment system for the peat bog module. Redrawn from /Bergström et al, 1999/.

The equation system given in /Bergström et al, 1999/ for the radionuclide transport in the peat module can be written

$$
\begin{aligned}
\frac{dy_1}{dt} &= \dot{y}_{in} + TC_{12}y_2 - TC_{01}y_1 - TC_{21}y_1 \\
\frac{dy_2}{dt} &= TC_{21}y_1 - TC_{12}y_2
\end{aligned}
\tag{7}
$$

With y_1 representing the activity in the compartment with radionuclides sorbed in the void water and y_2 corresponds to the activity of the particulate nuclides. The transfer constant TC_{01} corresponds to the nuclides leaving the system through the runoff water and TC_{21} and TC_{12} to nuclide transport from the desorbed to the particulate phase and in the reverse direction. A detailed description of these transfer coefficients is given in Table 11-5 and all associated input parameters are listed in Table 3-5. The activity concentration in each compartment is given in Table 13-1.

The peat module is defined by a set of seven different properties, see Table 3-5.

Table 3-5. Input parameters for the peat module.

Parameter	Variable name in Tensit	Unit
Depth of the peat bog	DEPTH	m
Area of the peat bog	AREA	m^2
Density of peat	DENSITY	kg/m^3
Porosity of peat	POROSITY	1
Runoff	RUNOFF	$m^3/(m^2 \cdot year)$
Reaktion half-time	TK	year
Distribution factor, concentration of radionuclides on solids compared to dissolved	KD	m^3/kg d.w.

3.6 Agricultural land

The agricultural model used in /Bergström et al, 1999/ consists of four different compartments, Figure 3-6, two representing the top and deep soil, compartment 1 and 2 respectively, and two compartments representing the ground water saturated zone, compartments 3 and 4. Nuclides may enter the agricultural model through the groundwater, compartment 3, and, if the topsoil is irrigated, through irrigation water to the topsoil compartment.

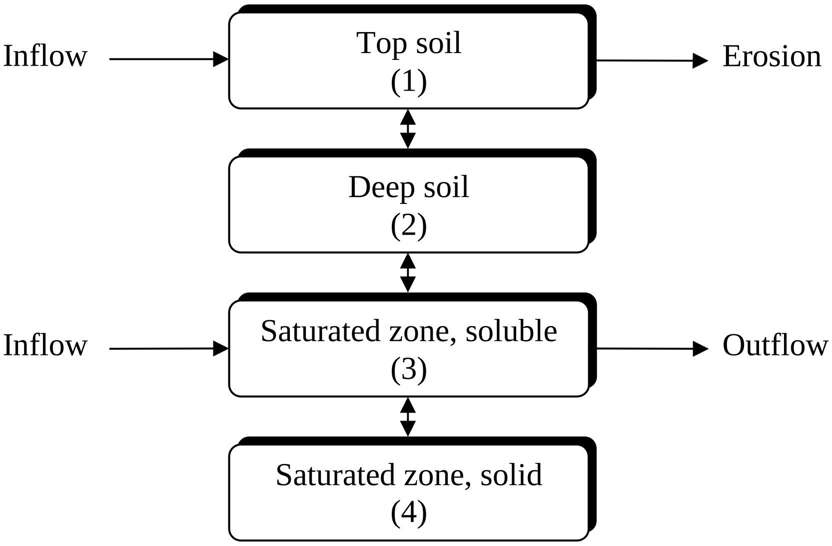


Figure 3-6. *Compartment system for the agricultural module. Redrawn from /Bergström et al, 1999/.*

The equation system given in /Bergström et al, 1999/ for the agricultural model can be written

$$\begin{aligned}
\frac{dy_1}{dt} &= \dot{y}_{in1} + TC_{12}y_2 - TC_{01}y_1 - TC_{21}y_1 \\
\frac{dy_2}{dt} &= TC_{21}y_1 + TC_{23}y_3 - TC_{12}y_2 - TC_{32}y_2 \\
\frac{dy_3}{dt} &= \dot{y}_{in3} + TC_{32}y_2 + TC_{34}y_4 - TC_{23}y_3 - TC_{43}y_3 \\
\frac{dy_4}{dt} &= TC_{43}y_3 - TC_{34}y_4
\end{aligned} \tag{8}$$

where TC_{01} corresponds to the outflow of nuclides trough erosion, TC_{12} and TC_{21} for the transfer between the top and deep soil originating from vertical water flow and from earth mixing by bioturbation. Vertical water flow is also the driving force for fluxes between the saturated and unsaturated zone, TC_{32} and TC_{23}. Chemical, biological and physical processes influence TC_{43}, where as TC_{34} is modelled with a reaction halftime.

A detailed description of these transfer coefficients is given in Table 11-6 and all associated input parameters are listed in Table 3-6. The activity concentration in each compartment is given in Table 13-1.

The agricultural module requires a total of 15 data parameters presented in Table 3-6.

Table 3-6. Input parameters for the agricultural land module.

Parameter	Variable name	Unit
Runoff	RUNOFF	$m^3/(m^2 \cdot year)$
Depth of top soil	DEPTHTS	m
Porosity of top soil	POROSITYTS	1
Depth of deep soil	DEPTHDS	m
Porosity of deep soil	POROSITYDS	1
Saturated zone depth	DEPTHSAT	m
Saturated zone porosity	POROSITYSAT	1
Water transport from saturated zone (groundwater) to deep soil	FSADS	$m^3/(m^2 \cdot year)$
Water transport from deep soil to top soil	FDSTS	$m^3/(m^2 \cdot year)$
Bioturbation	BIOTURBATION	$kg/(m^2 \cdot year)$
Erosion	EROSION	m/year
Soil particle density	DENSITYSOILP	kg/m^3
Area of agricultural land	IRRAREA	m^2
Reaktion half-time	TK	year
Distribution factor, concentration of radionuclides on solids compared to dissolved	KD	m^3/kg

3.7 Coast

The coast module given in /Bergström et al, 1999/ is divided into bay and open sea and consists of a total of five compartments, Figure 3-7. Three of these represent the water body, the upper sediment and the deep sediment in the bay area. The other two represents water body and the sediments of the open sea. Inflow of radionuclides is allowed both to the bay and the open sea, whereas the major downstream transport is from the bay to the open sea.

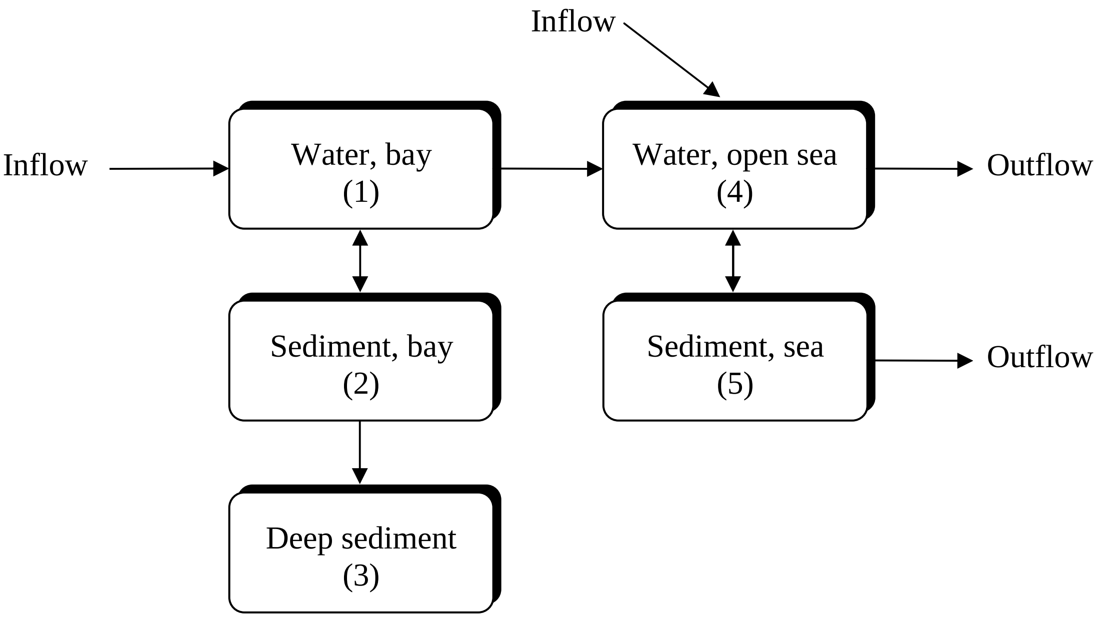


Figure 3-7. *Compartment system for the coast module. Redrawn from /Bergström et al, 1999/.*

The equation system given in /Bergström et al, 1999/ for the coast model can be written

$$
\begin{aligned}
\frac{dy_1}{dt} &= \dot{y}_{in1} + TC_{12}y_2 + TC_{14}y_4 - TC_{41}y_1 - TC_{21}y_1 \\
\frac{dy_2}{dt} &= TC_{21}y_1 - TC_{12}y_2 - TC_{32}y_2 \\
\frac{dy_3}{dt} &= TC_{32}y_2 \\
\frac{dy_4}{dt} &= \dot{y}_{in4} + TC_{41}y_1 + TC_{45}y_5 - TC_{04}y_4 - TC_{14}y_4 - TC_{54}y_4 \\
\frac{dy_5}{dt} &= TC_{54}y_4 - TC_{45}y_5 - TC_{05}y_5
\end{aligned}
\qquad (9)
$$

Constants TC_{04} and TC_{05} represents radionuclides leaving the system. Some of the suspended material in water will reach the sediment through gravitational settling, TC_{21} and TC_{54}. This material may also be resuspended, TC_{12} and TC_{45}. The third compartment represents the deep sediment where the nuclides are buried through the transport controlled by TC_{32}. A detailed description of these transfer coefficients is given in Table 11-7 and the activity concentration in each compartment is given in Table 13-1.

The coast module requires 16 input parameters presented in Table 3-7.

Table 3-7. Input parameters for the coast module.

Parameter	Variable name	Unit
Surface area, bay	AREABAY	m^2
Maximum depth, bay	MAXDEPTHBAY	m
Mean depth, bay	MEANDEPTHBAY	m
Residence time, bay	RETTIMEBAY	days
Gross sedimentation rate, bay	SRBAY	kg d.w./(m^2·year)
Suspended matter, bay	SUSPBAY	kg d.w./m^3
Mass of top sediment	MS	kg/m^2
Volume open sea	VSEA	m^3
Mean depth, sea	MEANDEPTHSEA	m
Water turnover, sea	TURNOVERSEA	1/year
Gross sedimentation rate, sea	SRSEA	kg d.w./(m^2·year)
Suspended matter, sea	SUSPSEA	kg d.w./m^3
Resuspension rate, sea	RESUSPSEA	1/year
Empirical factor	K	1
Distribution factor, concentration of radionuclides on solids compared to dissolved	KD	m^3/kg

4 Deterministic results

This section documents the deterministic results obtained with Tensit for the biosphere modules described in section 3. There are no deterministic results presented in /Bergström et al, 1999/, instead comparisons have been made with deterministic results from the same modules presented in /Karlsson et al, 2000/. The simulation time has been 10 000 years. The results are presented compartment wise in percent of total remaining activity in the corresponding module.

4.1 Running water

The running water module connected with the irrigation sub-module was simulated. The irrigation sub-module was set up for irrigation of agricultural land as assumed in /Bergström et al, 1999/.

The results from both Tensit and those reported in /Karlsson et al, 2000/ are presented below in Table 4-1 which shows that there are only minor deviations in the results.

Table 4-1. Distribution of radionuclides (%) between different compartments in the running water module after 10 000 years.

	^{36}Cl	^{93}Mo	^{237}Np	^{129}I	^{59}Ni	^{135}Cs	^{239}Pu
Tensit							
Running water	0.010	0.023	0.010	0.010	0.011	0.010	0.012
Top soil	0.000	0.011	0.005	0.014	0.021	0.030	0.048
Deep soil	0.000	0.041	0.021	0.055	0.081	0.113	0.173
Out	99.990	99.925	99.964	99.921	99.887	99.847	99.767
reference							
Running water	0.010	0.022	0.010	0.010	0.011	0.010	0.011
Top soil	0.000	0.011	0.005	0.014	0.021	0.030	0.048
Deep soil	0.000	0.039	0.021	0.055	0.081	0.113	0.173
Out	99.990	99.929	99.964	99.921	99.887	99.847	99.768

Parameter values used in the simulation are listed in Table 12-3.

4.2 Well

The well module connected with the irrigation sub module was simulated. The irrigation sub-module was set up for irrigation of garden plots as assumed in SR 97.

The results from both Tensit and those reported in /Karlsson et al, 2000/ are presented below in Table 4-2. There are some differences in the results. Deviations in the first decimal position or more are marked in bold.

Table 4-2. Distribution (%) of radionuclides between different compartments in the well module after 10 000 years. Results with differences in the first decimal position or more are written in bold.

	^{36}Cl	^{93}Mo	^{237}Np	^{129}I	^{59}Ni	^{135}Cs	^{239}Pu
Tensit							
Well water	0.011	0.025	0.011	0.011	0.011	0.011	0.012
Top soil	0.002	0.303	**0.146**	**0.429**	0.669	**0.991**	**1.634**
Deep soil	0.007	**1.096**	0.569	1.658	2.539	3.693	**5.793**
Out	99.980	98.576	99.273	97.902	96.781	**95.306**	92.561
reference							
Well water	0.011	0.023	0.011	0.011	0.011	0.011	0.011
Top soil	0.002	0.308	**0.157**	**0.479**	0.749	**1.112**	**1.821**
Deep soil	0.007	**1.047**	0.570	1.651	2.512	3.635	**5.612**
Out	99.980	98.622	99.262	97.859	96.727	**95.242**	92.555

Parameter values used in the simulation are listed in Table 12-4.

4.3 Lake

The lake module connected with the irrigation sub-module was simulated. The irrigation sub-module was set up for irrigation of agricultural land as assumed in SR 97.

The results from both Tensit and those reported in /Karlsson et al, 2000/ are presented below in Table 4-3 which shows that there are only minor deviations in the results.

Table 4-3. Distribution of radionuclides (%) between different compartments in the lake module after 10 000 years.

	^{36}Cl	^{93}Mo	^{237}Np	^{129}I	^{59}Ni	^{135}Cs	^{239}Pu
Tensit							
Water	0.003	0.007	0.003	0.003	0.003	0.003	0.004
Transport sediment	0.001	0.000	0.005	0.000	0.006	0.005	0.058
Accumulation sediment	0.002	0.000	0.022	0.001	0.023	0.022	0.232
Top soil	0.000	0.002	0.001	0.002	0.004	0.005	0.008
Deep soil	0.000	0.007	0.004	0.009	0.014	0.019	0.029
Out	99.994	99.984	99.965	99.984	99.951	99.945	99.670
reference							
Water	0.003	0.007	0.003	0.003	0.003	0.003	0.004
Transport sediment	0.001	0.000	0.005	0.000	0.006	0.005	0.056
Accumulation sediment	0.002	0.000	0.022	0.001	0.023	0.022	0.231
Top soil	0.000	0.002	0.001	0.002	0.004	0.005	0.008
Deep soil	0.000	0.007	0.004	0.009	0.014	0.019	0.029
Out	99.994	99.985	99.965	99.984	99.951	99.945	99.672

Parameter values used in the simulation are listed in Table 12-5.

4.4 Peat bog

The results from both Tensit and those reported in /Karlsson et al, 2000/ are presented below in Table 4-4 which shows that there are only minor deviations in the results.

Table 4-4. Distribution of radionuclides (%) between different compartments in the peat bog module after 10 000 years.

	^{36}Cl	^{93}Mo	^{237}Np	^{129}I	^{59}Ni	^{135}Cs	^{239}Pu
Tensit							
Water	0.019	0.043	0.019	0.019	0.020	0.019	0.021
Organic	0.021	0.144	2.087	0.063	2.178	0.626	4.746
Out	99.960	99.813	97.895	99.919	97.802	99.355	95.233
reference							
Water	0.019	0.043	0.019	0.019	0.020	0.019	0.021
Organic	0.021	0.143	2.084	0.063	2.176	0.626	4.744
Out	99.960	99.814	97.897	99.919	97.805	99.355	95.234

Parameter values used in the simulation are listed in Table 12-6.

4.5 Agricultural land module

The results from both Tensit and those reported in /Karlsson et al, 2000/, with inflow of nuclides connected to the saturated soluble compartment, are presented below in Table 4-5. There are differences in the results for ^{93}Mo in compartments *Solid* and *Out*.

Table 4-5. Distribution of radionuclides between different compartments in the agricultural land module after 10 000 years given in percent. Results with differences in the first decimal position or more are written in bold.

	^{36}Cl	^{93}Mo	^{237}Np	^{129}I	^{59}Ni	^{135}Cs	^{239}Pu
Tensit							
Top soil	0.003	0.507	0.394	0.844	0.935	0.850	0.035
Deep soil	0.038	3.698	2.834	4.657	4.741	3.998	0.150
Solid, saturated zone	0.354	**44.903**	31.987	59.896	70.869	81.586	99.505
Water, saturated zone	0.063	0.080	0.057	0.036	0.025	0.015	0.000
Out	99.542	**50.812**	64.728	34.567	23.430	13.551	0.310
reference							
Top soil	0.003	0.498	0.394	0.844	0.935	0.850	0.035
Deep soil	0.038	3.641	2.836	4.658	4.741	3.996	0.150
Solid, saturated zone	0.354	**43.774**	31.970	59.876	70.855	81.619	99.503
Water, saturated zone	0.063	0.078	0.057	0.036	0.025	0.015	0.000
Out	99.542	**52.009**	64.742	34.586	23.445	13.520	0.312

Parameter values used in the simulation are listed in Table 12-7.

4.6 Coast

The coast module was simulated with inflow of radioactive material to the bay water reservoir. The results from both Tensit and those reported in/Karlsson et al, 2000/ are presented below in Table 4-6 which shows that there are only minor deviations in the results.

Table 4-6. Distribution of radionuclides between different compartments in the coast module after 10 000 years. (External inflow only to the water bay compartment.)

	^{36}Cl	^{93}Mo	^{237}Np	^{129}I	^{59}Ni	^{135}Cs	^{239}Pu
Tensit							
Water, bay	0.001	0.003	0.001	0.001	0.001	0.001	0.001
Top sediment bay	0	0	0.013	0	0.014	0.013	0.141
Deep sediment bay	0	0	0	0	0	0	0
Water open sea	0	0.001	0	0	0	0	0
Sediment open sea	0	0	0	0	0	0	0
Out	99.999	99.997	99.985	99.998	99.985	99.985	99.858
reference							
Water, bay	0.001	0.003	0.001	0.001	0.001	0.001	0.001
Top sediment bay	0.000	0.000	0.013	0.000	0.014	0.013	0.139
Deep sediment bay	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Water open sea	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sediment open sea	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Out	99.999	99.997	99.985	99.998	99.984	99.985	99.856

Parameter values used in the simulation are listed in Table 12-8.

5 Probabilistic simulations

In /Bergström et al, 1999/ the EDF values in Sv/year were calculated probabilistically. The same models were used as in the deterministic case but now extended with dose calculations. Parameters were assigned probability distributions and each module was simulated for a simulation time of 10 000 years repeatedly, each time with new parameter values drawn. The mean value, is with a large enough number of realisations, expected to converge towards a specific value. This mean value has been presented as a part of the results and is also the value with which we will compare our results.

To enable probabilistic simulations in conjunction with Tensit, we have combined the Matlab/Simulink environment with a separate external software specialized in probabilistic simulations named *@Risk*. The choice of statistics software is free to change if one wishes since there are no strong couplings to Matlab/Simulink that would make a change difficult.

Another statistical tool that could be mentioned in this context is PRISM, /Gardner et al, 1983/, that was an early code for Monte Carlo simulation and with advanced features such as Latin hypercube sampling.

5.1 Probabilistic software *@Risk*

The *@Risk* software is a plug in application for Microsoft's spreadsheet application *Excel*. This software provides easy ways to assign probabilistic distributions to different parameters and also to obtain statistics from probabilistic simulations.

The simulation can be controlled in a number of ways. The number of iterations is of course adjustable. More importantly, the way in which random numbers are drawn from probability distributions can be selected between a few different possibilities. The traditional Monte Carlo method is available, and in addition, also the more advanced Latin Hypercube sampling method. This method is more efficient compared to Monte Carlo sampling in the way that significantly less iteration are normally needed to adequately simulate a given system.

Input parameters can be correlated to each other using correlation matrices which *@Risk* provides an interface for.

After a simulation has been run, statistics are easily obtained for all input parameters and outputs. This includes mean value, standard deviation, confidence intervals and sensitivity analysis.

5.2 Combining software

The @Risk software allows for Visual Basic macros to be run with each iteration of the probabilistic simulation. This feature is used to obtain results from Simulink and include them in the probabilistic calculations.

A Visual Basic macro has been written for the task of sending parameters to Simulink, start the simulation and fetch the result. The communication between Matlab/Simulink and @Risk is carried out trough the DDE-interface which both sides support.

This is a short description of the simulation strategy in large. The fundament of the simulation is a spreadsheet created in Excel running together with @Risk as a plug-in. In the spreadsheet all the data for the simulation, including constants and probability distributions are entered.

A description of the iteration process follows. When started, @Risk draws new data from the given probability distributions. A Visual Basic macro opens a communication channel to Matlab through the DDE-interface. Through this channel data from the spreadsheet is first sent to Matlab/Simulink. Thereafter the simulation is started remotely by sending a Matlab command through the communication channel. Finally, the result of the Simulink simulation is returned and put into the spreadsheet so that it can be a part of the probabilistic calculation. These steps are then repeated for each iteration.

5.3 Parameter correlations

Some of the parameter distributions are correlated with each other within the treated biosphere modules. The correlation coefficients used are the same as those documented in /Karlsson et al, 2000/ for all the modules except running water, which is not documented this way. All correlations used are listed in Appendix D.

The correlation coefficients have been entered into *@Risk* through special correlations matrixes and in this way been included in the simulations.

5.4 Software settings

Simulink has used the following settings listed in Table 5-1 for all probabilistic simulation.

Table 5-1. Simulink solver settings.

Simulation parameters	Value
Simulation time (start)	0
Simulation time (stop)	10 000
Solver options	Variable-step
Solver name	ode15s (stiff/NDF)
Max step size	auto
Min step size	auto
Initial step size	auto
Relative tolerance	1e–9
Absolute tolerance	1e–9
Maximum order	5
Output options	Refine output
Refine factor	1

The simulation settings generally used for probabilistic simulations with the risk analysis software @Risk is listed in Table 5-2.

Table 5-2. Setting for the @Risk software.

Simulation parameters	Value
Number of iterartions	10 000
Sampling type	Latin Hypercube

6 Dose calculations

The *dose* module calculates ecosystem specific dose conversion Factors (EDFs) to humans according to /Bergström et al, 1999/. It is based on a number of assumptions of how radioactivity in water, soil and peat reaches man through different pathways. The design is made for use in conjunction with the biosphere modules described in the previous chapter. Two simulated input parameters to the module are concentration in water and soil (peat in the peat bog), [Bq/m^3] and [Bq/kg]. These concentrations may be taken directly from the respective output of the biosphere modules presented in the previous chapter. The dose module then calculates the dose rate to man in [Sv/year].

This module has been implemented as a number of blocks representing different biological pathways to a human population. The human population is represented by a block named *man* which is the core of the dose module. The other blocks have names representing exposure pathways such as *inhalation*, *milk* and *vegetables*. These blocks may be added freely to the module in order to model different exposure scenarios for a given group of humans. The implementation is not fixed in this sense; it is defined by what blocks are used and how they are interconnected. This makes it easy to adjust for the various scenarios associated with the different biosphere modules. The only constraint is that this module minimally contains the block representing man.

The model equations implemented comes from /Bergström et al, 1999/. Some parameter names have for clarity been substituted and equations have occasionally been divided into smaller parts to better fit the block representation approach TENSIT has.

6.1 Man

A human population is in the *dose* module represented by the block named *man*. Man is assumed to be exposed only through three major pathways. These are ingestion, inhalation and external exposure. The equation, stemming from /Bergström et al, 1999/, determining the yearly dose to man, which also is the output from block *man*, is

$$dose = DC_{ing} \cdot AE_{ing} + DC_{inh} \cdot AE_{inh} + DC_{ext} \cdot AE_{ext} \tag{10}$$

where

DC_{ing} = Dose coefficient for ingestion [Sv/Bq] (DCING)

DC_{inh} = Dose coefficient for inhalation [Sv/Bq] (DCINH)

DC_{ext} = Dose coefficient for external exposure [(Sv/h)/(Bq/m^3)] (DCEXT)

AE_{ing} = Total activity exposure through ingestion per year [Bq/year] (*inport*)

AE_{inh} = Total activity exposure through inhalation per year [Bq/year] (*inport*)

AE_{ext} = Total external activity exposure per year [Bq/year] (*inport*)

6.2 Water and soil

Consumption of water, /Bergstöm et al, 1999/, gives trough ingestion an activity exposure that can be written

$$AE = CR \cdot C_w \cdot cv_1 \tag{11}$$

where

CR = Human consumption of water [liter/year] (CONSUMPTIONWATER)
C_w = Concentration of radionuclides in water [Bq/m^3] (*inport*)
cv_1 = Conversion factor (0.001) [m^3/litre] (–)

When consuming plants, man indivertibly consumes a fraction soil which gives an activity exposure, /Bergstöm et al, 1999/, that can be written

$$AE = CR \cdot C_s \tag{12}$$

where

CR = Human consumption of soil [kg/year] (CONSUMPTIONSOIL)
C_s = Concentration of radionuclides in soil [Bq/kg] (*inport*)

6.3 Crops

Crops are through ingestion an exposure pathway for man, /Bergstöm et al, 1999/. It is divided into three groups which are cereals, root crops and green vegetables. Each group is represented by its own block. The annual activity exposure to man from group *j*, cereals and root crops, in their respective block can be written

$$AE_j = CR_j\,(C_s \cdot RUF_j + n \cdot W_i \cdot TL \cdot C_w) \tag{13}$$

where

AE_j = Total annual activity exposure from respective group [Bq/year] (*outport*)
CR_j = Human consumption of respective group [kg/year] (CONSUMPTION$_j$)
C_s = Concentration of radionuclides in soil [Bq/kg] (*inport*)
RUF_j = Soil to plant root uptake factor [(Bq/kg)/(Bq/kg)] (RUF$_j$)
W_i = Remaining water on plant after irrigation [m] (REMAININGWATER)
TL = Translocation factor [(Bq/kg)/(Bq/m^2)] (TRANSLOCATION)
C_w = Concentration of radionuclides in irrigation water [Bq/m^3] (*inport*)
n = Irrigation events [1] (IRREVENTS)

The annual activity exposure to man from vegetables can be written

$$
\begin{aligned}
AE &= CR_v(C_s \cdot RUF_v + \frac{C_w \cdot W}{Y_v \cdot P}\sum_{i=1}^{n}\int_{0}^{t_i} e^{-\lambda_w t}dt) \\
&= CR_v\left[C_s \cdot RUF_v + \frac{C_w \cdot W}{Y_v \cdot P}\frac{1}{\lambda_w}(n - \sum_{i=1}^{n} e^{-\lambda_w t_i})\right]
\end{aligned}
\qquad (14)
$$

where

AE = Total annual activity exposure from vegetables [Bq/year] (*outport*)

CR_v = Human consumption of vegetables [kg/year] (CONSUMPTION)

C_s = Concentration of radionuclides in soil [Bq/kg] (*inport*)

RUF_v = Soil to plant root uptake factor [(Bq/kg)/(Bq/kg)] (RUF)

C_w = Concentration of radionuclides in irrigation water [Bq/m^3] (*inport*)

W = Remaining water on plant after irrigation [m] (REMAININGWATER)

P = Irrigation period [day] (IRRPERIOD)

Y_v = Yield of vegetables [kg/m^2] (YIELDVEGETABLES)

λ_w = Weathering decay constant = ln(2)/$T_{½w}$ [1/day] (–)

$T_{½w}$ = Weathering half-life [day] (WEATHERING)

n = Irrigation events [1] (IRREVENTS)

and

$$t_i = i\frac{P}{n}, \quad i = 1, 2, \ldots, n \qquad (15)$$

If irrigation is not included in the model, the concentration of radionuclides in irrigation water can be set to zero to cancel the irrigation dependent part of the equations above regarding crops.

In the Tensit implementation of exposure from vegetables, the sampled value for irrigation events, parameter *n*, has been rounded off to the nearest integer value. For cereals and rootcrops, the sampled decimal value has been used directly without rounding.

6.4 Aquatic food

Food from the aquatic system, /Bergstöm et al, 1999/, is another ingestion exposure pathway to man. It is divided into three groups, fish, crustacean and algae. Each group is represented by its own block. The annual activity exposure from group *j* in these blocks can be written

$$AE_i = C \cdot BIO_j \cdot CR_j \cdot cv_1 \tag{16}$$

where

AE_j = Total annual activity exposure from respective group [Bq/year] (*outport*)
C = Concentration in water [Bq/m^3] (*inport*)
BIO_j = Bio accumulation factor [(Bq/kg)/(Bq/litre)] (BAF)
CR_j = Humans consumption of respective group [kg/year] (CONSUMPTION)
Cv_1 = Conversion factor (0.001) [m^3/litre] (–)

6.5 Milk and meat

Mans annual activity exposure from consuming milk and meat from cattle is accounted for in block *cattle*. The annual activity exposure, /Bergstöm et al, 1999/, from this block can be written

$$AE = CI\,(CR_{milk} \cdot F_{milk} + CR_{meat} \cdot F_{meat}) \tag{17}$$

where

AE = Total annual activity exposure from milk and meat [Bq/year] (*outport*)
CI = Cow's daily activity exposure [Bq/day] (*inport*)
F_{milk} = Transfer factor for milk[(Bq/litre)/(Bq/day)] (FMILK)
CR_{milk} = Humans consumption rate of milk [litre/year] (MILKCONSUMPTION)
F_{meat} = Transfer factor for meat [(Bq/kg)/(Bq/day)] (FMEAT)
CR_{meat} = Humans consumption rate of meat [kg/year] (MEATCONSUMPTION)

The daily radioactive activity intake for cattle is calculated in block *Cattle metabolism*. The output from this block, /Bergstöm et al, 1999/, can be written

$$\begin{aligned}
CI &= CI_{soil} + CI_{water} + CI_{cereals} + CI_{pasturage} + CI_{waterpalnts} \\
CI_{soil} &= CC_s \cdot C_s \\
CI_{water} &= CC_w \cdot C_w \cdot cv_1 \\
CI_{cereals} &= CC_c\,(C_s \cdot RUF_c + n \cdot W_i \cdot TL \cdot C_w) \\
CI_{pasturage} &= CC_p\,(1 - ND/365)\,\left(C_s \cdot RUF_p + \frac{C_w \cdot W}{Y_p \cdot P}\frac{1}{\lambda_w}\left(n - \sum_{i=1}^{n} e^{-\lambda_w t_i}\right)\right)
\end{aligned} \tag{18}$$

$$CI_{waterpalnts} = CC_p \cdot C_w \cdot cv_1\ (ND/365)\ cv_2 \cdot TR \cdot GD/Y_{wp}$$

where

CI = Cow’s daily activity exposure [Bq/day] (*outport*)
C_w = Concentration of radionuclides in water [Bq/m^3] (*inport*)
C_s = Concentration of radionuclides in soil (or solid peat) [Bq/kg] (*inport*)
CC_c = Cattle’s consumption of cereals [kg/day] (CEREALSCONSUMPTION)
RUF_c = Soil to cereals root uptake factor [(Bq/kg)/(Bq/kg)] (CEREALSRUF)
TL = Translocation factor [m^2/kg] (TRANSLOCATION)
CC_s = Cattle’s consumption of soil [kg/day] (SOILCONSUMPTION)
CC_p = Consumption of pasturage [kg/day] (PASTURAGECONSUMPTION)
RUF_p = Soil to pasturage root uptake factor [1] (PASTURAGERUF)
ND = Number of days per year cattle graze on shores [1] (GRAZINGTIME)
cv_1 = Conversion factor (0.001) [m^3/litre] (–)
MC_w = Consumption of water [l/day] (WATERCONSUMPTION)
TR = Transpiration [g/(m^2·h)] (TRANSPIRATION)
GD = Mean plant transpiration before consumption [day] (GD)
cv_2 = Conversion factor (0.024) [(litre·h)/(g·day)] (–)
Y_{wp} = Yield of water plants [kg/m^2] (YIELDWATERPLANTS)
W = Remaining water on plant after irrigation [m] (REMAININGWATER)
P = Irrigation period [day] (IRRPERIOD)
Y_p = Yield of pasturage [kg/m^2] (YIELDVEGETABLES)
λ_w = Weathering decay constant = ln(2)/$T_{\frac{1}{2}w}$ [1/day] (–)
$T_{\frac{1}{2}w}$ = Weathering half-life [day] (WEATHERING)
n = Irrigation events [1] (IRREVENTS)

In the Tensit implementation of cattle’s exposure from pasturage, the sampled value for irrigation events, parameter *n*, has been rounded off to the nearest integer value. For cereals, the sampled decimal value has been used directly without rounding.

6.6 External exposure

Mans exposure from ground contaminated with radioactive material is calculated in block *External exposure*. The activity exposure, /Bergstöm et al, 1999/, can be written

$$AE = C \cdot \rho \cdot T_{external} \tag{19}$$

where

AE = Activity exposure [(Bq·h)/(m^3·year)] (*outport*)
C = Concentration in exposure source [Bq/kg] (*inport*)
ρ = Density of ground exposing human. [kg/m^3] (DENSITY)

$T_{external}$ = Exposure [h/year] (EXPOSURETIME)

Note: When using soil particle density (ρ_p) an input, the resulting ground density (ρ) should be calculated as $\rho = \rho_p (1 - \varepsilon)$, where ε is the (top) soil porosity.

6.7 Inhalation

Mans annual exposure to radioactive material trough inhalation of dust in air is calculated in block *Inhalation dust*. The activity exposure, /Bergstöm et al, 1999/, can be written.

$$AE = C \cdot S \cdot IR \cdot T_{dust} \tag{20}$$

where

AE = Activity exposure [Bq/year)] (*outport*)

C = Activity concentration in dust [Bq/kg] (*inport*)

S = Dust content in air [kg/m^3] (DUSTCONTENTINAIR)

IR = Inhalation rate [m^3/h] (INHALATIONRATE)

T_{dust} = Exposure time [h/year] (EXPOSURETIME)

Mans exposure trough inhalation of radioactivity stemming from combustion of contaminated material is calculated in block *Inhalation combustion*. The activity exposure, /Bergstöm et al, 1999/, can be written

$$AE = C \cdot IR \cdot FC \cdot RD \cdot FP \cdot T_{combustion} \tag{21}$$

where

AE = Activity exposure [Bq/year)] (*outport*)

C = Activity concentration in combusted material [Bq/kg] (*inport*)

IR = Inhalation rate [m^3/h] (INHALATIONRATE)

FC = Fuel consumption [kg/s] (FUELCONSUMPTION)

RD = Mean annual relative dispersion [s/m^3] (DISPERSION)

FP = Fraction of radioactivity passing through filter [1] (FILTERPASS)

$T_{combustion}$ = Exposure time [h/year] (EXPOSURETIME)

6.8 Dose modules

In SR 97 each module has its own contamination pathways, /Bergstöm et al, 1999/. An explanation of these follows for each module. Some of the normally abbreviated indexes have at some occasions been fully extended to simplify reading.

Running water

Irrigation is used for an agricultural (large area) type of soil in the running water model. Cattle are grazing at shores a fraction of the year. The concentration of radionuclides in water is taken directly from the stream compartment and the concentration in soil is taken from the top soil compartment. The bioaccumulation factor used for fish regards fresh water.

Human contamination pathways

- Consumption of irrigated crops: cereals, root crops and vegetables
- Consumption of food from cattle: milk and meat
- Consumption of aquatic food: fish and crustacean
- Consumption of water
- Inhalation of dust
- External exposure from ground

Contamination pathways for cattle

- Consumption of irrigated crops: cereals
- Consumption of irrigated pasturage only when *not* grazing at shores
- Consumption of water plants only when grazing at shores
- Consumption of water and soil

The expression for dose to man then becomes

$$\begin{gathered}
Dose = DC_{ingestion}\,[CR_{cereals}\,(C_{soil}\cdot RUF_{cereals} + n\cdot W\cdot TL\cdot C_{water}) + CR_{rootcrops} \\
(C_{soil}\cdot RUF_{rootcrops} + n\cdot W\cdot TL\cdot C_{water}) + CR_{vegetables}\,(C_{soil}\cdot RUF_{vegetables} + \\
\frac{C_{water}\cdot W}{Y_{vegetables}\cdot P}\frac{1}{\lambda_w}(n-\sum_{i=1}^{n}e^{-\lambda_w t_i})) + (CR_{milk}\cdot F_{milk} + CR_{meat}\cdot F_{meat})(C_{soil}\cdot CC_{soil} + \\
C_{soil}\cdot CC_{cereals}\cdot RUF_{cereals} + C_{soil}\cdot CC_{pasturage}\cdot RUF_{pasturage}\,(1-ND/365) + C_{water} \\
\cdot CC_{water}\cdot cv_1 + C_{water}\cdot CC_{cereals}\cdot n\cdot W\cdot TL + C_{water}\cdot CC_{pasturage}\,(1-ND/365) \\
\frac{W}{Y_{pasturage}\cdot P}\frac{1}{\lambda_w}(n-\sum_{i=1}^{n}e^{-\lambda_w t_i}) + C_{water}\cdot CC_{pasturage}\cdot cv_1\,(ND/365)\,cv_2\cdot TR\cdot GD/ \\
Y_{waterplants}) + C_{water}\cdot CR_{fish}\cdot BIO_{fish}\cdot cv_1 + C_{water}\cdot CR_{crustacea}\cdot BIO_{crustacea}\cdot cv_1 + \\
C_{water}\cdot CR_{water}\cdot cv_1] + DC_{inhalation}\cdot C_{soil}\cdot IR\cdot S\cdot T_{dust} + DC_{external}\cdot C_{soil}\cdot \rho\cdot \\
T_{external}
\end{gathered} \tag{22}$$

Well

Irrigation with well water is used for a garden plot (small area) type of soil. The concentration of radionuclides in water is taken directly from the well compartment and the concentration in soil is taken from the top soil compartment. Cattle are only contaminated with radionuclides through drinking water, since they are not eating anything grown in the garden plot. Cattle are not grazing at shores.

Human contamination pathways

- Consumption of irrigated crops: root crops and vegetables
- Consumption of food from cattle: milk and meat
- Consumption of water and soil
- Inhalation of dust
- External exposure from ground

Contamination pathway for cattle

- Consumption of water

The equation for dose to man then becomes

$$\begin{aligned} dose = {} & DC_{ingestion}\,[CR_{rootcrops}\ (C_{soil}\cdot RUF_{rootcrops} + n\cdot W\cdot TL\cdot C_{water}) + \\ & CR_{vegetables}\ (C_{soil}\cdot RUF_{vegetables} + \frac{C_{water}\cdot W}{Y_{vegetables}\cdot P}\frac{1}{\lambda_w}(n-\sum_{i=1}^{n} e^{-\lambda_w t_i})) + (CR_{milk}\cdot F_{milk} \\ & + CR_{meat}\cdot F_{meat})\,(C_{water}\cdot CC_{water}\cdot cv_1) + C_{water}\cdot CR_{water}\cdot cv_1 + C_{soil}\cdot CR_{soil}] \\ & + DC_{inhalation}\cdot C_{soil}\cdot IR\cdot S\cdot T_{dust} + DC_{external}\cdot C_{soil}\cdot \rho\cdot T_{external} \end{aligned} \tag{23}$$

Lake

The lake module in connected with the irrigation sub-module. In this case it represents an agricultural type of soil which is irrigated with lake water. Cattle are grazing at shores a fraction of the year. The concentration of radionuclides in water is taken directly from the water compartment and the concentration in soil is taken from the top soil compartment of the irrigation sub-module. The bioaccumulation factor used for fish regards fresh water.

Human contamination pathways

- Consumption of irrigated crops: cereals, root crops and vegetables
- Consumption of food from cattle: milk and meat
- Consumption of aquatic food: fish and crustacean
- Consumption of water and soil
- Inhalation of dust
- External exposure from ground

Contamination pathways for cattle

- Consumption of irrigated crops: cereals
- Consumption of irrigated pasturage only when *not* grazing at shores
- Consumption of water plants only when grazing at shores
- Consumption of water and soil

The expression for dose to man then becomes

$$
\begin{aligned}
&Dose = DC_{ingestion}\,[CR_{cereals}\,(C_{soil}\cdot RUF_{cereals} + n\cdot W\cdot TL\cdot C_{water}) + CR_{rootcrops} \\
&(C_{soil}\cdot RUF_{rootcrops} + n\cdot W\cdot TL\cdot C_{water}) + CR_{vegetables}\,(C_{soil}\cdot RUF_{vegetables} + \\
&\frac{C_{water}\cdot W}{Y_{vegetables}\cdot P}\frac{1}{\lambda_w}(n-\sum_{i=1}^{n} e^{-\lambda_w t_i})) + (CR_{milk}\cdot F_{milk} + CR_{meat}\cdot F_{meat})\,(C_{soil}\cdot CC_{soil} + \\
&C_{soil}\cdot CC_{cereals}\cdot RUF_{cereals} + C_{soil}\cdot CC_{pasturage}\cdot RUF_{pasturage}\,(1-ND/365) + C_{water} \\
&\cdot CC_{water}\cdot cv_1 + C_{water}\cdot CC_{cereals}\cdot n\cdot W\cdot TL + C_{water}\cdot CC_{pasturage}\,(1-ND/365) \\
&\frac{W}{Y_{pasturage}\cdot P}\frac{1}{\lambda_w}(n-\sum_{i=1}^{n} e^{-\lambda_w t_i}) + C_{water}\cdot CC_{pasturage}\cdot cv_1\,(ND/365)\,cv_2\cdot TR\cdot GD/ \\
&Y_{waterplants}) + C_{water}\cdot CR_{fish}\cdot BIO_{fish}\cdot cv_1 + C_{water}\cdot CR_{crustacea}\cdot BIO_{crustacea}\cdot cv_1 + \\
&C_{water}\cdot CR_{water}\cdot cv_1 + C_{soil}\cdot CR_{soil}] + DC_{inhalation}\cdot C_{soil}\cdot IR\cdot S\cdot T_{dust} + DC_{external} \\
&\cdot C_{soil}\cdot \rho\cdot T_{external}
\end{aligned}
\tag{24}
$$

Peat

No irrigation is used in the peat model. Cattle are not grazing at shores so that parameter *grazing time at shores* has been set to zero (ND=0).

Human contamination pathways

- Consumption of not irrigated crops: cereals, root crops and vegetables
- Consumption of food from cattle: milk and meat
- Inhalation of dust and combustion gases from burning of peat
- External exposure from ground

Contamination pathways for cattle

- Consumption of not irrigated crops: cereals
- Consumption of not irrigated pasturage
- Consumption of soil

Concentration in peat's solid compartment is used in substitution for concentration in soil to derive the expression for dose which then becomes

$$dose = C_{solid}\,[DC_{ingestion}\ (RUF_{cereals} \cdot CR_{cereals} + RUF_{rootcrops} \cdot CR_{rootcrops} + RUF_{vegetables} \cdot CR_{vegetables} + (CR_{milk} \cdot F_{milk} + CR_{meat} \cdot F_{meat})\,(CC_{soil} + CC_{cereals} \cdot RUF_{cereals} + CC_{pasturage} \cdot RUF_{pasturage})) + DC_{inhalation} \cdot IR\,(S \cdot T_{dust} + FC \cdot RD \cdot FP \cdot T_{combustion}) + DC_{external} \cdot \rho \cdot T_{external}] \qquad (25)$$

Agricultural land

No irrigation is used in this module. Cattle are not grazing at shore lines so no water plants are eaten.

Human contamination pathways

- Consumption of not irrigated crops: cereals, root crops and vegetables
- Consumption of food from cattle: milk and meat
- Consumption of soil
- Inhalation of dust
- External exposure from ground

Contamination pathways for cattle

- Consumption of not irrigated: pasturage and cereals
- Consumption of soil

$$dose = DC_{ingestion}\,[CR_{cereals} \cdot C_{soil} \cdot RUF_{cereals} + CR_{rootcrops} \cdot C_{soil} \cdot RUF_{rootcrops} + CR_{vegetables} \cdot C_{soil} \cdot RUF_{vegetables} + (CR_{milk} \cdot F_{milk} + CR_{meat} \cdot F_{meat})\,(C_{soil} \cdot CC_{soil} + C_{soil} \cdot CC_{cereals} \cdot RUF_{cereals} + C_{soil} \cdot CC_{pasturage} \cdot RUF_{pasturage}) + C_{soil} \cdot CR_{soil}] + DC_{inhalation} \cdot C_{soil} \cdot IR \cdot S \cdot T_{dust} + DC_{external} \cdot C_{soil} \cdot \rho \cdot T_{external} \qquad (26)$$

Coast

The coast module is not using irrigation. Cattle are grazing at shores in the bay a fraction of the year where they drink bay water eat water plants. Observe that algae are collected from the sea whereas fish is caught in the bay. Thus these pathways are affected by different concentrations.

Human contamination pathways

- Consumption of food from cattle: milk and meat
- Consumption of fish living in bay water
- Consumption of algae grown in sea water

Contamination pathways for cattle

- Consumption of bay water
- Consumption of water plants in bay, only when grazing at shores

The expression for the resulting dose to human then becomes

$$dose = DC_{ingestion}\,[C_{baywater} \cdot CR_{fish} \cdot BIO_{fish} \cdot cv_1 + C_{seawater} \cdot CR_{algae} \cdot BIO_{algae} \cdot cv_1 + (CR_{milk} \cdot F_{milk} + CR_{meat} \cdot F_{meat})\,(C_{baywater} \cdot cv_1 \cdot CC_{water} + C_{baywater} \cdot CC_{pasturage} \cdot cv_1\,(ND/365)\,cv_2 \cdot TR \cdot GD / Y_{waterplants})] \qquad (27)$$

7 Probabilistic results

The probabilistic simulations estimate the yearly dose to human. The results were obtained by running each module together with its corresponding dose calculation block with the @Risk software for 10 000 iterations. More detailed data on the results are listed in Appendix G. The difference in the results compared with those reported in /Bergström et al, 1999/ is plotted as (%) deviation from the latter mentioned results. The min and max values of Tensit's results corresponds to the 0.5% and 99.5% percentiles. The reference results are known through one of the authors to be obtained by 200 iterations whereas the Tensit has been run 10 000 iterations for increased accuracy.

An approximate confidence interval for the differences between two results like in the present situation is derived from /Blom, 1989/. Assuming $x_1, \ldots, x_{n1}$ and $y_1,\ldots,y_{n2}$ to be random samples of two unknown distributions with expected values m_1 likewise m_2 and furthermore standard deviations σ_1 likewise σ_2. To approximate these parameters as of normal distribution are fair according to /Blom, 1989/ given a relative high number of samples. In this situation we have n_1 = 200 and n_2 = 10 000, which should be enough given the basic guide line of at least 20 samples for this approximation. This gives, also due to the high number of samples, similar results as a confidence interval for passing a t-test. An approximate confidence interval for the spread between sampled means $\bar{x} - \bar{y}$ under the assumption that $m_1 – m_2 = 0$ is then

$$I_{\bar{x}-\bar{y}} = (0 - \lambda_{\alpha/2} d, 0 + \lambda_{\alpha/2} d) \tag{28}$$

where

$$d = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \tag{29}$$

A 95% confidence interval, giving $\lambda_{\alpha/2} = 1.96$, of this sort has been calculated and expressed as the maximal difference Tensit results should diverge from the reference results. This interval has been plotted as vertical bars for each nuclide in the coming result figures. The confidence interval can also be used as a test at a 95% significance level if the hypothesis that the two distributions match each other may be discarded or not. The hypothesis is rejected if a nuclide falls outside its calculated confidence interval. Given that there are 44 nuclides and that the confidence interval is of 95%, two nuclides (per module) are statistically expected to fail the test by pure chance.

7.1 Running water

The running water module, Figure 7-1, shows the deviation between the simulation in Tensit and the reported results in /Bergström et al, 1999/. From the figure it can be seen that 6 nuclides, not counting H-3, lies outside of the 95% confidence interval. Nuclide H-3 is not counted since its K_d values are unclear and have been set to zero in the simulation.

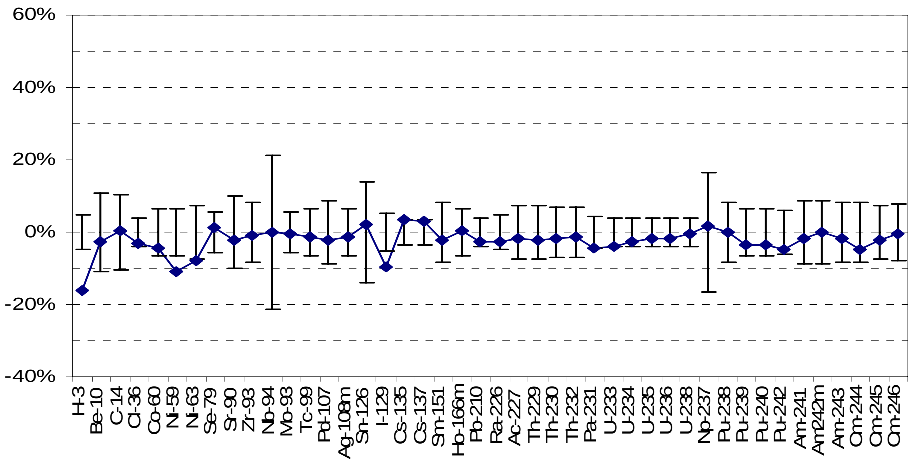


Figure 7-1. *Difference in percent for the Tensit results comapared to the reference for the probabilistic simulation of the Peat bog module. A 95% confidence interval is plotted with bars. Results generally show good agreement.*

The results comparing minimum, maximum and standard deviation shows generally good agreement between the results except for the two obvious peaks in standard deviation for Cs-135 and Cs-137 seen in Figure 7-2.

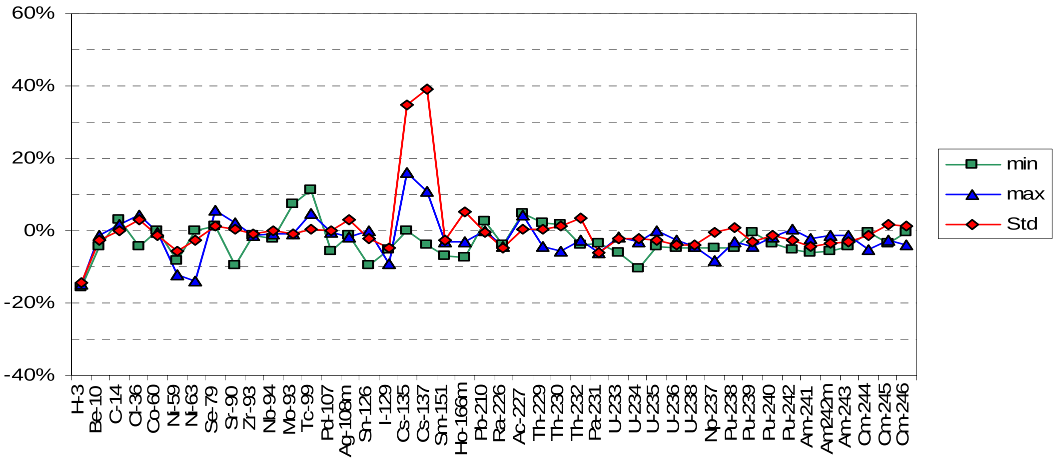


Figure 7-2. *Difference in min, max and standard deviation in the well module.*

7.2 Well

The results from the well module at first showed an apparent systematic deviation from the reference and the cause was investigated. It was found after consultation with one of the authors that there were differences between documentation and implementation as listed in listed in Table 7-1.

Table 7-1. Updates to the well module. These updates were only used in the well simulation.

Reference in /Bergström et al, 1999/	Update
Transfer constant from deep soil to well (representing TC_{13}), page 25 (to 26).	Reported (using the notation of this report) $TC_{13} = \frac{R}{\varepsilon_{ds} \cdot h_{ds}} Ret$ used $TC_{13} = \frac{R \cdot h_{ds}}{\varepsilon_{ds}} Ret$
Transfer constant from deep soil to top soil (representing TC_{23}), page 25 (to 26).	Reported (using the notation of this report) $TC_{23} = \frac{BioT}{h_{ds}(1-\varepsilon_{ds})\rho_p}$ used (changed index of ε) $TC_{23} = \frac{BioT}{h_{ds}(1-\varepsilon_{ts})\rho_p}$
Concentarion in surface water, page 144.	Reported (using the notation of this report) $AE = CR_v(C_s \cdot RUF_v + \frac{C_w \cdot W}{Y_v \cdot P}\sum_{i=1}^{n}\int_0^{t_i} e^{-\lambda_w t} dt)$ used (includes a factor 2) $AE = CR_v(C_s \cdot RUF_v + 2\frac{C_w \cdot W}{Y_v \cdot P}\sum_{i=1}^{n}\int_0^{t_i} e^{-\lambda_w t} dt)$
Topsoil porosity	Documented T (0.3, 0.4, 0.5) distribution, used T (0.3, 0.4, 0.6)
BAF invertebrates for Mo-93, Table A-14	Documented T (1, 10, 100) distribution, used LT (1, 10, 100).
RUF rootcrops Mo-93, Table A-3	Documented LT (0.02, 0.2, 2) distribution, used LT (0.016, 0.16, 1.6)
Ingestion dose conversion factor for Sr-90, Table 2-1	Documented 2.8E-8, used 3.6E-8
Ingestion dose conversion factor for Zr-93, Table 2-1	Documented 1.1E-9, used 4.2E-10
Inhalation dose conversion factor for Sr-90, Table 2-1	Documented 3.6E-8, used 1.5E-7
Inhalation dose conversion factor for Zr-93, Table 2-1	Documented 1.0E-8, used 2.9E-8
Inhalation dose conversion factor for U-233, Table 2-1	Documented 3.6E-6, used 9.6E-6
Inhalation dose conversion factor for U-234,	Documented 3.5E-6, used E-9.4E-6

Table 2-1	
Inhalation dose conversion factor for U-235, Table 2-1	Documented 3.1E-6, used 8.5E-6
Inhalation dose conversion factor for U-236, Table 2-1	Documented 3.2E-6, used 8.7E-6
Inhalation dose conversion factor for U-238, Table 2-1	Documented 2.9E-6, used 8.0E-6
Irrigationevents	In the calculation of dose from vegetables, the sampled value of irrigation events has been transformed into an integer by truncating all decimals. In the other modules Tensit has been implemented using rounding to the nearest integer.

The well module was simulated again with the new updates and the result can be seen below in Figure 7-3. The results are improved and much better centred around zero. From the figure it can be seen that 16 nuclides, not counting H-3, lies outside of the 95% confidence interval. This is more than the approximately two outliers that would be statistically expected. Nuclide H-3 for which K_d values are unclear and have been set to zero is of this reason not counted. The deviation in results and especially the peaks for Sr-90, Zr-93 and Mo-93 are assumed to be associated with the unclarity surrounding the reported dose conversion factors for the well.

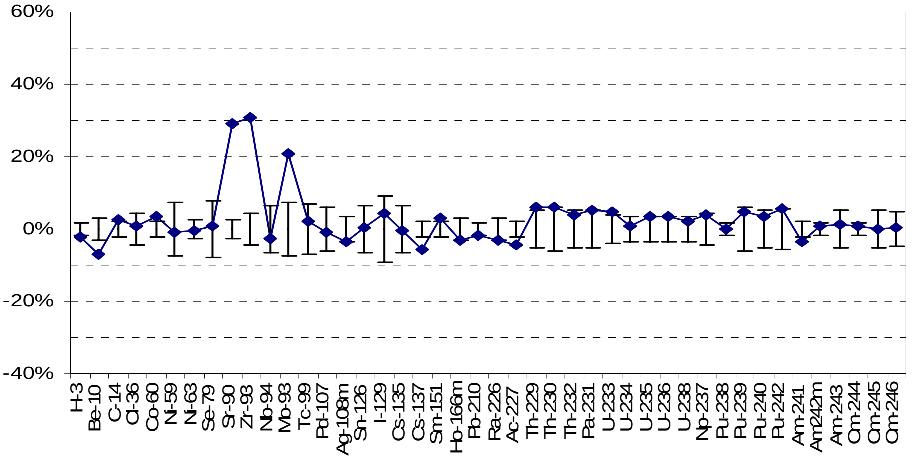


Figure 7-3. *Difference in percent for the Tensit results compared to the reference for the probabilistic simulation of the well module. A 95% confidence interval is plotted with bars. Results show important disagreements.*

The results comparing minimum, maximum and standard deviation shows deviation peaks for Sr-90, Zr-93 and Mo-93 between the results as seen in Figure 7-4.

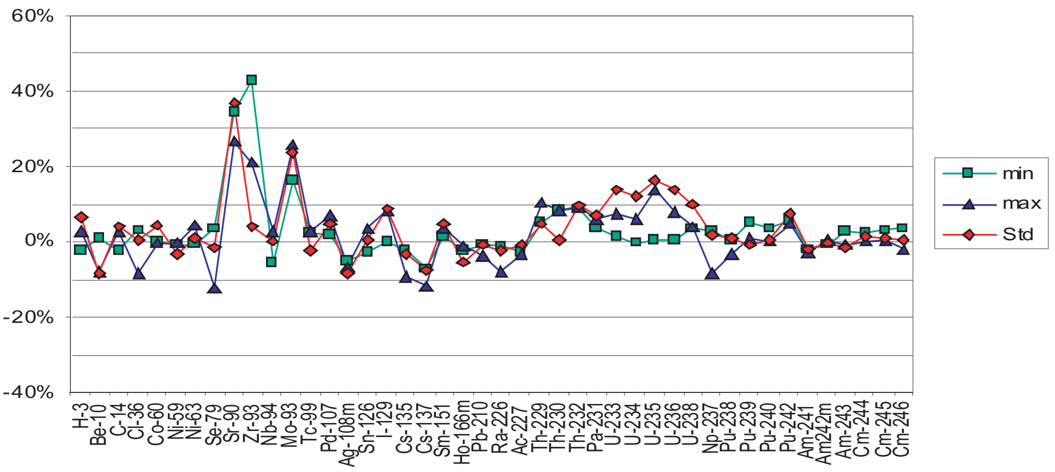


Figure 7-4. *Difference in min, max and standard deviation in the peat bog module.*

7.3 Lake

The results from the lake compared with the reference is shown below in Figure 7-5. The figure shows that 5 nuclides, not counting H-3, lies outside of the 95% confidence interval. Nuclide H-3 is for which K_d values are unclear and have been set to zero is therefore not counted.

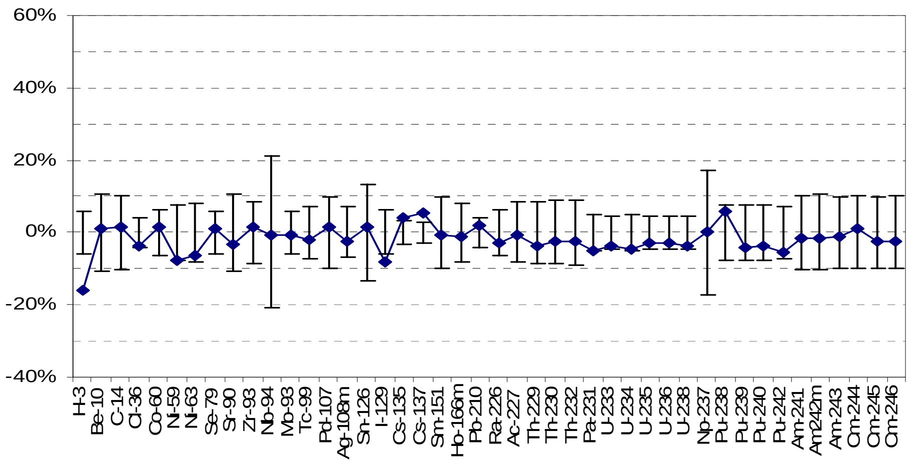


Figure 7-5. *Difference in percent for the Tensit results compared to the reference for the probabilistic simulation of the lake module. A 95% confidence interval is plotted with bars. Results generally show good agreement.*

The results comparing minimum, maximum and standard deviation shows deviation between the results with peaks for Co-60 and Cs-137 as seen in Figure 7-6.

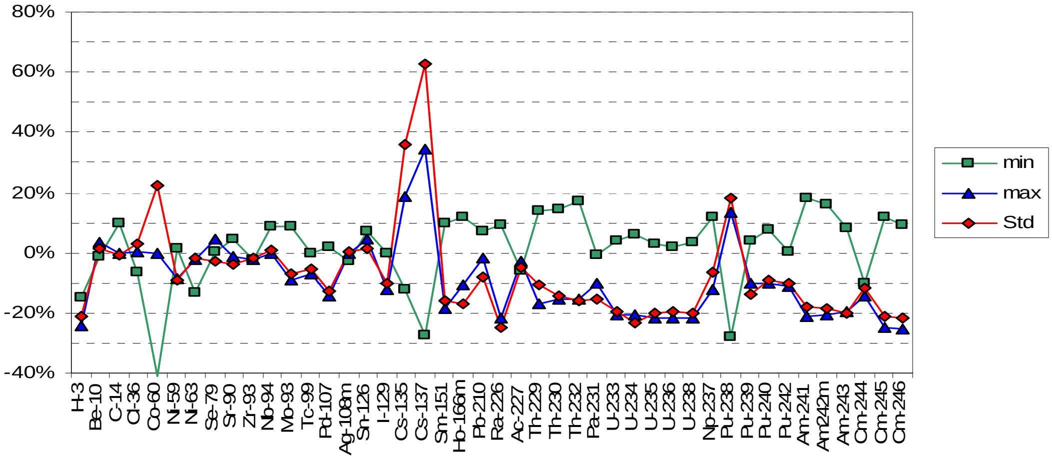


Figure 7-6. *Difference in min, max and standard deviation in the lake module.*

7.4 Peat bog

The peat bog shows generally good agreement between the simulation in Tensit and the reported results in /Bergström et al, 1999/ as seen below in Figure 7-7. Nuclide H-3 for which K_d values are unclear have been excluded. The figure shows that no nuclides lie outside of the 95% confidence interval.

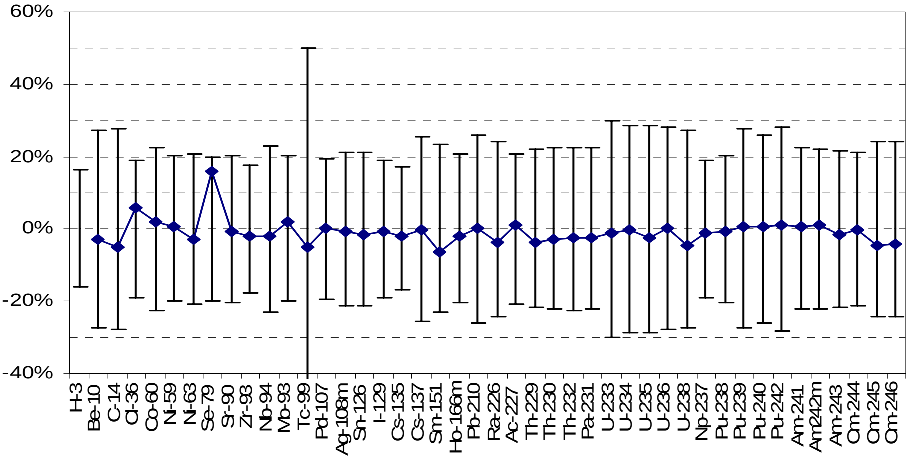


Figure 7-7. *Difference in percent for the Tensit results compared to the reference for the probabilistic simulation of the Peat bog module. A 95% confidence interval is plotted with bars. Results generally show good agreement.*

The results comparing minimum, maximum and standard deviation shows deviation between the results as seen in Figure 7-8.

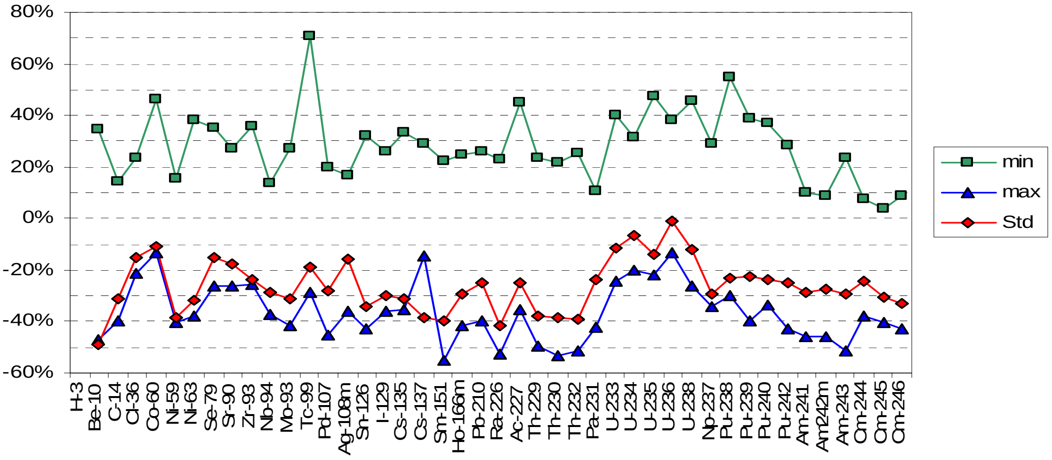


Figure 7-8. *Difference in min, max and standard deviation in the peat bog module.*

7.5 Agricultural land

The agricultural using inflow of nuclides connected to the saturated soluble compartment shows the most divergent results of all the modules as seen in Figure 7-9. The figure shows that no nuclides lie outside of the 95% confidence interval.

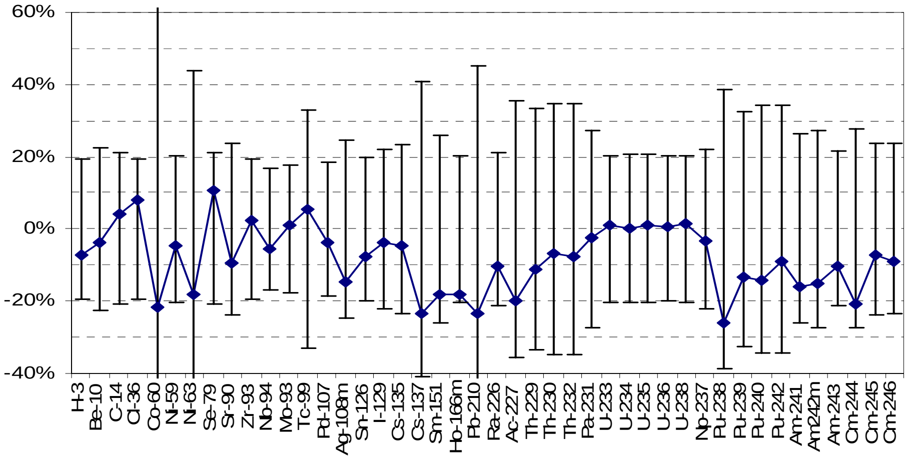


Figure 7-9. *Difference in percent for the Tensit results compared to the reference for the probabilistic simulation of the agricultural land module. A 95% confidence interval is plotted with bars.*

The results comparing minimum, maximum and standard deviation shows deviation between the results as seen in Figure 7-10.

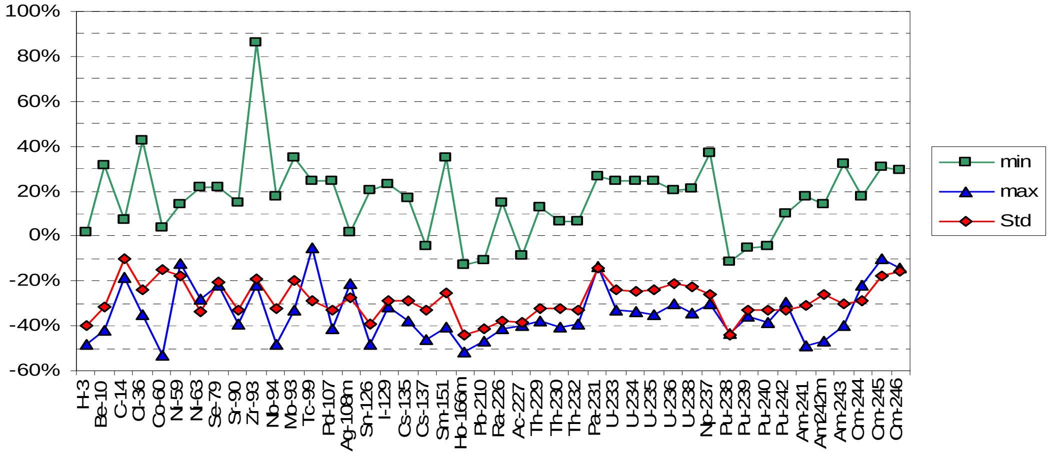


Figure 7-10. *Difference in min, max and standard deviation between Tensit and reference in the agricultural land module.*

7.6 Coast

The coast module was simulated with inflow of nuclides to the baywater reservoir. The results generally shows very good agreement with the reference as seen in Figure 7-11. The figure shows that only one nuclide, C-14, lies outside of the 95% confidence interval.

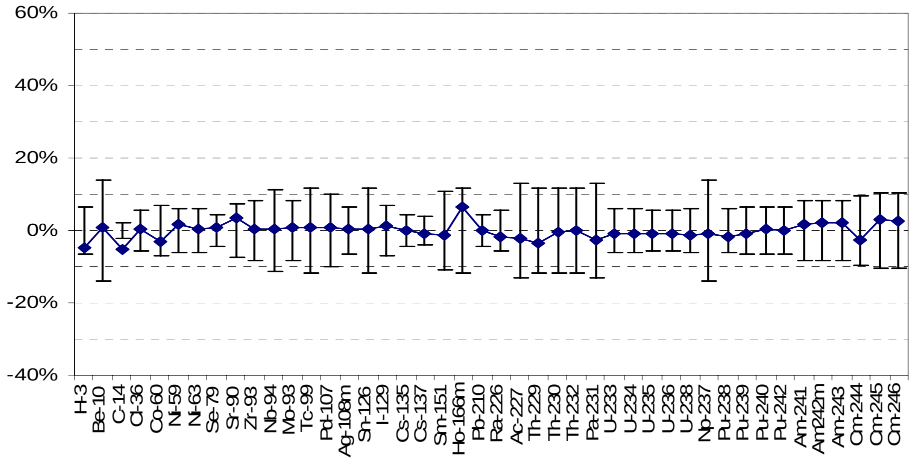


Figure 7-11. *Difference in percent for the Tensit results compared to the reference for the probabilistic simulation of the coast module. A 95% confidence interval is plotted with bars. Results generally show good agreement.*

The results comparing minimum, maximum and standard deviation shows generally good agreement with some exceptions for the min value as seen in Figure 7-12.

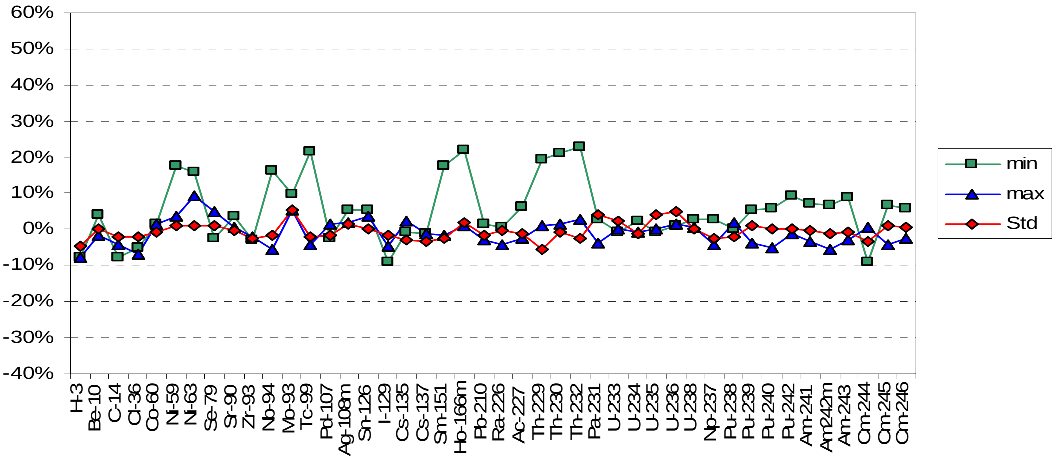


Figure 7-12. *Difference in min, max and standard deviation in the coast module.*

8 Additional verifications

This section starts with three smaller deterministic cases testing the integrator block for its basic functionality and with chain decay. There after follows a more comprehensive probabilistic case, Level 1B from PSACOIN. All simulations have used the same general solver settings in Simulink as listed in Table 12-1.

8.1 Verification of the fundamental Reservoir block

Three test cases were setup and tested from the Amber 4.5 Verification summary by /Robinson et al, 2003/ which was used as reference for the comparisons in this subsection. The introduced definitions of each respective case are repeated in this text.

These tests are intended to indicate the precision in results when using Tensit's *Reservoir* block with a given error tolerance.

8.1.1 SN 2

Using the same nomenclature as in /Robinson et al, 2003/, we have a system schematically described as in Figure 8-1.

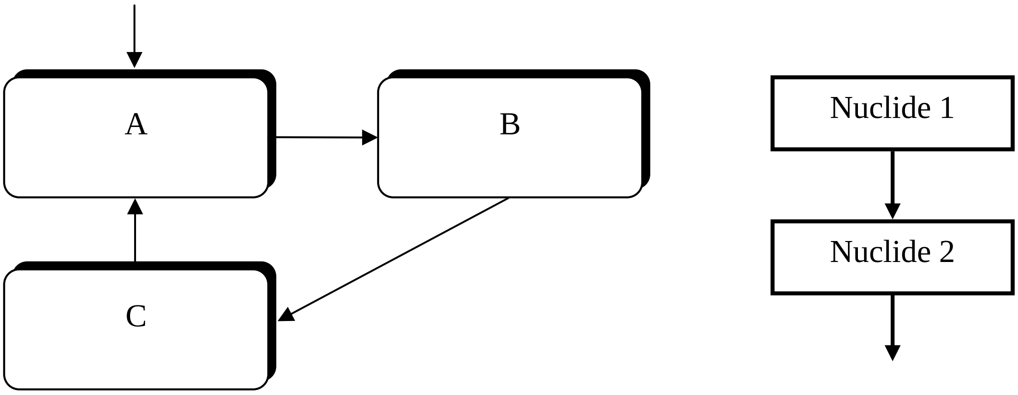


Figure 8-1. *Visualisation of the SN 2 test case.*

Model definition:
Nuclide 1 decays at a rate of $1{\cdot}10^{-4}$ per year and Nuclide 2 at a rate of $1{\cdot}10^{-2}$ per year. The source to A is for Nuclide 1 only. It is zero except for two time intervals: from 0 to 10 years it is 1 mol/year, and from 30 to 50 years it is 2 mol/year. The initial transfer rates are given in Table 8-1. After 40 years they all fall by a factor of 100.

Table 8-1. Initial transfer rates for SN2.

Transfer		Initial Transfer Rate (per year)	
From	**To**	**Nuclide 1**	**Nuclide 2**
A	B	0.01	0.001
B	C	0.001	0.1
C	A	0.1	0.1

Results are compared after 10 and 100 years and as listed in Table 8-2. As can be seen in the table, the results are identical.

Table 8-2. Comparing Tensit results with AMBER. No differences were found.

Compartment	Nuclide	Time (years)	AMBER with Laplace Solver	Tensit
A	Nuclide 1	10	9.51191	9.51191
A	Nuclide 2	10	0.00466821	0.00466821
B	Nuclide 1	10	0.481807	0.481807
B	Nuclide 2	10	0.000137849	0.000137849
C	Nuclide 1	10	0.00128305	0.00128305
C	Nuclide 2	10	2.97307E–5	2.97307E–5
A	Nuclide 1	100	45.5501	45.5501
A	Nuclide 2	100	0.220230	0.220230
B	Nuclide 1	100	4.09113	4.09113
B	Nuclide 2	100	0.0188336	0.0188336
C	Nuclide 1	100	0.0249555	0.0249555
C	Nuclide 2	100	0.00142203	0.00142203

8.1.2 SN 5

Using the same nomenclature as in /Robinson et al, 2003/, we have a system schematically described as in Figure 8-2.

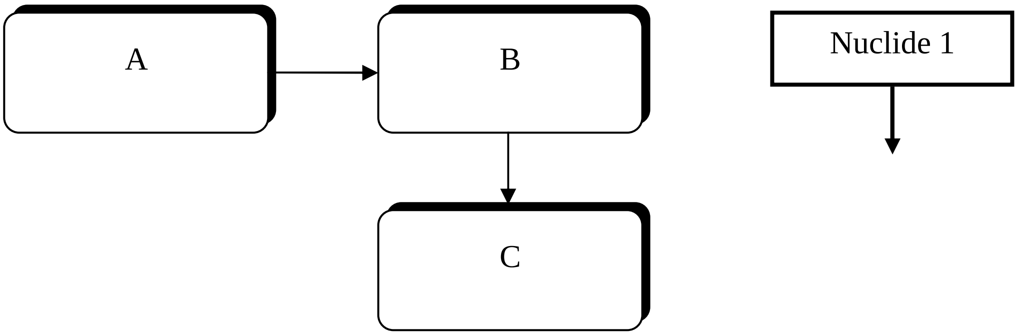


Figure 8-2. *Visualisation of the SN 5 test case.*

Definition:

Nuclide 1 decays at a rate of 0.01 per year in compartment A only. The transfers are both non-depleting and have a rate of 1 per year. Thus, B calculates the integral of A, and C calculates the integral of B. Initially, there is a unit mass in A.

An analytical solution is given by

$$\begin{aligned} A &= e^{-\lambda t} \\ B &= \frac{1-e^{-\lambda t}}{\lambda} \\ C &= \frac{1}{\lambda} - \frac{1-e^{-\lambda t}}{\lambda^2} \end{aligned} \tag{30}$$

where λ is the decay constant.

Results from Tensit are compared with the analytical solution in Table 8-3.

Table 8-3. Comparing Tensit with an analytical solution. Differing digits are written in bold font.

Time	Compartment	Analytical solution	Tensit
0.01	A	0.999900	0.999900
0.01	B	0.0099995	0.0099995
0.01	C	4.99983E–5	**5.00005**E–5
10	A	0.904837	0.904837
10	B	9.51626	9.51626
10	C	48.3742	48.3742
100	A	0.367879	0.367879
100	B	63.2121	63.2121
100	C	3678.79	3678.79
1000	A	4.53999E–5	4.5**4012E–5**
1000	B	99.9955	99.9955
1000	C	90000.5	9000.5

The tableshows there are only differences in two occasions. These deviations are however comparably small with a largest relative error of $4.4 \cdot 10^{-5}$ and a largest absolute error of $2.2 \cdot 10^{-5}$.

8.1.3 SN 7

Using the same nomenclature as in /Robinson et al, 2003/, we have a system schematically described as in Table 8-3.

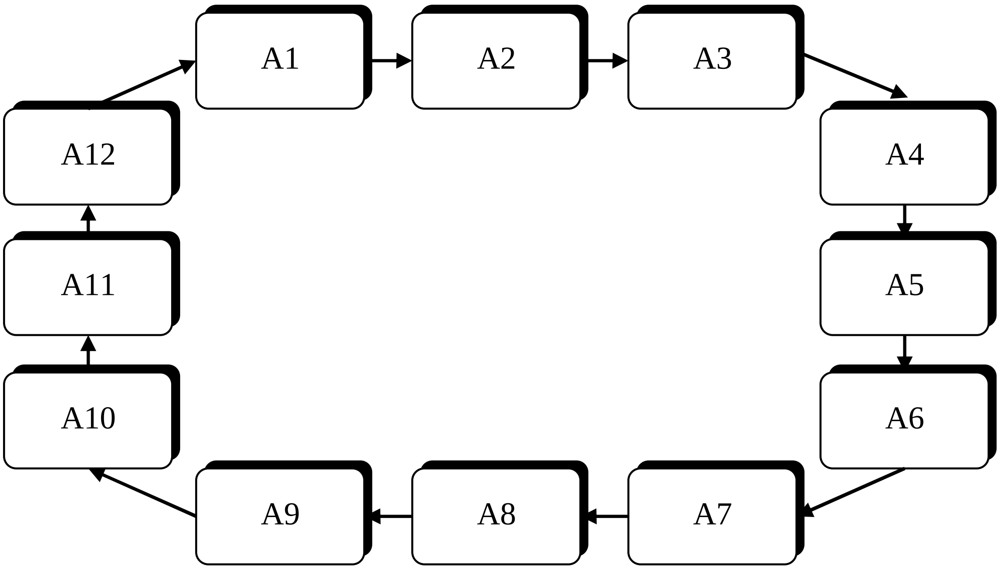


Figure 8-3. *Visualisation of the SN 7 test case.*

Model definition:

All the transfer rates are 0.1 per year and the initial amounts are: 1 mol in A1, A2, A4, A6, A7 and A10; zero elsewhere.

In Table 8-4 results are listed from an analytical solution presented in the reference.

Table 8-4. Analytical results for SN 7.

Compartment	Amounts [moles]				
	t=20	t=40	t=60	t=80	t=100
A1	0.331448	0.393231	0.493590	0.545518	0.541057
A2	0.500565	0.382391	0.450256	0.521544	0.542698
A3	0.578488	0.421262	0.422288	0.489768	0.532723
A4	0.598713	0.483640	0.421521	0.460279	0.513205
A5	0.544824	0.530970	0.445906	0.443184	0.489534
A6	0.533186	0.548898	0.481307	0.443560	0.468849
A7	0.634764	0.561520	0.514184	0.459365	0.457322
A8	0.647070	0.584441	0.540759	0.484075	0.457839
A9	0.491510	0.589493	0.561193	0.510966	0.469434
A10	0.419087	0.556907	0.570820	0.534847	0.488415
A11	0.400650	0.503189	0.562832	0.551199	0.509930
A12	0.319694	0.444059	0.535343	0.555695	0.528994

Results from Tensit are listed in Table 8-5. These match the analytical solution in Table 8-4 without any deviation.

Table 8-5. Tensit results for SN 7. These match the analytical solution perfectly.

Compartment	Amounts [moles]				
	t=20	t=40	t=60	t=80	t=100
A1	0.331448	0.393231	0.493590	0.545518	0.541057
A2	0.500565	0.382391	0.450256	0.521544	0.542698
A3	0.578488	0.421262	0.422288	0.489768	0.532723
A4	0.598713	0.483640	0.421521	0.460279	0.513205
A5	0.544824	0.530970	0.445906	0.443184	0.489534
A6	0.533186	0.548898	0.481307	0.443560	0.468849
A7	0.634764	0.561520	0.514184	0.459365	0.457322
A8	0.647070	0.584441	0.540759	0.484075	0.457839
A9	0.491510	0.589493	0.561193	0.510966	0.469434
A10	0.419087	0.556907	0.570820	0.534847	0.488415
A11	0.400650	0.503189	0.562832	0.551199	0.509930
A12	0.319694	0.444059	0.535343	0.555695	0.528994

8.2 PSACOIN Level 1B

The PSACOIN Level 1B exercise, /Klos et al, 1993/, is an international test case from 1993 where eight participating groups compared their results after having simulated a given dose model both deterministically and probabilistically. This model was implemented using Tensit for result comparison.

Three occurrences were found of what is believed, due to otherwise following inconsistency, to be printing errors in the documentation. The following changes were made. In Equation 16, tan was substituted with sin. In Equations 37 and 38 the denominators was changed to match the food type.

8.2.1 Deterministic results

The test included eight groups. Of these a group using a simulation tool named Mascot was selected for comparison. Since this software uses semi-analytical methods it should be one of the more accurate participants. The resulting inventories in the respective compartments after the deterministic simulation are listed in Table 8-6.

Table 8-6. Compartment inventory comparison between Tensit and Mascot in the deterministic case.

Time (year)	Tensit: activity (Bq)				Mascot: activity (Bq)			
	Water	Sediment	TopSoil	DeepSoil	Water	Sediment	TopSoil	DeepSoil
	Nuclide: ^{14}C							
1	4.6**7**E+03	1.20E+03	1.8**2**E+06	2.21E+08	4.66E+03	1.20E+03	1.81E+06	2.21E+08
1000	2.7**2**E+03	3.8**9**E+03	2.7**7**E+09	1.21E+11	2.70E+03	3.86E+03	2.76E+09	1.21E+11
100000	2.1**8**E-03	3.1**1**E-03	5.**03**E+03	2.**19**E+05	2.19E-03	3.13E-03	5.11E+03	2.24E+05
	Nuclide: ^{235}U							
1	3.4**2**E+00	8.**71**E-01	4.64E+02	1.63E+05	3.41E+00	8.68E-01	4.64E+02	1.63E+05
1000	9.**70**E+00	1.08E+01	4.88E+07	1.0**7**E+08	9.67E+00	1.08E+01	4.88E+07	1.06E+08
100000	7.5**6**E+00	8.4**6**E+00	5.66E+07	1.13E+08	7.55E+00	8.45E+00	5.66E+07	1.13E+08
	Nuclide: ^{231}Pa							
1	7.2**6**E-05	1.6**3**E-05	9.**81**E-03	3.45E+00	7.24E-05	1.62E-05	9.78E-03	3.45E+00
1000	2.32E-01	2.6**3**E-01	1.24E+06	**2.00E+06**	2.32E-01	2.62E-01	1.24E+06	**1.80E+06**
100000	6.5**8**E+00	7.4**8**E+00	4.93E+07	6.8**1**E+07	6.57E+00	7.46E+00	4.93E+07	6.82E+07
	Nuclide: ^{227}Ac							
1	1.14E-06	2.30E-07	1.5**9**E-04	5.4**4**E-02	1.14E-06	2.30E-07	1.54E-04	5.42E-02
1000	2.16E-01	2.08E-01	1.14E+06	2.00E+06	2.16E-01	2.08E-01	1.14E+06	2.00E+06
100000	6.1**9**E+00	**6.01**E+00	4.6**2**E+07	7.1**1**E+07	6.18E+00	5.99E+00	4.63E+07	7.12E+07

The results match each other well with the only significant exception being the activity of ^{231}Pa in the deep soil compartment after 1 000 years. Five of the eight participating groups, however, report the same value as obtained with Tensit, and thus this value is not rejected.

Doses from respective contamination pathway are compared in Table 8-7.

Table 8-7. Deterministic dose comparison. Entries marked '*' indicate either a zero value was returned or no value was submitted.

Code/ nuclide	Time [year]	Individual dose [Sv/year] by exposure pathway						
		water	fish	grain	meat	milk	dust	external
Tensit	1	5.**90**E–11	6.3**1**E–09	8.3**8**E–09	9.9**5**E–09	2.46E–09	2.4**5**E–14	0
^{14}C	1 000	3.4**3**E–11	3.66E–09	1.28E–05	1.48E–05	3.65E–06	3.73E–11	0
	100 000	2.77E–17	2.97E–15	2.37E–11	2.74E–11	6.75E–12	6.91E–17	0
Mascot	1	5.89E–11	6.30E–09	8.37E–09	9.94E–09	2.46E–09	2.44E–14	*
^{14}C	1 000	3.42E–11	3.66E–09	1.28E–05	1.48E–05	3.65E–06	3.73E–11	*
	100 000	*	2.97E–15	2.37E–11	2.74E–11	6.7**6**E–12	*	*
Tensit	1	5.1E–12	1.1E–12	1.5E–13	7.0E–12	4.5E–14	1.9E–14	**3.9**E–14
^{235}U	1 000	1.4E–11	3.1E–12	1.8E–09	1.6E–08	9.9E–11	2.0E–09	**4.1**E–09
	100 000	1.1E–11	2.4E–12	2.1E–09	1.8E–08	1.**2**E–10	2.3E–09	4.8E–09
Mascot	1	5.1E–12	1.1E–12	1.5E–13	7.0E–12	4.5E–14	1.9E–14	4.0E–14
^{235}U	1 000	1.4E–11	3.1E–12	1.8E–09	1.6E–08	9.9E–11	2.0E–09	4.2E–09
	100 000	1.1E–11	2.4E–12	2.1E–09	1.8E–08	1.1E–10	2.3E–09	4.8E–09
Tensit	1	4.5E–15	9.7E–16	4.4E–16	2.4E–16	5.8E–19	8.3E–17	3.9E–19
^{231}Pa	1 000	1.**5**E–11	3.1E–12	4.0E–08	3.2E–09	7.9E–12	1.**1**E–08	4.9E–11
	100 000	4.1E–10	8.8E–11	1.6E–06	1.3E–07	3.1E–10	4.2E–07	1.9E–09
Mascot	1	4.5E–15	*	*	*	*	*	*
^{231}Pa	1 000	1.4E–11	3.1E–12	4.0E–08	3.2–09	7.9E–12	1.0E–08	4.9E–11
	100 000	4.1E–10	8.8E–11	1.6E–06	1.3E–07	3.1E–10	4.2E–07	1.9E–09
Tensit	1	9.4E–17	6.0E–17	2.9E–18	9.5E–20	9.0E–22	6.9E–18	7.2E–20
^{227}Ac	1 000	1.8E–11	1.1E–11	1.3E–09	1.3E–11	1.2E–13	**5.0**E–08	5.**2**E–10
	100 000	5.1E–10	3.3E–10	5.2E–08	5.3E–10	5.0E–12	2.0E–06	2.1E–08
Mascot	1	*	*	*	*	*	*	*
^{227}Ac	1 000	1.8E–11	1.1E–11	1.3E–09	1.3E–11	1.2E–13	4.9E–08	5.1E–10
	100 000	5.1E–10	3.3E–10	5.2E–08	5.3E–10	5.0E–12	2.0E–06	2.1E–08

The results agree rather well although the values marked with '*' not can be directly compared with Tensit since its interpretation is either zero value or no value. The corresponding Tensit results are however on a low level at all these occasions, without any data contradicting each other.

8.2.2 Probabilistic results

When analyzing Tensit results in the probabilistic simulations, the result was compared to the whole range of answers given by the participating groups. This is motivated by the relatively low number of iterations the groups undertaken in their simulations, usually 1 000, whereas the results are found to converge first with a significantly higher number. This is also why Tensit was simulated with 10 000 iterations.

The total annual dose from a simulated ^{235}U chain was simulated and the results are listed in Table 8-8.

Table 8-8. Dose from the ^{235}U chain computed with Tensit compared to the range of values reported by the eight participating test groups. Tensit results are within the range.

Time (year)	Tensit (Sv/year)	min (Sv/year)	max (Sv/year)
1	2.3E–11	2.1E–11	5.4E–11
3	2.9E–11	2.8E–11	5.9E–11
10	8.8E–11	7.9E–11	1.0E–10
30	4.3E–10	1.7E–10	4.4E–10
100	2.7E–09	1.3E–09	2.7E–09
300	1.6E–08	9.4E–09	1.6E–08
1 000	1.3E–07	8.9E–08	1.4E–07
3 000	9.3E–07	6.6E–07	9.5E–07
10 000	6.4E–06	4.7E–06	6.5E–06
30 000	2.2E–05	1.6E–05	2.3E–05
100 000	2.2E–05	1.7E–05	2.4E–05
300 000	3.5E–06	2.6E–06	4.2E–06
1 000 000	2.2E–07	1.3E–07	3.5E–07

The results from Tensit falls within the range of results reported by the participating groups. This is also illustrated in the plot below in Figure 8-4.

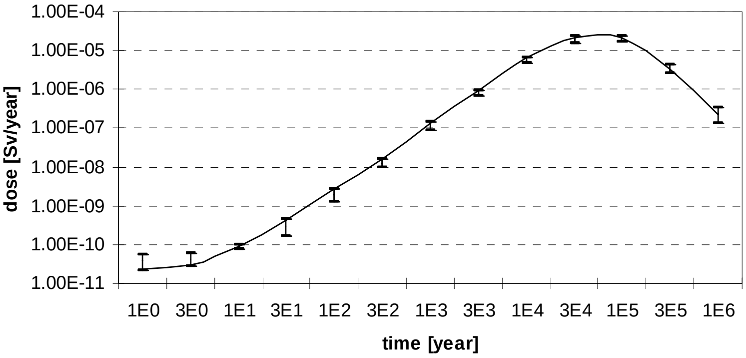


Figure 8-4. *Doserate from the ^{235}U chain. An interpolated line between data has been added. The staples show the span of results reported from the eight participating groups.*

The total annual dose from ^{14}C was simulated and the results are listed in Table 8-9.

Table 8-9. Dose rate from ^{14}C computed with Tensit compared to the range of values reported by the eight participating test groups. Tensit's results are with two exceptions within the range.

Time (year)	Tensit (Sv/year)	min (Sv/year)	max (Sv/year)
1	1,5E–07	1.3E–7	1.5E–7
3	6,8E–07	5.3E–7	7.0E–7
10	2,7E–06	2.0E–6	2.8E–6
30	8,5E–06	6.2E–6	8.7E–6
100	2,7E–05	2.0E–5	2.8E–5
300	7,1E–05	5.1E–5	7.1E–5
1 000	1,4E–04	1.0E–4	1.4E–4
3 000	**1,2E–04**	9.3E–5	1.1E–4
10 000	2,7E–05	2.2E–5	2.7E–5
30 000	1,2E–06	9.6E–7	1.2E–6
100 000	9,8E–11	7.8E–11	1.0E–10
300 000	**–1,3E–15**	7.3E–22	5.1E–13
1 000 000	1,1E–16	*	6.9E–15

The probabilistic dose results from C14 shows two deviations compared with the range reported from the participants. The first instance is a small deviation after 3 000 years. This might have to do with the small number of iterations used by the participants.

The other deviation is the results after 300 000 years. Here Tensit gives a negative result. This is of course physically impossible but is explained by the step length used by Simulink given the selected error tolerance.

To overcome this problem, a smaller step length can be used. Another technique is to set let all states in Simulink not to be smaller than a given constant of say 10^{-15}. The negative results are however reported here as an example of possible simulation results and are regarded as numbers close to zero.

The results from Tensit compared to the participants is illustrated in Figure 8-5. (The results after 100 000 years are not shown in the graph due to the irrelevance of non-positive numbers in a logarithmic scale.)

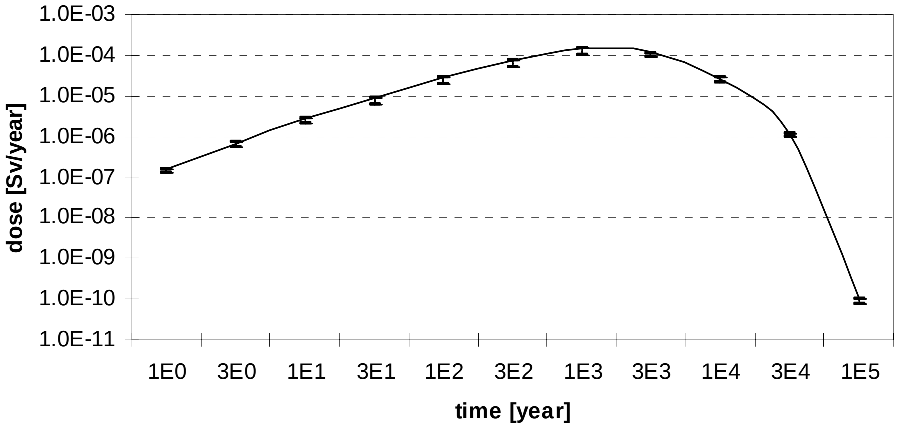


Figure 8-5. *Dose from ^{14}C in the time span from one to 100 000 years. An interpolated line between data has been added. The staples show the interval of results reported from the eight participating groups.*

9 Discussion

The verification of Tensit by comparing results with /Bergström et al, 1999/ was satisfactory in three modules namely coast, peat bog and agricultural land. For these modules the hypothesis that the results are equal could not be statistically rejected using a 95% confidence interval approximation. This serves as a good verification of the Tensit concept since the chance of accidentally obtaining an agreement this good for all nuclides would be negligibly small.

For the lake and running water module 5 likewise 6 simulated nuclides could be rejected. This is more than the two statistically expected rejections and suggests some deviation in the results. The divergence is however not far from the limits of the confidence interval and is likely not explained by Tensit but rather other discussed below.

The remaining well module shows most deviation. The equality hypothesis can be rejected for a volume of nuclides. It was found that this may have a number of explanations foremost related to misprints. The most important sources are believed to be the following.

- In the well module it has been unclear what dose conversion factor values have been used to obtain the documented results.
- In the documentation many tabulated input data were documented with one significant digit, while calculations for the presented results have been known to be carried out using higher precision. This has the potential to introduce a significant noise to the results obtained with Tensit.
- In the Tensit implementation, the sampled value for irrigation events, parameter n, has been rounded to the nearest integer value in the vegetable and pasturage block while left unchanged in all other blocks. In the implementation of /Bergström et al, 1999/ decimals of the sampled value has been truncated at all occasions in the implementation.

The verification of Tensit is strengthened by the comparison done with the results delivered from the participants in the PSACOIN level 1B exercise. In these simulations Tensit's result are successfully verified by arriving inline with or very close to documented results. Also the three simple deterministic test cases verified against the AMBER simulation tool are considered successful with only virtually insignificant deviations.

Some lessons have been learned during this work, especially in the perspective of the abundance of parameters and the high number of iterated simulations needed for these types of calculation. Desirable would thus be a simulation tool that by it self produces tables that are ready to publish of input and result data. This would assist the handling and correct association of input and output data of different versions. The importance of a version manager is also underlined and will be in thought for the future progress.

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Available August 18th 2003
http://www.enviros.com/PDF/Services/Users&References_v102e.pdf

Appendix A

Transfer coefficients

Definition of transfer coefficients

The transfer coefficients listed in this section are given in order to document how the Simulink simulations were executed. All definitions stems from interpretation of each model's original documentation. After the expression for each transfer coefficient, the included parameters are listed. Each parameter is followed by units written within square brackets and the name of the corresponding *Tensit* variable within normal parentheses. The parameter names are kept as similar as possible to the original documentation, but with some exceptions in order to be more precise or to simplify expressions at a few occurrences.

In both the well and the running water module, a capacity or a flow of water is used as an input parameter to the model. These are expressed in the unit m^3/year. It is however our interpretation that the mixing volumes referred to in the original documentation assumes annual volumes and not year based flows. Thus the flow has been multiplied with 1 year, so that the mixing volume takes the unit m^3. See TC_{i1} in well and running water.

Table 11-1. Transfer coefficients occurring in the irrigation sub-module.

Name	Description
TC_{21}	Transport coefficient representing water transport from the water source to the irrigated land. TC_{21} = See respectiv module.
TC_{01}	Transport coefficient representing the outflow of nuclides from water source. TC_{01} = See respectiv module.
TC_{12}	Transport coefficient representing the return of nuclides through erosion from top soil to the water source. $TC_{12} = \frac{Eros}{h_s}$ *Eros* = Erosion rate [m/year] (EROSION) h_s = Depth of top soil [m] (DEPTHTS)
TC_{02}	Transport coefficient representing nuclides leaving the system by removal of soil from the top soil compartment. $TC_{02} = \frac{Rem}{h_s(1-\varepsilon)\cdot\rho_p}$ *Rem* = Removal of soil [kg/(m^2·year)] (WEEDING) h_s = Depth of top soil [m] (DEPTHTS) ε = Porosity of top soil layer [m^3/m^3] (POROSITYTS) ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP)
TC_{32}	Transport coefficient from top soil to deep soil. $TC_{32} = \frac{R}{\varepsilon\cdot h_s}Ret + \frac{BioT}{h_s(1-\varepsilon)\rho_p}$ *R* = Runoff [m^3/(m^2·year)] (RUNOFF) ε = Porosity of top soil layer [m^3/m^3] (POROSITYTS) h_s = Depth of top soil [m] (DEPTHTS) *BioT* = Bio-transport due to bioturbation [kg/(m^2·yr)] (BIOTURBATION) ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP)

	Ret = See expression below. $$Ret = \frac{1}{1+K_d \cdot \rho_p \frac{1-\varepsilon}{\varepsilon}}$$ K_d = Distribution factor for radionuclides [m^3/kg] (KD)
TC_{23}	Transport coefficient from deep soil to top soil. $$TC_{23} = \frac{BioT}{h_{ds}(1-\varepsilon_{ds})\rho_p}$$ ε = Porosity of deep soil layer [m^3/m^3] (POROSITYDS) h_{ds} = Depth of deep soil [m] (DEPTHDS) *BioT* = Bio-transport due to bioturbation [$kg/(m^2 \cdot year)$] (BIOTURBATION) ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP)
TC_{13}	Transport coefficient from deep soil to the water source compartment. $$TC_{13} = \frac{R}{\varepsilon_{ds} \cdot h_{ds}} Ret$$ *R* = Runoff [$m^3/(m^2 \cdot year)$] (RUNOFF) ε_{ds} = Porosity of deep soil layer [m^3/m^3] (POROSITYDS) h_{ds} = Depth of deep soil [m] (DEPTHDS) *Ret* = See expression below. $$Ret = \frac{1}{1+K_d \cdot \rho_p \frac{1-\varepsilon_{ds}}{\varepsilon_{ds}}}$$ K_d = Distribution factor for radionuclides [m^3/kg] (KD) ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP)

Table 11-2. Transfer coefficients occurring in the running water module.

Name	Description
TC_{i1}	Transport coefficient representing transport from the stream (1) to irrigated land (i). $$TC_{i1} = \frac{I}{V_{mix}}$$ *I* = Yearly irrigation water valume [m^3] (IRRIGATION) V_{mix} = Mixing volume based on one year [m^3], see expression below $$V_{mix} = A_c \cdot R \cdot 1[year]$$ A_c = Catchment area [m^2] (CATCHMENTAREA) *R* = Runoff [$m^3/(m^2 \cdot year)$] (RUNOFF)
TC_{01}	Transport coefficient representing the outflow of nuclides downstream (out). This expression assumes a yearly unit inflow to the stream. $$TC_{01} = 1 - TC_{i1}$$

Table 11-3. Transfer coefficients occurring in the well module.

Name	Description
TC_{i1}	Transport coefficient representing the water transported from the well to irrigated land. $TC_{i1} = \frac{I}{V_{mix}}$ I = Yearly irrigation water valume [m^3] (IRRIGATION) V_{mix} = Mixing volume based on one year [m^3], see expression below $V_{mix} = C_{well} \cdot 1[year]$ C_{well} = Water capacity of well [m^3/year] (CAPACITY)
TC_{01}	Transport coefficient representing the outflow of nuclides from the well leaving the system. This expression assumes a yearly unit inflow to the well. $TC_{01} = 1 - TC_{i1}$

Table 11-4. Transfer coefficients occurring in the lake module.

Name	Description
TC_{01}	Transport coefficient representing the outflow of water from the lake, corresponding to the retention time. $TC_{01} = \frac{A_c \cdot R}{V}$ A_c = Catchment area of the lake [m^2] (CATCHAREA) R = Runoff from the catchment area of the lake [m/year] (RUNOFF) V = Volume of the lake, see expression below, [m^3] (–) $V = a \cdot D$ a = Lake area [m^2] (AREA) D = Mean depth of lake [m] (MEANDEPTH)
TC_{i1}	Transport coefficient representing the water transported from the lake to irrigated land. $TC_{i1} = \frac{I}{V}$ I = Yearly irrigation water valume [m^3/year] (IRRIGATION) V = Volume of the lake, see expression below, [m^3] (-) $V = a \cdot D$ a = Lake area [m^2] (AREA) D = Mean depth of lake [m] (MEANDEPTH)
TC_{03}	$TC_{03} = 0$ (Not used)
TC_{21}	Transport coefficient representing transport from the water phase to transport sediment. $TC_{21} = P_{et} \cdot \frac{K_d \cdot SR}{D(1 + K_d \cdot Susp)}$ Kd = Distribution coefficient for radionuclides [m^3/kg] (KD) SR = Gross sediment rate [kg/(m^2·year)] (SEDRATE) $Susp$ = Concentration of suspended matter in the lake water [kg/m^3] (SUSP) P_{et} = Fraction transportation bottoms, see expression below, [m^2/m^2] (FRAC) $P_{et} = 2.5 \cdot 10^{-4} \frac{\sqrt{a}}{D} e^{\left(230 \frac{D}{\sqrt{a}}\right)}$ D = Mean depth of lake [m] (MEANDEPTH) a = Lake area [m^2] (AREA)

TC_{31}	Transport coefficient representing transport from the water phase to accumulation sediment. $TC_{31} = (1-P_{et})\cdot\frac{K_d \cdot SR}{D(1+K_d \cdot Susp)}$ *Kd* = Distribution coefficient for radionuclides [m^3/kg] (KD) *SR* = Gross sediment rate [kg/(m^2·year)] (SEDRATE) *Susp* = Concentration of suspended matter in the lake water [kg/m^3] (SUSP) P_{et} = Fraction transportation bottoms, see TC_{21}, [m^2/m^2] (FRAC) *D* = Mean depth of lake [m] (MEANDEPTH) *a* = Lake area [m^2] (AREA)
TC_{12}	Transport coefficient representing flow from transportation bottoms to the water phase. $TC_{12} = 0.9$ [1/year]
TC_{13}	Transport coefficient representing flow from accumulation bottoms to the water phase. $TC_{13} = e^{\left(-\frac{k}{1000}\frac{\sqrt{a}}{D_m}\right)}$ *k* = Empirical factor, varied uniformely between 1 and 2. [1] (K) D_m = Max depth of lake [m] (MAXDEPTH) *a* = Lake area [m^2] (AREA) NOTICE: This expression is clearified to be correct by one of the authors.
TC_{43}	Transport coefficient representing flow from accumulation bottoms to to deep sediment. $TC_{43} = \max\left(0, \frac{(SR - PP \cdot f_{sed})P_a}{M_{sed}} - TC_{13}\right)$ *SR* = Gross sediment rate [kg/(m^2·year)] (SEDRATE) *PP* = Primary production [kg/(m^2·year)] (PRIMEPROD) f_{sed} = Fraction of primary production reaching the sediment [1] (FSED) P_a = $1-P_{et}$ P_{et} = Fraction transportation bottoms, see TC_{21}, [m^2/m^2] (FRAC) M_{sed} = Mass of top sediment per area in accumulation buttoms [kg/m^2] (MSED) NOTICE: This expression is clearified to be correct by one of the authors, August 2002.

Table 11-5. Transfer coefficients occurring in the peat module.

Name	Description
TC_{01}	Transport coefficient reprecenting horizontal outflow from the soluble compartment. $TC_{01} = \frac{R}{\varepsilon_p \cdot D_p}$ R = Runoff [m^3/(m^2 ·year)] (RUNOFF) ε_p = Porosity of peat bog [m^3/m^3] (POROSITY) D_p = Depth of peat bog [m] (DEPTH)
TC_{21}	Transport coefficient representing transport to solid from soluble compartment. $TC_{21} = \frac{K_d \cdot \ln(2)}{T_k}\frac{\rho_p}{\varepsilon_p}$ K_d = Distribution coefficient for radionuclides [m^3/kg] (KD) T_k = Reaction half-time [year] (TK) ε_p = Porosity of peat [1] (POROSITY) ρ_p = Density of peat [kg/m^3] (DENSITY)

TC$_{12}$	Transport coefficient represneting transportation to soluble from solid compartment. $TC_{12} = \frac{\ln(2)}{T_k}$ T_k = Reaction half-time [year] (TK)

Table 11-6. Transfer coefficients occurring in the agricultural land module.

Name	Description
TC$_{01}$	Transport coefficient representing the outflow of nuclides through erosion from the top soil compartment. $TC_{01} = \frac{E_r}{D_{ts}}$ E_r = Eroision [m/year] (EROSION) D_{ts} = Depth of top soil [m] (DEPTHTS)
TC$_{03}$	Transport coefficient representing horisontal outflow of radionuclides from the saturated soluble zone. $TC_{03} = \frac{R}{\varepsilon_{sa} \cdot D_{sa}}$ R = Runoff [m^3/(m^2·year)] (RUNOFF) ε_{sa} = Porosity of saturated zone [m^3/m^3] (POROSITYSAT) D_{sa} = Depth of saturated zone [m] (DEPTHSAT)
TC$_{12}$	Transport coefficient representing the water transport to top soil from deep soil. $TC_{12} = \frac{F_{ds,ts}}{\varepsilon_{ds} \cdot D_{ds}} \cdot \mathrm{Re}\,t + \frac{BioT}{(1-\varepsilon_{ds})\rho_p D_{ds}}$ $F_{ds,ts}$ = Flow [m^3/(m^2·year)] (FDSTS) ε_{ds} = Porosity of deep soil [m^3/m^3] (POROSITYTS) D_{ds} = Depth of deep soil [m] (DEPTHDS) ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP) *BioT* = Bio-transport due to bioturbation [kg/(m^2 ·year)] (BIOTURBATION) *Ret* = see, expression below $Ret = \frac{1}{1 + K_d \cdot \rho_p \frac{1-\varepsilon_{ds}}{\varepsilon_{ds}}}$ *Kd* = Distribution coefficient for radionuclides [m^3/kg] (KD)
TC$_{21}$	Transport coefficient representing the water transport to deep soil from top soil. $TC_{21} = \frac{R + F_{ds,ts}}{\varepsilon_{ts} \cdot D_{ts}} \cdot \mathrm{Re}\,t + \frac{BioT}{(1-\varepsilon_{ts})\rho_p D_{ts}}$ R = Runoff [m^3/(m^2·year)] (RUNOFF) $F_{ds,ts}$ = Flow [m^3/(m^2·year)] (FDSTS) ε_{ts} = Porosity of deep soil [m^3/m^3] (POROSITYTS) D_{ts} = Depth of deep soil [m] (DEPTHDS) ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP) *BioT* = Bio-transport due to bioturbation [kg/(m^2 ·year)] (BIOTURBATION) *Ret* = see, expression below $Ret = \frac{1}{1 + K_d \cdot \rho_p \frac{1-\varepsilon_{ts}}{\varepsilon_{ts}}}$ *Kd* = Distribution coefficient for radionuclides [m^3/kg] (KD)

TC_{32} Transport coefficient representing the water transport to saturated soluble zone from deep soil.

$$TC_{32} = \frac{(R + F_{ds,sa})}{\varepsilon_{ds} \cdot D_{ds}} \cdot \mathrm{Re}\,t$$

R = Runoff [m^3/(m^2·year)] (RUNOFF)
$F_{ds,sa}$ = Flow from deep soil to saturated zone soluble [m^3/(m^2·year)] (FSADS)
ε_{ds} = Porosity of deep soil [m^3/m^3] (POROSITYTS)
D_{ds} = Depth of deep soil [m] (DEPTHDS)
ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP)
Ret = see, expression below

$$Ret = \frac{1}{1 + K_d \cdot \rho_p \frac{1 - \varepsilon_{ds}}{\varepsilon_{ds}}}$$

Kd = Distribution coefficient for radionuclides [m^3/kg] (KD)

TC_{23} Transport coefficient representing the water transport to deep soil from saturated soluble zone.

$$TC_{23} = \frac{F_{sa,ds}}{\varepsilon_{sa} \cdot D_{sa}}$$

$F_{sa,ds}$ = Flow from saturated zone soluble to deep soil [m^3/(m^2·year)] (FSADS)
ε_{sa} = Porosity of saturated zone [m^3/m^3] (POROSITYSAT)
D_{sa} = Depth of saturated zone [m] (DEPTHSAT)

TC_{34} Transport coefficient representing the water transport to soluble from saturated solid zone.

$$TC_{34} = \frac{\ln(2)}{T_k}$$

T_k = Reaktion half-time [year] (TK)

TC_{43} Transport coefficient representing the water transport to solid from saturated soluble zone.

$$TC_{43} = \frac{K_d \cdot \ln(2)}{T_k} \cdot \frac{(1 - \varepsilon_{sa})\rho_{sa}}{\varepsilon_{sa}}$$

Kd = Distribution coefficient for radionuclides [m^3/kg] (KD)
T_k = Reaktion half-time [year] (TK)
ε_{sa} = Porosity of saturated zone [m^3/m^3] (POROSITYTS)
ρ_{sa} = Density of soil particles [kg/m^3] (DENSITYSOILP)

Table 11-7. Transfer coefficients occurring in the coast module.

Name **Description**

TC_{21} Transport coefficient representing sedimentation from bay water to bay sediment.

$$TC_{21} = \frac{K_d \cdot \mathrm{SR}}{D(1 + K_d \cdot Susp)}$$

Susp = Concentration of suspended matter in water [kg d.w./m^3] (SUSPBAY)
SR = Gross sediment rate [kg d.w./(m^2·year)] (SRBAY)
D = Mean depth of bay [m] (MEANDEPTHBAY)
K_d = Distribution coefficient for radionuclides [m^3/kg] (KD)

TC_{41} Transport coefficient representing water outflow from bay to open sea

$$TC_{41} = \frac{365}{\mathrm{RETTIME}}$$

RETTIME = Mean retension time of water in the bay [day] (RETTIMEBAY)

Transport coefficient representing resuspension from bay sediments to bay water.

TC_{12}

$$TC_{12} = e^{\frac{-k}{1000}\frac{\sqrt{a}}{D_{\max}}}$$

a = Area of the bay [m^2] (AREABAY)
k = Empirical factor, varied uniformly between 1 and 2, here set to 1.5 [1] (–)
D_{max} = Maximum depth of the bay [m] (MAXDEPTHBAY)

Notice:
This expression is an updated version.

TC_{32} Transport coefficient representing transport from bay sediment to deep sediment.

$$TC_{32} = \max\left(\frac{\mathrm{SR}}{\mathrm{M}_{\mathrm{sed}}} - TC_{12}, 0\right)$$

SR = Gross sedimentation rate [kg d.w./(m^2·year)] (SRBAY)
M_{sed} = Mass of the top sediment per area [kg/m^2] (MS)

Notice:
This expression is an updated version.

TC_{04} Transport coefficient representing outflow from the open sea.

$$TC_{04} = c_1$$

c_1 = Water turn over in open sea [1/year] (TURNOVERSEA)

TC_{14} Transport coefficient representing inflow to the bay from the open sea.

$$TC_{14} = \frac{365}{\mathrm{RETTIME}} \cdot \frac{V_b}{V_o}$$

RETTIME = Mean retension time of water in the bay [day] (RETTIMEBAY)
Vo = Volume of the open sea box [m^3] (VSEA)
Vb = Volume of the bay, see expression below, [m^3] (–)

$$V_b = a_b \cdot D$$

a_b = Area of bay [m^2] (AREABAY)
D = Mean depth of bay [m] (MEANDEPTHBAY)

TC_{54} Transport coefficient representing sedimentation from sea water to sea sediment.

$$TC_{54} = \frac{K_d \cdot \mathrm{SR}}{D(1 + K_d \cdot Susp)}$$

$Susp$ = Concentration of suspended matter in water [kg d.w./m^3] (SUSPSEA)
SR = Gross sediment rate [kg d.w./(m^2·year)] (SRSEA)
D = Mean depth of bay [m] (MEANDEPTHSEA)
K_d = Distribution coefficient for radionuclides [m^3/kg] (KD)

TC_{45} Transport coefficienting resuspension from sea sediment to sea water.

$$TC_{45} = c_2$$

c_2 = Resuspension rate for sea sediment [1/year] (RESUSPSEA)

TC_{05} Represents outflow from the open sea sediments, same as for *TC_{04}*.

Appendix B

Deterministic parameters

Simulation parameter values.

The solver settings were generally set as in Table 12-1 for all simulations.

Table 12-1. Simulink solver settings.

Simulation parameters	Value
Simulation time (start)	0
Simulation time (stop)	10000
Solver options	Variable-step
Solver name	ode15s (stiff/NDF)
Max step size	auto
Min step size	auto
Initial step size	auto
Relative tolerance	1e–9
Absolute tolerance	1e–9
Maximum order	5
Output options	Refine output
Refine factor	1

The parameter values for blocks *TENSIT* and *Release* were the same in all simulations, and are listed in Table 12-2.

Table 12-2. Common parameter values used in all simulation.

Parameter	Value	Unit
Block TENSIT		
NUCLIDES	['Cl36 '; 'Mo93 '; 'Np237 '; 'I129 '; 'Ni59 '; 'Cs135 '; 'Pu239 ']	(–)
HALFLIFE	[301000; 3500; 2140000; 15700000; 75000; 2300000; 24065]	year
CHAIN	Zeros (7, 7)[*] [*](7×7 matrix with all elemets set to zero.)	(–)
Block Release		
Constant value	[1 1 1 1 1 1 1]	Bq/year

Table 12-3. Parameter values used in running water simulation.

Parameter	Value	Unit
Module running water		
Annual irrigation water volume	15000	m^3/year
Catchment area	20000000	m^2
Runoff	0.24	$m^3/(m^2 \cdot year)$
Module irrigation		
Irrigation volume per area	0.15	$m^3/(m^2 \cdot year)$
Irrigated area	100000	m^2
Top soil depth	0.3	m
Top soil porosity	0.4	1
Deep soil depth	1	m
Deep soil porosity	0.3	1
Bioturbation	2	$kg/(m^2 \cdot year)$
Erosion	0.0001	m/year
Soil removal by weeding	0	$kg/(m^2 \cdot year)$
Runoff	0.24	$m^3/(m^2 \cdot year)$
Soil particle density	2400	kg/m^3
Distribution factor, concentration of radionuclides on solids compared to dissolved	[0.001; 0.1; 0.1; 0.3; 0.5; 1; 50]	m^3/(kg d.w.)

Table 12-4. Parameter values used in well simulation.

Parameter	Value	Unit
Module well		
Annual irrigation water volume	150	m^3/year
Capacity	2000	m^3/year
Module irrigation		
Irrigation volume per area	0.15	$m^3/(m^2 \cdot year)$
Irrigated area	1000	m^2
Top soil depth	0.3	m
Top soil porosity	0.4	1
Deep soil depth	1	m
Deep soil porosity	0.3	1
Bioturbation	2	$kg/(m^2 \cdot year)$
Erosion	0	m/year
Soil removal by weeding	0	$kg/(m^2 \cdot year)$
Runoff	0.24	$m^3/(m^2 \cdot year)$
Soil particle density	2400	kg/m^3
Distribution factor, concentration of radionuclides on solids compared to dissolved	[0.001; 0.1; 0.1; 0.3; 0.5; 1; 50]	m^3/(kg d.w.)

Table 12-5. Parameter values used in lake simulation.

Parameter	Value	Unit
Module lake		
Annual irrigation water volume	15000	m^3/year
Catchment area	117000000	m^2
Run off	0.24	m/year
Lake area	4300000	m^2
Mean depth	2	m
Gross sediment rate	1	$kg/(m^2 \cdot year)$
Suspended matter	0.001	kg/m^3
Fraction transportation bottoms	32.3582	1
Max depth	4.1	m
Primary production	0.01	$kg/(m^2 \cdot year)$
Fraction primary production reaching sediment	0.35	1
Mass of top sediment per area in accumulation bottoms	10	kg/m^2
Empirical factor, K	1.5	1
Distribution factor, concentration of radionuclides on solids compared to dissolved	[1; 0.001; 10; 0.3; 10; 10; 100]	m^3/kg

Module irrigation		
Irrigation volume per area	0.15	m^3/(m^2·year)
Irrigated area	100000	m^2
Top soil depth	0.3	m
Top soil porosity	0.4	1
Deep soil depth	1	m
Deep soil porosity	0.3	1
Bioturbation	2	kg/(m^2·year)
Erosion	0.0001	m/year
Soil removal by weeding	0	kg/(m^2·year)
Runoff	0.24	m^3/(m^2·year)
Soil particle density	2400	kg/m^3
Distribution factor, concentration of radionuclides on solids compared to dissolved	[0.001; 0.1; 0.1; 0.3; 0.5; 1; 50]	m^3/(kg d.w.)

Table 12-6. Parameter values used in peat bog simulation.

Parameter	Value	Unit
Depth of the peat bog	0.5	m
Area of the peat bog	10000	m^2
Density of peat	100	kg/m^3
Porosity of peat	0.9	1
Runoff	0.24	m^3/(m^2·year)
Reaktion half-time	0.001	year
Distribution factor, concentration of radionuclides on solids compared to dissolved	[0.01; 0.03; 1; 0.03; 1; 0.3; 2]	m^3/kg d.w.

Table 12-7. Parameter values used in agricultural land simulation.

Parameter	Value	Unit
Runoff	0.24	m^3/(m^2·year)
Depth of top soil	0.3	m
Porosity of top soil	0.4	1
Depth of deep soil	1	m
Porosity of deep soil	0.3	1
Saturated zone depth	5	m
Saturated zone porosity	0.3	1
Water transport from saturated zone to deep soil	0.2	m^3/(m^2·year)
Water transport from deep soil to top soil	0.1	m^3/(m^2·year)
Bioturbation	2	kg/(m^2·year)
Erosion	1.00E–04	m/year
Soil particle density	2400	kg/m^3
Area of agricultural land	10000	m^2
Reaktion half-time	1	year
Distribution factor, concentration of radionuclides on solids compared to dissolved	[0.001; 0.1; 0.1; 0.3; 0.5; 1; 50]	m^3/kg

Table 12-8. Parameter values used in coast simulation.

Parameter	Value	Unit
Surface area, bay	1400000	m^2
Maximum depth, bay	8	m
Mean depth, bay	2.3	m
Residence time, bay	45	days
Gross sedimentation rate, bay	2	kg/(m^2·year)
Suspended matter, bay	0.001	kg d.w./m^3
Mass of top sediment	10	kg/m^2
Volume open sea	170000000	m^3
Mean depth, sea	7	m
Water turnover, sea	44	1/year
Gross sedimentation rate, sea	0.2	kg/(m^2·year)
Suspended matter, sea	0.001	kg d.w./m^3
Resuspension rate, sea	0.2	1/year
Empirical factor, K	1.5	1
Distribution factor, concentration of radionuclides on solids compared to dissolved	[0.001; 0.001; 10; 0.3; 10; 10; 100]	m^3/kg

Appendix C

Concentration equations

Activity concentration in compartments

The dose module requires concentrations in either Bq per litre or Bq per kg as input parameters. The conversion from activity to concentration for the various biosphere modules are listed below.

In both the well and the running water module, a capacity or a flow of water is used as an input parameter to the model. These are expressed in the unit m^3/year. It is however our interpretation that the mixing volumes referred to in the original documentation assumes annual volumes and not year based flows. Thus the flow has been multiplied with 1 year, so that the mixing volume takes the unit m^3. See well and running water in Table 13-1.

Table 13-1. Activity concentration C for a selected nuclide in compartment of interest for dose calculations.

Irrigation-Submodule

$$C_{TopSoil} = \frac{level}{(1-\varepsilon_{ts})\rho_p \cdot h_{ts} \cdot A}$$

$$C_{DeepSoil} = \frac{level}{(1-\varepsilon_{ds})\rho_p \cdot h_{ds} \cdot A}$$

where

level = Amount of a selected nuclide in respective compartment [mol] (–)
ε_{ts} = Porosity of top soil layer [m^3/m^3] (POROSITYTS)
ε_{ds} = Porosity of deep soil layer [m^3/m^3] (POROSITYDS)
h_{ts} = Depth of top soil [m] (DEPTHTS)
h_{ds} = Depth of deep soil [m] (DEPTHDS)
ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP)
A = Irrigated area [m^2] (IRRAREA)

Running water

$$C_{stream} = \frac{level}{V_{mix}}$$

where

level = Amount of a selected nuclide in compartment [mol] (-)
V_{mix} = Mixing volume based on one year [m^3], see expression below

$$V_{mix} = R \cdot A_c \cdot 1\,[year]$$

R = Runoff [m^3/(m^2·year)] (RUNOFF)
A_c = Catchment area [m^2] (CATCHMENTAREA)

Well

$$C_{well} = \frac{level}{V_{mix}}$$

where

level = Amount of a selected nuclide in compartment [mol] (-)
V_{mix} = Mixing volume based on one year [m^3], see expression below

$$V_{mix} = Capacity \cdot 1\,[year]$$

Capacity = Well capacity [m^3/year] (CAPACITY)

Lake

$$C_{water} = \frac{level}{a_l \cdot D}$$

$$C_{transport\ sediment} = \frac{level}{a_l \cdot D}$$

where
level = Amount of a selected nuclide in respective compartment [mol] (–)
a_l = Area of the lake [m^2] (AREA)
D = Mean depth of lake [m] (MEANDEPTH)

Peat

$$C_{Soluble} = \frac{level}{\varepsilon_p \cdot D_p \cdot A}$$

$$C_{Solid} = \frac{level}{\rho_p \cdot D_p \cdot A}$$

where
level = Amount of a selected nuclide in respective compartment [mol] (–)
ε_p = Porosity in peat [m^3/m^3] (POROSITY)
Dp = Depth of peat [m] (DEPTH)
A = Area of peat bog [m^2] (AREA)
ρ_p = Density of peat [kg/ m^3] (DENSITY)

Agricultural land

$$C_{TopSoil} = \frac{level}{(1-\varepsilon_{ts})\rho_p \cdot D_{ts} \cdot A}$$

$$C_{DeepSoil} = \frac{level}{(1-\varepsilon_{ds})\rho_p \cdot D_{ds} \cdot A}$$

where
level = Amount of a selected nuclide in respective compartment [mol] (–)
ρ_p = Density of soil particles [kg/m^3] (DENSITYSOILP)
A = Area of agricultural land [m^2] (IRRAREA)
ε_{ts} = Porosity of top soil layer [m^3/m^3] (POROSITYTS)
ε_{ds} = Porosity of deep soil layer [m^3/m^3] (POROSITYDS)
h_{ts} = Depth of top soil [m] (DEPTHTS)
h_{ds} = Depth of deep soil [m] (DEPTHDS)

Coast

$$C_{Bay} = \frac{level}{a_b \cdot D}$$

$$C_{Sea} = \frac{level}{V_o}$$

where
level = Amount of a selected nuclide in respective compartment [mol] (–)
a_b = Area of surface bay [m^2] (AREABAY)
D = Mean depth of bay [m] (MEANDEPTHBAY)
V_o = Volume of open sea box [m^3] (VSEA)

Appendix D

Correlation coefficients

This appendix documents the correlation factors between simulation parameters that were used in the Tensit simulations of the biosphere modules in /Bergström et al, 1999/.

The correlations for the well and coast module has been verified to be correct. In the running water module the same correlations were used as for the lake for applicable parameters. For the remaining modules, correlation factors were gathered from the corresponding modules in /Karlsson et al, 2001/, where applicable.

Table 14-1. Correlations coefficients applied in the running water module.

Parameter 1	Parameter 2	Correlation coefficient
K_d soil	Root uptake factor, root crops	–0.8
K_d soil	Root uptake factor, cereals	–0.8
K_d soil	Root uptake factor, pasturage	–0.8
Root uptake factor, cereals	Root uptake factor, pasturage	0.64
Root uptake factor, cereals	Root uptake factor, root crops	0.64
Root uptake factor, pasturage	Root uptake factor, root crops	0.41
Porosity of top soil	Porosity of deep soil	0.7
Consumption of cereals	Consumption of root crops	–0.7

Table 14-2. Correlations coefficients applied in the well module.

Parameter 1	Parameter 2	Correlation coefficient
K_d soil	Root uptake factor, vegetables	–0.7
K_d soil	Root uptake factor, root crops	–0.56
Root uptake factor, vegetables	Root uptake factor, root crops	0.8
Porosity of top soil	Porosity of deep soil	0.7
Irrigation events	Irrigation	0.8

Table 14-3. Correlations coefficients applied in the lake module.

Parameter 1	Parameter 2	Correlation coefficient
Meat consumption	Fish consumption	–0.7
K_d soil	Root uptake factor, root crops	–0.8
K_d soil	Root uptake factor, cereals	–0.8
K_d soil	Root uptake factor, pasturage	–0.8
Root uptake factor, cereals	Root uptake factor, pasturage	0.64
Root uptake factor, cereals	Root uptake factor, root crops	0.64
Root uptake factor, pasturage	Root uptake factor, root crops	0.41
Porosity of top soil	Porosity of deep soil	0.7
Consumption of cereals	Consumption of root crops	–0.7
Bioaccumulation factor fish	Kd suspended matter in lake	–0.7

Table 14-4. Correlations coefficients applied in the peat module.

Parameter 1	Parameter 2	Correlation coefficient
K_d peat	Root uptake factor, root crops	–0.8
K_d peat	Root uptake factor, cereals	–0.8
K_d peat	Root uptake factor, pasturage	–0.8
Root uptake factor, cereals	Root uptake factor, pasturage	0.64
Root uptake factor, cereals	Root uptake factor, root crops	0.64
Root uptake factor, pasturage	Root uptake factor, root crops	0.41
Consumption of cereals	Consumption of root crops	–0.7

Table 14-5. Correlations coefficients applied in the agricultural land module.

Parameter 1	Parameter 2	Correlation coefficient
K_d soil	Root uptake factor, root crops	–0.8
K_d soil	Root uptake factor, cereals	–0.8
K_d soil	Root uptake factor, pasturage	–0.8
Root uptake factor, cereals	Root uptake factor, pasturage	0.64
Root uptake factor, cereals	Root uptake factor, root crops	0.64
Root uptake factor, pasturage	Root uptake factor, root crops	0.41
Porosity of top soil	Porosity of deep soil	0.7
Consumption of cereals	Consumption of root crops	–0.7

Table 14-6. Correlations coefficients applied in the coast module.

Parameter 1	Parameter 2	Correlation coefficient
Meat consumption	Fish consumption	–0.7
K_d coast	Bioaccumulation factor fish coast	0.56
K_d coast	Bioaccumulation factor algae	0.7

Appendix E

Nuclide independent probabilistic parameters

This appendix lists nuclide independent parameters from /Bergström et al, 1999/. A few parameters have been updated, see Table 18-3.

Distributions used are

T = Triangular (*minimum*, *most likely*, *maximum*)
LT = Log Triangular (*minimum*, *most likely*, *maximum*)
N = Normal (*mean, standard deviation*)
U = Uniform (*minimum*, *maximum*)
D = Discrete (*value*)

Table 15-1. Irrigation sub-module specific parameters.

Parameter	Unit	Distr	Min	M. likely	Max
DEPTHTS	m	T	0.25	0.3	0.35
POROSITYTS	1	T	0.3	0.4	0.5
DEPTHDS	m	T	0.9	1	1.1
POROSITYDS	1	T	0.2	0.3	0.4
IRRVOL	$m^3/(m^2·year)$	T	0.1	0.15	0.2
BIOTURBATION	$kg/(m^2·year)$	T	1	2	3
EROSION (agricultural soils)	m/year	T	0.00003	0.0001	0.0003
EROSION (garden plots)	m/year	D	–	0	–
WEEDING (agricultural soils)	$kg/(m^2·year)$	D	–	0	–
WEEDING (garden plots) *	$kg/(m^2·year)$	D	–	0	–
DENSITYSOILP	kg/m^3	T	2000	2400	2800
IRRAREA (agricultural soils)	m^2	T	98000	100000	110000
IRRAREA (garden plots)	m^2	T	900	1000	1100
RUNOFF	$m^3/(m^2·year)$	T	0.20	0.24	0.28
KD (see table Table 16-7)	m^3/kg	–	–	–	–

Table 15-2. Running water specific parameters.

Parameter	Unit	Distr	Min	M. likely	Max
CATCHMENTAREA	m^2	T	1.8E+07	2.0E+07	2.2E+07
RUNOFF	$m^3(m^2·year)$	T	0.2	0.24	0.28
Irrigation (see irr. sub-module)	$m^3/year$	–	–	–	–

Table 15-3. Well specific parameters.

Parameter	Unit	Distr	Min	M. likely	Max
IRRIGATION (see irr. sub-modul)	$m^3/year$	–	–	–	–
CAPACITY*	$m^3/year$	T	1800	2000	2200

Table 15-4. Parameters specific for the lake module.

Parameter	Unit	Distr	Min	M. likely	Max
AREA	m^2	T	3.9E+06	4.3E+06	4.7E+06
MAXDEPTH	m	T	3.7	4.1	4.5
MEANDEPTH	m	T	1.2	2	2.3
CATCHAREA	m^2	T	1.05E+8	1.17E+08	1.29E+08
RUNOFF	m/year	T	0.2	0.24	0.28
SEDRATE	$kg/(m^2 \cdot year)$	T	0.2	1	2
SUSP	kg/m^3	T	0.0005	0.001	0.01
PRIMEPROD	$kg/(m^2 \cdot year)$	T	0.005	0.01	0.06
FSED	1	T	0.1	0.35	0.5
MSED	kg/m^2	T	5	10	15
IRRIGATION (see irr. sub-module)	$m^3/year$	–	–	–	–
FRAC (see TC_{21} in Table 11-4)	1	–	–	–	–
K	1	U	1	–	2
KD (see Table 16–9)	m^3/kg	–	–	–	–

Table 15-5. Peat specific parameters.

Parameter	Unit	Distr	Min	M. likely	Max
RUNOFF	$m^3/(m^2 \cdot year)$	T	0.2	0.24	0.28
DENSITY	kg/m^3	T	70	100	200
POROSITY	1	T	0.8	0.9	0.95
AREA	m^2	T	2000	10000	50000
DEPTH	m	T	0.3	0.5	2
TK	year	D	–	0.001	–
KD (see Table 16-8)	m^3/kg	–	–	–	–

Table 15-6. Agricultural land specific parameters.

Parameter	Unit	Distr	Min	M. likely	Max
RUNOFF	$m^3/(m^2 \cdot year)$	T	0.2	0.24	0.28
DEPTHTS	m	T	0.25	0.3	0.35
POROSITYTS	1	T	0.3	0.4	0.5
DEPTHDS	m	T	0.9	1	1.1
POROSITYDS	1	T	0.2	0.3	0.4
DEPTHSAT	m	T	2	5	8
POROSITYSAT	1	T	0.2	0.3	0.35
FSADS	$m^3/(m^2 \cdot year)$	T	0.1	0.2	0.3
FDSTS	$m^3/(m^2 \cdot year)$	T	0.05	0.1	0.2
BIOTURBATION	$kg/(m^2 \cdot year)$	T	1	2	3
EROSION	m/year	T	0.00003	0.0001	0.0003
DENSITYSOILP	kg/m^3	T	2000	2400	2800
IRRAREA	m^2	T	2000	10000	50000
TK	year	D	–	0.001	–
KD (see Table 16-7)	m^3/kg	–	–	–	–

Table 15-7. Parameters specific for the coast module.

Parameter	Unit	Distr	Min	M. likely	Max
AREABAY	m^2	T	1.3E+06	1.4E+06	1.5E+06
MEANDEPTHBAY	m	T	2.1	2.3	2.5
MAXDEPTHBAY	m	T	7.5	8	8.5
RETTIMEBAY	day	T	42	45	48
VSEA	m^3	T	1.4E+08	1.7E+08	2.0E+08
MEANDEPTHSEA	m	T	6	7	8
TURNOVERSEA	1/year	T	30	44	57
SRBAY	$kg/(m^2 \cdot year)$	T	0.5	2	5
SUSPBAY	kg/m^3	T	0.0005	0.001	0.002
MS	kg/m^2	T	5	10	15
SRSEA	$kg/(m^2 \cdot year)$	T	0.05	0.2	0.4
SUSPSEA	kg/m^3	T	0.0005	0.001	0.002
RESUSPSEA	1/year	T	0.1	0.2	0.3
K	1	U	1	–	2
KD (see Table 16-10)	m^3/kg	–	–	–	–

Table 15-8. Consumption rates assumed for humans.

Parameter	Unit	Distr	Mean	Std.
CONSUMPTIONWATER	litre/year	N	600	60
MILKCONSUMPTION	litre/year	N	200	20
MEATCONSUMPTION	kg/year	N	55	5.5
CONSUMPTIONVEGETABLES	kg/year	N	40	4
CONSUMPTIONROOTCROPS	kg/year	N	70	7
CONSUMPTIONCEREALS	kg/year	N	80	8
CONSUMPTIONSOIL	kg/year	N	0.01	0.001
CONSUMPTIONFISH	kg/year	N	30	3
CONSUMPTIONCRUSTACEANS	kg/year	N	2	0.2
CONSUMPTIONALGAE	kg/year	N	2	0.2

Table 15-9. Consumption rates assumed for cattle.

Parameter	Unit	Distr	Min	M. likely	Max
WATERCONSUMPTION	litre/day	T	60	70	80
PASTURAGECONSUMPTION	kg/day	T	4	5	6
CEREALSCONSUMPTION	kg/day	T	10	12	15
SOILCONSUMPTION	kg/day	T	0.05	0.1	0.15

Table 15-10. Cattle metabolism specific parameters.

Parameter	Unit	Distr	Min	M. likely	Max
GD	day	T	80	100	120
GRAZINGTIME	day	T	75	90	105
TRANSPIRATION	$g/(m^2 \cdot h)$	T	50	100	300

Table 15-11. Yield values.

Parameter	Unit	Distr	Min	M. likely	Max
YIELDPASTURAGE	Kg/m^2	T	0.4	0.5	0.6
YIELDVEGETABLES	Kg/m^2	T	2	3	4
YIELDWATERPLANTS	Kg/m^2	T	0.4	0.5	0.6

Table 15-12. Irrigation specific parameters.

Parameter	Unit	Distr	Min	M. likely	Max
IRREVENTS*	1	U	3	–	7
IRRPERIOD	day	D	–	90	–
WEATHERHALF*	day	LT	10	15	20
REMAININGWATER (agricultural land)	m	T	0.001	0.003	0.005
REMAININGWATER (garden plot) *	m	T	0.001	0.003	0.005

Table 15-13. Parameters associated with combustion of peat.

Parameter	Unit	Distr	Min	M. likely	Max
INHALATIONRATE	m^3/h	T	0.8	1	1.2
FUELCONSUMPTION*	kg/s	T	0.5/3600	1/3600	2/3600
FILTERPASS	1	D	–	1	–
DISPERSION	s/m^3	LT	3E–06	1E–05	3E–05
EXPOSURETIME	h/year	T	6500	8000	8760

Table 15-14. **Parameters associated with external exposure through radiation from ground and inhalation of dust and.**

Parameter	Unit	Distr	Min	M. likely	Max
INHALATIONRATE	m^3/h	T	0.8	1	1.2
EXPOSURETIME	h/year	T	50	100	150
DUSTCONTENTINAIR*	kg/m^3	LT	3.0E–05	1.0E–04	3.0E–04

* Updated parameters. See Table 18-3 for details.

Appendix F

Nuclide specific probabalistic parameters

This appendix lists all the nuclide specific parameters from /Bergström et al, 1999/ and their assigned probability distribution and ranges. Some parameters have been updated, see Table 18-2.

Distributions used are

T = Triangular (*minimum*, *most likely*, *maximum*)
LT = Log Triangular (*minimum*, *most likely*, *maximum*)
N = Normal (*mean, standard deviation*)
U = Uniform (*minimum*, *maximum*)
D = Discrete (*value*)

Table 16-1. Half-lives and dose conversion factors.

	Half-life	Ingestion	Inhalation	External exposure
	[Year]	[Sv/Bq]	[Sv/Bq]	[(Sv·m^3)/(Bq·h)]
H-3	12	1.8E–11	4.5E–11	0
Be-10	1 600 000	1.1E–09	9.6E–09	0
C-14	5 730	5.8E–10	2.0E–09	0
Cl-36	301 000	9.3E–10	7.3E–09	0
Co-60	5.3	3.4E–09	1.0E–08	2.8E–13
Ni-59	75 000	6.3E–11	1.3E–10	0
Ni-63	96	1.5E–10	4.8E–10	0
Se-79	1 130 000	2.9E–09	2.6E–09	0
Sr-90	29	2.8E–08	3.6E–08	0
Zr-93	1 530 000	1.1E–09	1.0E–08	0
Nb-94	20 300	1.7E–09	1.5E–09	1.6E–13
Mo-93	3500	3.1E–09	5.9E–10	0
Tc-99	213 000	6.4E–10	4.0E–09	0
Pd-107	6 500 000	3.7E–11	8.5E–11	0
Ag-108m	127	2.3E–09	7.4E–09	1.6E–13
Sn-126	100 000	4.7E–09	2.8E–08	3.0E–15
I-129	15 700 000	1.1E–07	1.5E–08	3.4E–16
Cs-135	2 300 000	2.0E–09	3.1E–09	0
Cs-137	30	1.3E–08	9.7E–09	5.6E–14
Sm-151	90	9.8E–11	4.0E–09	4.6E–18
Ho-166m	1 200	2.0E–09	1.2E–07	1.6E–13
Pb-210	22	6.9E–07	1.1E–06	7.2E–17
Ra-226	1 600	2.8E–07	3.5E–06	6.0E–16
Ac-227	22	1.1E–06	2.2E–04	0
Th-229	7 340	4.9E–07	1.1E–04	2.0E–15
Th-230	77 000	2.1E–07	4.3E–05	3.5E–17
Th-232	14 050 000 000	2.3E–07	4.5E–05	1.5E–17
Pa-231	32 760	7.1E–07	1.4E–04	1.8E–15
U-233	158 500	5.1E–08	3.6E–06	5.9E–17
U-234	244 500	4.9E–08	3.5E–06	3.1E–17
U-235	703 800 000	4.7E–08	3.1E–06	1.1E–14
U-236	23 415 000	4.7E–08	3.2E–06	0
U-238	4 468 000 000	4.5E–08	2.9E–06	0
Np-237	2 140 000	1.1E–07	2.3E–05	1.8E–15
Pu-238	88	2.3E–07	4.6E–05	1.3E–17
Pu-239	24 065	2.5E–07	5.0E–05	6.6E–18
Pu-240	6 537	2.5E–07	5.0E–05	0
Pu-242	376 300	2.4E–07	4.8E–05	0
Am-241	432	2.0E–07	4.2E–05	1.1E–15
Am-242m	152	1.9E–07	3.7E–05	1.5E–17
Am-243	7 380	2.0E–07	4.1E–05	2.9E–15
Cm-244	18	1.2E–07	2.7E–05	0
Cm-245	8 500	2.1E–07	4.2E–05	3.2E–15
Cm-246	4 730	2.1E–07	4.2E–05	0

Table 16-2. Pasturage root uptake factors (RUF), units [1].

	Distribution	Minimum	Most likely	maximum
H-3	LT	2E+01	5E+01	8E+01
Be-10	LT	1E–03	1E–02	1E–01
C-14	D	–	0E+00	–
Cl-36	T	1E+01	3E+01	1E+02
Co–60	LT	1E–02	1E–01	1E+00
Ni-59	LT	2E–02	2E–01	2E+00
Ni-63	LT	2E–02	2E–01	2E+00
Se-79	LT	1E+00	2E+01	3E+01
Sr-90	LT	4E–01	1E+00	3E+00
Zr-93	LT	1E–04	1E–03	1E–02
Nb-94	LT	5E–04	5E–03	5E–02
Mo-93	LT	8E–02	8E–01	8E+00
Tc-99	LT	8E–01	8E+00	8E+01
Pd-107	LT	2E–02	2E–01	2E+00
Ag-108m	LT	5E–02	5E–01	4E+00
Sn-126	LT	1E–02	1E–01	2E+00
I-129	LT	6E–02	6E–01	6E+00
Cs-135	LT	2E–02	2E–01	2E+00
Cs-137	LT	2E–02	2E–01	2E+00
Sm-151	LT	1E–03	1E–02	1E–01
Ho-166m	LT	1E–04	1E–03	1E–02
Pb-210	LT	1E–03	1E–02	1E–01
Ra-226	LT	8E–03	8E–02	8E–01
Ac-227	LT	3E–05	5E–04	7E–03
Th-229	LT	1E–03	1E–02	1E–01
Th-230	LT	1E–03	1E–02	1E–01
Th-232	LT	1E–03	1E–02	1E–01
Pa-231	LT	3E–04	3E–03	3E–02
U-233	LT	2E–03	2E–02	2E–01
U-234	LT	2E–03	2E–02	2E–01
U-235	LT	2E–03	2E–02	2E–01
U-236	LT	2E–03	2E–02	2E–01
U-238	LT	2E–03	2E–02	2E–01
Np-237	LT	7E–03	7E–02	7E–01
Pu-238	LT	5E–05	4E–04	7E–01
Pu-239	LT	5E–05	4E–04	7E–01
Pu-240	LT	5E–05	4E–04	7E–01
Pu-242	LT	5E–05	4E–04	7E–01
Am-241	LT	5E–04	1E–03	2E–01
Am-242m	LT	5E–04	1E–03	2E–01
Am-243	LT	5E–04	1E–03	2E–01
Cm-244	LT	1E–04	1E–03	4E–03
Cm-245	LT	1E–04	1E–03	4E–03
Cm-246	LT	1E–04	1E–03	4E–03

Table 16-3. Cereals root uptake factors (RUF), unit [1].

	Distribution	Minimum	Most Likely	Maximum
H-3	LT	2E+1	5E+1	8E+1
Be-10	LT	3E–4	3E–3	3E–2
C-14	D	–	0E+00	–
Cl-36	T	9E+0	3E+1	9E+1
Co-60	LT	1E–2	1E–1	1E+0
Ni-59	LT	3E–3	3E–2	3E–1
Ni-63	LT	3E–3	3E–2	3E–1
Se-79	LT	9E–1	2E+1	3E+1
Sr-90	LT	2E–2	2E–1	1E+0
Zr-93	LT	9E–5	9E–4	9E–3
Nb-94	LT	4E–4	4E–3	4E–2
Mo-93	LT	7E–2	7E–1	7E+0
Tc-99	LT	6E–2	6E–1	3E+0
Pd-107	LT	3E–3	3E–2	3E–1
Ag-108m	LT	4E–2	4E–1	3E+0
Sn-126	LT	1E–2	4E–1	1E+0
I-129	LT	1E–2	1E–1	1E+0
Cs-135	LT	2E–3	2E–2	2E–1
Cs-137	LT	2E–3	2E–2	2E–1
Sm-151	LT	1E–5	1E–4	1E–3
Ho-166m	LT	1E–5	1E–4	1E–3
Pb-210	LT	4E–4	4E–3	4E–2
Ra-226	LT	7E–3	7E–2	7E–1
Ac-227	LT	1E–5	4E–4	1E–3
Th-229	LT	1E–3	1E–2	1E–1
Th-230	LT	1E–3	1E–2	1E–1
Th-232	LT	1E–3	1E–2	1E–1
Pa-231	LT	3E–4	3E–3	3E–2
U-233	LT	1E–4	1E–3	1E–2
U-234	LT	1E–4	1E–3	1E–2
U-235	LT	1E–4	1E–3	1E–2
U-236	LT	1E–4	1E–3	1E–2
U-238	LT	1E–4	1E–3	1E–2
Np-237	LT	2E–4	2E–3	2E–2
Pu-238	LT	7E–7	7E–6	7E–5
Pu-239	LT	7E–7	7E–6	7E–5
Pu-240	LT	7E–7	7E–6	7E–5
Pu-242	LT	7E–7	7E–6	7E–5
Am-241	LT	2E–6	2E–5	2E–4
Am-242m	LT	2E–6	2E–5	2E–4
Am-243	LT	2E–6	2E–5	2E–4
Cm-244	LT	1E–6	2E–5	3E–4
Cm-245	LT	1E–6	2E–5	3E–4
Cm-246	LT	1E–6	2E–5	3E–4

Table 16-4. Root-crops root uptake factors (RUF), unit [1].

	Distribution	Minimum	Most Likely	Maximum
H-3	T	5E+00	1E+01	2E+01
Be-10	LT	3E–04	3E–03	3E–02
C-14	D	–	0E+00	–
Cl-36	T	2E+00	6E+00	2E+01
Co-60	LT	1E–03	1E–02	1E–01
Ni-59	LT	4E–03	4E–02	4E–01
Ni-63	LT	4E–03	4E–02	4E–01
Se-79	LT	2E–01	4E+00	6E+00
Sr-90	LT	1E–02	6E–02	3E–01
Zr-93	LT	2E–05	2E–04	2E–03
Nb-94	LT	1E–04	1E–03	1E–02
Mo-93*	LT	2E–02	2E–01	2E+00
Tc-99	LT	5E–03	5E–02	5E–01
Pd-107	LT	4E–03	4E–02	4E–01
Ag-108m	LT	2E–02	2E–01	1E+00
Sn-126	LT	1E–02	5E–02	1E+00
I-129	LT	1E–03	1E–02	1E+00
Cs-135	LT	2E–03	2E–02	2E–01
Cs-137	LT	2E–03	2E–02	2E–01
Sm-151	LT	4E–06	4E–05	4E–04
Ho-166m	LT	9E–06	9E–05	9E–04
Pb-210	LT	4E–04	4E–03	4E–02
Ra-226	LT	2E–04	2E–03	2E–02
Ac-227	LT	2E–05	5E–05	1E–02
Th-229	LT	1E–06	1E–05	1E–04
Th-230	LT	1E–06	1E–05	1E–04
Th-232	LT	1E–06	1E–05	1E–04
Pa-231	LT	6E–05	6E–04	6E–03
U-233	LT	3E–04	3E–03	3E–02
U-234	LT	3E–04	3E–03	3E–02
U-235	LT	3E–04	3E–03	3E–02
U-236	LT	3E–04	3E–03	3E–02
U-238	LT	3E–04	3E–03	3E–02
Np-237	LT	2E–04	2E–03	2E–02
Pu-238	LT	3E–06	3E–05	3E–04
Pu-239	LT	3E–06	3E–05	3E–04
Pu-240	LT	3E–06	3E–05	3E–04
Pu-242	LT	3E–06	3E–05	3E–04
Am-241	LT	4E–06	4E–05	4E–04
Am-242m	LT	4E–06	4E–05	4E–04
Am-243	LT	4E–06	4E–05	4E–04
Cm-244	LT	2E–06	3E–05	5E–04
Cm-245	LT	2E–06	3E–05	5E–04
Cm-246	LT	2E–06	3E–05	5E–04

[*] In the well module LT (0.0016, 0.16, 1.6) was used foe Mo-93.

Table 16-5. Vegetables root uptake factors (RUF), unit [1].

	Distribution	Minimum	Most Likely	Maximum
H-3	T	5E+00	1E+01	2E+01
Be-10	LT	3E–04	3E–03	3E–02
C-14	D	–	0E+00	–
Cl-36	T	1E+00	3E+00	1E+01
Co-60	LT	1E–03	1E–02	1E–01
Ni-59	LT	2E–03	2E–02	2E–01
Ni-63	LT	2E–03	2E–02	2E–01
Se-79	LT	1E–01	2E+00	3E+00
Sr-90	LT	3E–02	3E–01	3E+00
Zr-93	LT	1E–05	1E–04	1E–03
Nb-94	LT	5E–05	5E–04	5E–03
Mo-93	LT	8E–03	8E–02	8E–01
Tc-99	LT	1E–01	2E+01	8E+01
Pd-107	LT	2E–03	2E–02	2E–01
Ag-108m	LT	1E–02	1E–01	8E–01
Sn-126	LT	1E–02	6E–02	1E+00
I-129	LT	3E–03	3E–02	3E–01
Cs-135	LT	2E–03	2E–02	2E–01
Cs-137	LT	2E–03	2E-02	2E–01
Sm-151	LT	3E–04	3E–03	3E–02
Ho-166m	LT	3E–04	3E–03	3E–02
Pb-210	LT	1E–04	1E–03	1E–02
Ra-226	LT	5E–03	5E–02	5E–01
Ac-227	LT	2E–04	4E–03	8E–02
Th-229	LT	2E–05	2E–04	2E–03
Th-230	LT	2E–05	2E–04	2E–03
Th-232	LT	2E–05	2E–04	2E–03
Pa-231	LT	3E–05	3E–04	3E–03
U-233	LT	1E–04	1E–03	1E–02
U-234	LT	1E–04	1E–03	1E–02
U-235	LT	1E–04	1E–03	1E–02
U-236	LT	1E–04	1E–03	1E–02
U-238	LT	1E–04	1E–03	1E–02
Np-237	LT	4E–04	4E–03	4E–02
Pu-238	LT	2E–06	2E–05	2E–04
Pu-239	LT	2E–06	2E–05	2E–04
Pu-240	LT	2E–06	2E–05	2E–04
Pu-242	LT	2E–06	2E–05	2E–04
Am-241	LT	7E–06	7E–05	7E–04
Am-242m	LT	7E–06	7E–05	7E–04
Am-243	LT	7E–06	7E–05	7E–04
Cm-244	LT	2E–05	2E–04	2E–03
Cm-245	LT	2E–05	2E–04	2E–03
Cm-246	LT	2E–05	2E–04	2E–03

Table 16-6. Translocation factors for surface to edible parts of cereals and root-crops, units [m^2/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3	T	1E–02	1E–01	3E–01
Be-10	T	2E–02	1E–01	3E–01
C-14	T	1E–02	1E–01	3E–01
Cl-36	T	1E–02	1E–01	3E–01
Co-60	T	1E–01	2E–01	3E–01
Ni-59	T	5E–03	1E–02	4E–02
Ni-63	T	5E–03	1E–02	4E–02
Se-79	T	1E–02	1E–01	3E–01
Sr-90	T	1E–01	4E–01	7E–01
Zr-93	T	5E–02	1E–01	2E–01
Nb-94	T	1E–01	2E–01	3E–01
Mo-93	T	1E–02	1E–01	3E–01
Tc-99	T	4E–01	5E–01	6E–01
Pd-107	T	1E–02	1E–01	3E–01
Ag-108m	T	1E–02	1E–01	3E–01
Sn-126	T	1E–02	1E–01	3E–01
I-129	T	5E–02	1E–01	2E–01
Cs-135	T	1E–01	2E–01	3E–01
Cs-137	T	1E–01	2E–01	3E–01
Sm-151	T	1E–02	1E–01	3E–01
Ho-166m	T	1E–02	1E–01	3E–01
Pb-210	T	1E–02	3E–02	1E–01
Ra-226	T	1E–02	1E–01	3E–01
Ac-227	T	1E–02	1E–01	3E–01
Th-229	T	1E–02	1E–01	3E–01
Th-230	T	1E–02	1E–01	3E–01
Th-232	T	1E–02	1E–01	3E–01
Pa-231	T	1E–02	1E–01	3E–01
U-233	T	1E–02	1E–01	3E–01
U-234	T	1E–02	1E–01	3E–01
U-235	T	1E–02	1E–01	3E–01
U-236	T	1E–02	1E–01	3E–01
U-238	T	1E–02	1E–01	3E–01
Np-237	T	5E–02	1E–01	2E–01
Pu-238	T	1E–02	2E–02	3E–02
Pu-239	T	1E–02	2E–02	3E–02
Pu-240	T	1E–02	2E–02	3E–02
Pu-242	T	1E–02	2E–02	3E–02
Am-241	T	5E–03	1E–02	2E–02
Am-242m	T	5E–03	1E–02	2E–02
Am-243	T	5E–03	1E–02	2E–02
Cm-244	T	1E–02	2E–02	3E–02
Cm-245	T	1E–02	2E–02	3E–02
Cm-246	T	1E–02	2E–02	3E–02

Table 16-7. Distribution values (Kd) for soil, units [m^3/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3[*]	D	–	0E+00	–
Be-10	LT	1E–01	1E+00	1E+01
C-14	LT	4E–04	1E–03	1E–02
Cl-36	LT	1E–04	1E–03	1E–02
Co-60	LT	1E–02	1E+00	2E+01
Ni-59	LT	5E–02	5E–01	5E+00
Ni-63	LT	5E–02	5E–01	5E+00
Se-79	LT	1E–03	1E–02	1E–01
Sr-90	LT	1E–03	1E–02	1E–01
Zr-93	LT	1E–01	1E+00	1E+01
Nb-94	LT	5E–02	5E–01	5E+00
Mo-93	LT	1E–02	1E–01	1E+00
Tc-99	LT	1E–03	5E–03	1E–02
Pd-107	LT	2E–02	2E–01	2E+00
Ag-108m	LT	1E–02	1E–01	1E+00
Sn-126	LT	5E–02	1E–01	5E–01
I-129	LT	1E–01	3E–01	1E+00
Cs-135	LT	1E–01	1E+00	1E+01
Cs-137	LT	1E–01	1E+00	1E+01
Sm-151	LT	1E–01	1E+00	1E+01
Ho-166m	LT	1E–01	1E+00	1E+01
Pb-210	LT	1E–02	1E–01	1E+00
Ra-226	LT	1E–02	5E–01	1E+00
Ac-227	LT	1E–01	1E+00	1E+01
Th-229	LT	1E+00	1E+01	1E+02
Th-230	LT	1E+00	1E+01	1E+02
Th-232	LT	1E+00	1E+01	1E+02
Pa-231	LT	1E+00	1E+01	1E+02
U-233	LT	1E–02	1E–01	1E+00
U-234	LT	1E–02	1E–01	1E+00
U-235	LT	1E–02	1E–01	1E+00
U-236	LT	1E–02	1E–01	1E+00
U-238	LT	1E–02	1E–01	1E+00
Np-237	LT	1E–02	1E–01	1E+00
Pu-238	LT	1E+00	5E+01	1E+02
Pu-239	LT	1E+00	5E+01	1E+02
Pu-240	LT	1E+00	5E+01	1E+02
Pu-242	LT	1E+00	5E+01	1E+02
Am-241	LT	2E–01	2E+00	2E+01
Am-242m	LT	2E–01	2E+00	2E+01
Am-243	LT	2E–01	2E+00	2E+01
Cm-244	LT	1E+00	1E+01	1E+02
Cm-245	LT	1E+00	1E+01	1E+02
Cm-246	LT	1E+00	1E+01	1E+02

[*] Data not specified in reference.

Table 16-8. Distribution values (Kd) for peat, units [m^3/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3[*]	D	–	0E+00	–
Be-10	LT	3E–01	3E+00	3E+01
C-14	LT	7E–03	7E–02	7E–01
Cl-36	LT	1E–03	1E–02	1E–01
Co-60	LT	5E–02	1E+00	2E+01
Ni-59	LT	2E–01	1E+00	7E+00
Ni-63	LT	2E–01	1E+00	7E+00
Se-79	LT	2E–01	2E+00	2E+01
Sr-90	LT	4E–03	2E–01	6E+00
Zr-93	LT	7E–01	7E+00	7E+01
Nb-94	LT	2E–01	2E+00	2E+01
Mo-93	LT	3E–03	3E–02	3E–01
Tc-99	LT	4E–05	2E–03	6E–02
Pd-107	LT	7E–02	7E–01	7E+00
Ag-108m	LT	2E+00	2E+01	9E+01
Sn–126	LT	2E–01	2E+00	2E+01
I-129	LT	3E–03	3E–02	3E–01
Cs-135	LT	1E–01	3E–01	3E+00
Cs-137	LT	1E–01	3E–01	3E+00
Sm-151	LT	3E–01	3E+00	3E+01
Ho-166m	LT	3E–01	3E+00	3E+01
Pb-210	LT	8E+00	2E+01	6E+01
Ra-226	LT	2E–01	2E+00	2E+01
Ac-227	LT	5E–01	5E+00	5E+01
Th-229	LT	9E+00	9E+01	9E+02
Th-230	LT	9E+00	9E+01	9E+02
Th-232	LT	9E+00	9E+01	9E+02
Pa-231	LT	7E–01	7E+00	7E+01
U-233	LT	3E–03	4E–01	4E+00
U-234	LT	3E–03	4E–01	4E+00
U-235	LT	3E–03	4E–01	4E+00
U-236	LT	3E–03	4E–01	4E+00
U-238	LT	3E–03	4E–01	4E+00
Np-237	LT	5E–01	1E+00	3E+00
Pu-238	LT	2E–01	2E+00	2E+01
Pu-239	LT	2E–01	2E+00	2E+01
Pu-240	LT	2E–01	2E+00	2E+01
Pu-242	LT	2E–01	2E+00	2E+01
Am-241	LT	1E+01	1E+02	1E+03
Am-242m	LT	1E+01	1E+02	1E+03
Am-243	LT	1E+01	1E+02	1E+03
Cm-244	LT	1E+00	1E+01	1E+02
Cm-245	LT	1E+00	1E+01	1E+02
Cm-246	LT	1E+00	1E+01	1E+02

[*] Data not specified in reference.

Table 16-9. Distribution values (Kd) for lakes, units [m^3/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3[*]	D	–	0.0E+00	–
Be-10	LT	1.0E–01	1.0E+00	1.0E+01
C-14	LT	1.0E–04	1.0E–03	1.0E–02
Cl-36	LT	1.0E–01	1.0E+00	1.0E+01
Co-60	LT	1.0E+00	5.0E+00	7.0E+01
Ni-59	LT	1.0E+00	1.0E+01	1.0E+02
Ni-63	LT	1.0E+00	1.0E+01	1.0E+02
Se-79	LT	1.0E+00	5.0E+00	1.0E+01
Sr-90	LT	1.0E–01	1.0E+00	1.0E+01
Zr-93	LT	1.0E–01	1.0E+00	1.0E+01
Nb-94	LT	1.0E+00	1.0E+01	1.0E+02
Mo-93	LT	1.0E–04	1.0E–03	1.0E–02
Tc-99	LT	1.0E–02	1.0E–01	1.0E+00
Pd-107	LT	2.0E–01	2.0E+00	2.0E+01
Ag-108m	LT	2.0E–01	2.0E+00	2.0E+01
Sn-126	LT	1.0E+01	5.0E+01	1.0E+02
I-129	LT	1.0E–01	3.0E–01	1.0E+00
Cs-135	LT	1.0E+00	1.0E+01	1.0E+02
Cs-137	LT	1.0E+00	1.0E+01	1.0E+02
Sm-151	LT	5.0E–01	5.0E+00	5.0E+01
Ho-166m	LT	3.0E–02	3.0E–01	3.0E+00
Pb-210	LT	1.0E–02	5.0E–02	1.0E–01
Ra-226	LT	1.0E+00	1.0E+01	1.0E+02
Ac-227	LT	1.0E+00	1.0E+01	1.0E+02
Th-229	LT	1.0E+01	1.0E+02	1.0E+03
Th-230	LT	1.0E+01	1.0E+02	1.0E+03
Th-232	LT	1.0E+01	1.0E+02	1.0E+03
Pa-231	LT	1.0E+01	1.0E+02	1.0E+03
U-233	LT	1.0E+00	1.0E+01	1.0E+02
U-234	LT	1.0E+00	1.0E+01	1.0E+02
U-235	LT	1.0E+00	1.0E+01	1.0E+02
U-236	LT	1.0E+00	1.0E+01	1.0E+02
U-238	LT	1.0E+00	1.0E+01	1.0E+02
Np-237	LT	1.0E+00	1.0E+01	1.0E+02
Pu-238	LT	1.0E+01	1.0E+02	1.0E+03
Pu-239	LT	1.0E+01	1.0E+02	1.0E+03
Pu-240	LT	1.0E+01	1.0E+02	1.0E+03
Pu-242	LT	1.0E+01	1.0E+02	1.0E+03
Am-241	LT	5.0E–01	5.0E+00	5.0E+01
Am-242m	LT	5.0E–01	5.0E+00	5.0E+01
Am-243	LT	5.0E–01	5.0E+00	5.0E+01
Cm-244	LT	1.0E–01	5.0E+00	7.0E+01
Cm-245	LT	1.0E–01	5.0E+00	7.0E+01
Cm-246	LT	1.0E–01	5.0E+00	7.0E+01

[*] Data not specified in reference.

Table 16-10. Distribution values (Kd) for coast, units [m^3/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3	LT	5E–05	1E–03	1E–02
Be-10	LT	1E–01	1E+00	1E+01
C-14	LT	1E–04	1E–03	1E–02
Cl-36	LT	1E–04	1E–03	1E–02
Co-60	LT	1E+00	1E+02	2E+02
Ni-59	LT	1E+00	1E+01	1E+02
Ni-63	LT	1E+00	1E+01	1E+02
Se-79	LT	1E+00	5E+00	1E+01
Sr-90	LT	1E–02	1E–01	1E+00
Zr-93	LT	5E+00	5E+01	5E+02
Nb-94	LT	1E+00	1E+01	1E+02
Mo-93	LT	1E–04	1E–03	1E–02
Tc-99	LT	1E–02	1E–01	1E+00
Pd-107	LT	1E+00	1E+01	1E+02
Ag-108m	LT	1E–01	1E+00	1E+01
Sn-126	LT	1E+01	5E+01	1E+02
I-129	LT	1E–01	3E–01	1E+00
Cs-135	LT	1E+00	1E+01	1E+02
Cs-137	LT	1E+00	1E+01	1E+02
Sm-151	LT	1E+01	1E+02	1E+03
Ho-166m	LT	1E–02	1E–01	1E+00
Pb-210	LT	1E–02	5E–02	1E–01
Ra-226	LT	1E+00	1E+01	1E+02
Ac-227	LT	1E+00	1E+01	1E+02
Th-229	LT	1E+01	1E+02	1E+03
Th-230	LT	1E+01	1E+02	1E+03
Th-232	LT	1E+01	1E+02	1E+03
Pa-231	LT	1E+01	1E+02	1E+03
U-233	LT	1E+00	1E+01	1E+02
U-234	LT	1E+00	1E+01	1E+02
U-235	LT	1E+00	1E+01	1E+02
U-236	LT	1E+00	1E+01	1E+02
U-238	LT	1E+00	1E+01	1E+02
Np-237	LT	1E+00	1E+01	1E+02
Pu-238	LT	1E+01	1E+02	1E+03
Pu-239	LT	1E+01	1E+02	1E+03
Pu-240	LT	1E+01	1E+02	1E+03
Pu-242	LT	1E+01	1E+02	1E+03
Am-241	LT	1E+00	1E+01	1E+02
Am-242m	LT	1E+00	1E+01	1E+02
Am-243	LT	1E+00	1E+01	1E+02
Cm-244	LT	1E+01	1E+03	2E+03
Cm-245	LT	1E+01	1E+03	2E+03
Cm-246	LT	1E+01	1E+03	2E+03

Table 16-11. Bioaccumulation factors for fish in fresh water, units [litre/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3	LT	6.0E–01	1.0E+00	1.0E+00
Be-10	LT	1.0E+01	1.0E+02	1.0E+03
C-14	LT	1.0E+03	5.0E+04	6.0E+04
Cl-36	LT	1.0E+01	5.0E+01	1.0E+02
Co-60	LT	1.0E+01	3.0E+02	4.0E+02
Ni-59	LT	1.0E+01	1.0E+02	1.0E+03
Ni-63	LT	1.0E+01	1.0E+02	1.0E+03
Se-79	LT	5.0E+02	2.0E+03	5.0E+03
Sr-90	LT	1.0E+00	6.0E+01	1.0E+03
Zr-93	LT	3.0E+00	2.0E+02	3.0E+02
Nb-94	LT	1.0E+02	3.0E+02	3.0E+04
Mo-93	LT	1.0E+00	1.0E+01	1.0E+02
Tc-99	LT	2.0E+00	2.0E+01	8.0E+01
Pd-107	LT	1.0E+01	1.0E+02	1.0E+03
Ag-108m	LT	2.0E–01	5.0E+00	1.0E+01
Sn-126	LT	3.0E+02	3.0E+03	3.0E+04
I-129	LT	1.0E+01	2.0E+02	6.0E+02
Cs-135	LT	5.0E+03	1.0E+04	2.0E+04
Cs-137	LT	5.0E+03	1.0E+04	2.0E+04
Sm-151	LT	2.0E+00	3.0E+01	3.0E+02
Ho-166m	LT	3.0E+00	3.0E+01	3.0E+02
Pb-210	LT	1.0E+02	3.0E+02	4.0E+02
Ra-226	LT	1.0E+01	5.0E+01	2.0E+02
Ac-227	LT	1.0E+01	1.0E+02	2.0E+02
Th-229	LT	3.0E+01	1.0E+02	1.0E+03
Th-230	LT	3.0E+01	1.0E+02	1.0E+03
Th-232	LT	3.0E+01	1.0E+02	1.0E+03
Pa-231	LT	1.0E+00	1.0E+01	1.0E+02
U-233	LT	2.0E+00	1.0E+01	5.0E+01
U-234	LT	2.0E+00	1.0E+01	5.0E+01
U-235	LT	2.0E+00	1.0E+01	5.0E+01
U-236	LT	2.0E+00	1.0E+01	5.0E+01
U-238	LT	2.0E+00	1.0E+01	5.0E+01
Np-237	LT	1.0E+01	5.0E+01	3.0E+03
Pu-238	LT	4.0E+00	3.0E+01	3.0E+02
Pu-239	LT	4.0E+00	3.0E+01	3.0E+02
Pu-240	LT	4.0E+00	3.0E+01	3.0E+02
Pu-242	LT	4.0E+00	3.0E+01	3.0E+02
Am-241	LT	1.0E+01	3.0E+01	3.0E+02
Am-242m	LT	1.0E+01	3.0E+01	3.0E+02
Am-243	LT	1.0E+01	3.0E+01	3.0E+02
Cm-244	LT	1.0E+01	3.0E+01	3.0E+02
Cm-245	LT	1.0E+01	3.0E+01	3.0E+02
Cm-246	LT	1.0E+01	3.0E+01	3.0E+02

Table 16-12. Bioaccumulation factors for fish in the coastal module, units [litre/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3	LT	8E–01	1E+00	1E+00
Be-10	LT	2E+01	2E+02	2E+03
C-14	LT	2E+03	2E+03	3E+03
Cl-36	LT	1E–01	1E+00	1E+01
Co-60	LT	3E+01	3E+02	5E+02
Ni-59	LT	3E+01	3E+02	5E+02
Ni-63	LT	3E+01	3E+02	5E+02
Se-79	LT	2E+03	4E+03	8E+03
Sr-90	LT	1E+00	3E+01	1E+02
Zr-93	LT	1E+01	1E+02	2E+02
Nb-94	LT	1E+01	1E+02	5E+02
Mo-93	LT	1E+00	1E+01	5E+01
Tc-99	LT	1E+00	3E+01	1E+02
Pd-107	LT	1E+00	1E+01	1E+02
Ag-108m	LT	1E+02	5E+02	1E+03
Sn-126	LT	1E+01	1E+02	1E+03
I-129	LT	1E+01	3E+01	1E+02
Cs-135	LT	1E+02	2E+02	5E+02
Cs-137	LT	1E+02	2E+02	5E+02
Sm-151	LT	3E+00	3E+01	3E+02
Ho-166m	LT	3E+00	3E+01	3E+02
Pb-210	LT	5E+01	1E+02	2E+02
Ra-226	LT	1E+01	5E+01	1E+02
Ac-227	LT	1E+01	1E+02	1E+03
Th-229	LT	1E+00	3E+01	1E+02
Th-230	LT	1E+00	3E+01	1E+02
Th-232	LT	1E+00	3E+01	1E+02
Pa-231	LT	1E+00	1E+01	1E+02
U-233	LT	1E+01	5E+01	1E+02
U-234	LT	1E+01	5E+01	1E+02
U-235	LT	1E+01	5E+01	1E+02
U-236	LT	1E+01	5E+01	1E+02
U-238	LT	1E+01	5E+01	1E+02
Np-237	LT	1E+00	1E+01	1E+02
Pu-238	LT	5E+00	3E+01	5E+01
Pu-239	LT	5E+00	3E+01	5E+01
Pu-240	LT	5E+00	3E+01	5E+01
Pu-242	LT	5E+00	3E+01	5E+01
Am-241	LT	1E+01	1E+02	2E+02
Am-242m	LT	1E+01	1E+02	2E+02
Am-243	LT	1E+01	1E+02	2E+02
Cm-244	LT	1E+01	5E+01	3E+02
Cm-245	LT	1E+01	5E+01	3E+02
Cm-246	LT	1E+01	5E+01	3E+02

Table 16-13. Bioaccumulation factors for crustacea, units [litre/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3	LT	5E–01	1E+00	2E+00
Be-10	LT	1E+00	1E+01	1E+02
C-14	LT	9E+02	9E+03	1E+04
Cl-36	LT	1E+01	1E+02	1E+03
Co-60	LT	2E+01	2E+02	2E+03
Ni-59	LT	1E+01	1E+02	1E+03
Ni-63	LT	1E+01	1E+02	1E+03
Se-79	LT	2E+01	2E+02	2E+03
Sr-90	LT	1E+01	1E+02	1E+03
Zr-93	LT	7E–01	7E+00	7E+01
Nb-94	LT	1E+01	1E+02	1E+03
Mo-93*	T	1E+00	1E+01	1E+02
Tc-99	LT	5E–01	5E+00	5E+01
Pd-107	LT	3E+01	3E+02	3E+03
Ag-108m	LT	8E+01	8E+02	8E+03
Sn-126	LT	1E+02	1E+03	1E+04
I-129	LT	5E–01	5E+00	5E+01
Cs-135	LT	1E+01	1E+02	1E+03
Cs-137	LT	1E+01	1E+02	1E+03
Sm-151	LT	1E+02	1E+03	1E+04
Ho-166m	LT	1E+02	1E+03	1E+04
Pb-210	LT	1E+01	1E+02	1E+03
Ra-226	LT	3E+01	3E+02	3E+03
Ac-227	LT	1E+02	1E+03	1E+04
Th-229	LT	5E+01	5E+02	5E+03
Th-230	LT	5E+01	5E+02	5E+03
Th-232	LT	5E+01	5E+02	5E+03
Pa-231	LT	1E+01	1E+02	1E+03
U-233	LT	1E+01	1E+02	1E+03
U-234	LT	1E+01	1E+02	1E+03
U-235	LT	1E+01	1E+02	1E+03
U-236	LT	1E+01	1E+02	1E+03
U-238	LT	1E+01	1E+02	1E+03
Np-237	LT	4E+01	4E+02	4E+03
Pu-238	LT	1E+01	1E+02	1E+03
Pu-239	LT	1E+01	1E+02	1E+03
Pu-240	LT	1E+01	1E+02	1E+03
Pu-242	LT	1E+01	1E+02	1E+03
Am-241	LT	1E+02	1E+03	1E+04
Am-242m	LT	1E+02	1E+03	1E+04
Am-243	LT	1E+02	1E+03	1E+04
Cm-244	LT	1E+02	1E+03	1E+04
Cm-245	LT	1E+02	1E+03	1E+04
Cm-246	LT	1E+02	1E+03	1E+04

[*] In the well module LT (1, 10, 100) was used for Mo-93.

Table 16-14. Bioaccumulation factors for algae, units [litre/kg].

	Distribution	Minimum	Most Likely	Maximum
H-3	LT	5E–01	1E+00	2E+00
Be-10	LT	1E+02	1E+03	1E+04
C-14	LT	2E+02	2E+03	1E+04
Cl-36	LT	1E–02	1E–01	1E+00
Co-60	LT	1E+02	1E+03	1E+04
Ni-59	LT	3E+01	3E+02	3E+03
Ni-63	LT	3E+01	3E+02	3E+03
Se-79	LT	1E+02	1E+03	1E+04
Sr-90	LT	1E+00	1E+01	1E+02
Zr-93	LT	2E+02	2E+03	1E+04
Nb-94	LT	1E+02	1E+03	1E+04
Mo-93	LT	1E+00	1E+01	1E+02
Tc-99	LT	4E+02	4E+03	1E+04
Pd-107	LT	2E+02	2E+03	1E+04
Ag-108m	LT	2E+01	2E+02	2E+03
Sn-126	LT	1E+01	1E+02	1E+03
I-129	LT	1E+02	1E+03	1E+04
Cs-135	LT	5E+00	5E+01	5E+02
Cs-137	LT	5E+00	5E+01	5E+02
Sm-151	LT	1E+02	5E+03	1E+04
Ho-166m	LT	1E+02	5E+03	1E+04
Pb-210	LT	1E+02	1E+03	1E+04
Ra-226	LT	1E+01	1E+02	1E+03
Ac-227	LT	1E+02	5E+03	1E+04
Th-229	LT	3E+02	3E+03	1E+04
Th-230	LT	3E+02	3E+03	1E+04
Th-232	LT	3E+02	3E+03	1E+04
Pa-231	LT	6E–01	6E+00	6E+01
U-233	LT	7E+00	7E+01	7E+02
U-234	LT	7E+00	7E+01	7E+02
U-235	LT	7E+00	7E+01	7E+02
U-236	LT	7E+00	7E+01	7E+02
U-238	LT	7E+00	7E+01	7E+02
Np-237	LT	6E–01	6E+00	6E+01
Pu-238	LT	3E+01	3E+02	3E+03
Pu-239	LT	3E+01	3E+02	3E+03
Pu-240	LT	3E+01	3E+02	3E+03
Pu-242	LT	3E+01	3E+02	3E+03
Am-241	LT	1E+02	5E+03	1E+04
Am-242m	LT	1E+02	5E+03	1E+04
Am-243	LT	1E+02	5E+03	1E+04
Cm-244	LT	1E+02	5E+03	1E+04
Cm-245	LT	1E+02	5E+03	1E+04
Cm-246	LT	1E+02	5E+03	1E+04

Table 16-15. Transfer coefficient to milk (F_{milk}), units [day/litre].

	Distribution	Minimum	Most Likely	Maximum
H-3	LT	1.0E–02	2.0E–02	3.0E–02
Be-10	LT	9.0E–08	9.0E–07	9.0E–06
C-14	LT	5.0E–03	1.0E–02	2.0E–02
Cl-36	T	1.5E–02	1.7E–02	2.0E–02
Co-60	LT	6.0E–05	3.0E–04	1.0E–02
Ni-59	LT	2.0E–03	2.0E–02	5.0E–02
Ni-63	LT	2.0E–03	2.0E–02	5.0E–02
Se-79	LT	4.0E–04	4.0E–03	4.0E–02
Sr-90	LT	1.0E–03	2.8E–03	3.0E–03
Zr-93	LT	6.0E–08	6.0E–07	6.0E–06
Nb-94	LT	1.0E–07	4.0E–07	4.0E–06
Mo-93	LT	1.0E–04	1.0E–03	1.0E–02
Tc-99	LT	1.0E–05	2.0E–05	1.0E–03
Pd-107	LT	1.0E–04	1.0E–03	1.0E–02
Ag-108m	LT	5.0E–06	5.0E–05	5.0E–04
Sn-126	LT	1.0E–03	3.0E–03	1.0E–02
I-129	LT	1.0E–03	1.0E–02	4.0E–02
Cs-135	LT	1.0E–03	8.0E–03	3.0E–02
Cs-137	LT	1.0E–03	8.0E–03	3.0E–02
Sm-151	LT	2.0E–06	2.0E–05	2.0E–03
Ho-166m	LT	3.0E–07	2.5E–06	3.0E–05
Pb-210	LT	2.0E–05	3.0E–04	2.0E–03
Ra-226	LT	1.0E–04	1.3E–03	2.0E–03
Ac-227	LT	3.0E–08	3.0E–07	3.0E–06
Th-229	LT	1.0E–07	5.0E–06	1.0E–04
Th-230	LT	1.0E–07	5.0E–06	1.0E–04
Th-232	LT	1.0E–07	5.0E–06	1.0E–04
Pa-231	LT	1.0E–06	5.0E–05	1.0E–04
U-233	LT	7.0E–05	4.0E–04	6.0E–04
U-234	LT	7.0E–05	4.0E–04	6.0E–04
U-235	LT	7.0E–05	4.0E–04	6.0E–04
U-236	LT	7.0E–05	4.0E–04	6.0E–04
U-238	LT	7.0E–05	4.0E–04	6.0E–04
Np-237	LT	5.0E–07	5.0E–06	5.0E–05
Pu-238	LT	3.0E–09	1.0E–06	3.0E–06
Pu-239	LT	3.0E–09	1.0E–06	3.0E–06
Pu-240	LT	3.0E–09	1.0E–06	3.0E–06
Pu-242	LT	3.0E–09	1.0E–06	3.0E–06
Am-241	LT	4.0E–07	2.0E–06	2.0E–05
Am-242m	LT	4.0E–07	2.0E–06	2.0E–05
Am-243	LT	4.0E–07	2.0E–06	2.0E–05
Cm-244	LT	2.0E–06	2.0E–05	2.0E–04
Cm-245	LT	2.0E–06	2.0E–05	2.0E–04
Cm-246	LT	2.0E–06	2.0E–05	2.0E–04

Table 16-16. Transfer coefficient to meat (F_{meat}), units [day/kg].

Nuclide	Distribution	Minimum	Most Likely	Maximum
H-3	LT	1.0E–03	1.0E–02	1.0E–01
Be-10	LT	1.0E–04	1.0E–03	1.0E–02
C-14	LT	1.0E–03	3.0E–02	1.0E–01
Cl-36	LT	1.0E–02	2.0E–02	4.0E–02
Co-60	LT	4.0E–05	1.0E–02	7.0E–02
Ni-59	LT	5.0E–04	5.0E–03	5.0E–02
Ni-63	LT	5.0E–04	5.0E–03	5.0E–02
Se-79	LT	1.0E–04	1.5E–02	2.0E–02
Sr-90	LT	3.0E–04	8.0E–03	1.0E–02
Zr-93	LT	1.0E–07	1.0E–06	1.0E–02
Nb-94	LT	3.0E–08	3.0E–07	1.0E–02
Mo-93	LT	2.0E–04	2.0E–03	2.0E–02
Tc-99	LT	1.0E–05	1.0E–04	1.0E–03
Pd-107	LT	1.0E–04	1.0E–03	1.0E–02
Ag-108m	LT	2.0E–03	3.0E–03	6.0E–03
Sn-126	LT	3.0E–04	3.0E–03	3.0E–02
I-129	LT	7.0E–03	4.0E–02	5.0E–02
Cs-135	LT	1.0E–02	5.0E–02	6.0E–02
Cs-137	LT	1.0E–02	5.0E–02	6.0E–02
Sm-151	LT	5.0E–04	5.0E–03	5.0E–02
Ho-166m	LT	5.0E–04	5.0E–03	5.0E–02
Pb-210	LT	1.0E–04	4.0E–04	7.0E–04
Ra-226	LT	5.0E–04	9.0E–04	5.0E–03
Ac-227	LT	1.0E–06	1.0E–05	1.0E–04
Th-229	LT	6.0E–07	6.0E–06	6.0E–05
Th-230	LT	6.0E–07	6.0E–06	6.0E–05
Th-232	LT	6.0E–07	6.0E–06	6.0E–05
Pa-231	LT	1.0E–06	1.0E–05	1.0E–04
U-233	LT	3.0E–05	3.0E–04	3.0E–03
U-234	LT	3.0E–05	3.0E–04	3.0E–03
U-235	LT	3.0E–05	3.0E–04	3.0E–03
U-236	LT	3.0E–05	3.0E–04	3.0E–03
U-238	LT	3.0E–05	3.0E–04	3.0E–03
Np-237	LT	1.0E–05	1.0E–04	1.0E–03
Pu-238	LT	2.0E–07	1.0E–05	2.0E–04
Pu-239	LT	2.0E–07	1.0E–05	2.0E–04
Pu-240	LT	2.0E–07	1.0E–05	2.0E–04
Pu-242	LT	2.0E–07	1.0E–05	2.0E–04
Am-241	LT	4.0E–06	4.0E–05	1.0E–04
Am-242m	LT	4.0E–06	4.0E–05	1.0E–04
Am-243	LT	4.0E–06	4.0E–05	1.0E–04
Cm-244	LT	2.0E–06	2.0E–05	2.0E–04
Cm-245	LT	2.0E–06	2.0E–05	2.0E–04
Cm-246	LT	2.0E–06	2.0E–05	2.0E–04

Appendix G

Probabilistic results

Probabilistic results from Tensit compared with reference /Bergström et al, 1999/. The reference simulations has been run for 200 iterations whereas Tensit has been run for 10 000 iterations for increased accuracy. A deviation in the range of a few percent, see section 7, between the results in mean value could be expected because of the relative low number of iterations in the reference. Min and max values correspond to the 0.5% and 99.5% percentiles of the EDF distribution for the respective nuclides.

Table 17-1. Probabilistic results from the running water module compared with reference results. All units in Sv/year.

Nuclide	Tensit				Reference			
	Mean	Std.	Min	Max	Mean	Std.	Min	Max
H-3	2.51E–17	8.59E–18	1.10E–17	5.62E–17	3.0E–17	1.0E–17	1.3E–17	6.6E–17
Be-10	1.36E–15	1.07E–15	3.25E–16	6.01E–15	1.4E–15	1.1E–15	3.4E–16	6.1E–15
C-14	7.75E–14	5.71E–14	6.39E–15	2.34E–13	7.7E–14	5.7E–14	6.2E–15	2.3E–13
Cl-36	2.72E–15	8.45E–16	1.34E–15	5.84E–15	2.8E–15	8.2E–16	1.4E–15	5.6E–15
Co-60	4.21E–15	1.97E–15	1.20E–15	9.75E–15	4.4E–15	2.0E–15	1.2E–15	9.8E–15
Ni-59	1.52E–16	7.44E–17	4.76E–17	4.38E–16	1.7E–16	7.9E–17	5.2E–17	5.0E–16
Ni-63	2.95E–16	1.66E–16	7.70E–17	9.49E–16	3.2E–16	1.7E–16	7.7E–17	1.1E–15
Se-79	4.15E–14	1.72E–14	1.42E–14	9.62E–14	4.1E–14	1.7E–14	1.4E–14	9.1E–14
Sr-90	3.13E–14	2.31E–14	9.96E–15	1.43E–13	3.2E–14	2.3E–14	1.1E–14	1.4E–13
Zr-93	8.31E–16	4.96E–16	2.17E–16	2.27E–15	8.4E–16	5.0E–16	2.2E–16	2.3E–15
Nb-94	2.50E–14	3.79E–14	2.25E–15	2.28E–13	2.5E–14	3.8E–14	2.3E–15	2.3E–13
Mo-93	4.37E–15	1.79E–15	1.72E–15	1.19E–14	4.4E–15	1.8E–15	1.6E–15	1.2E–14
Tc-99	5.13E–16	2.51E–16	2.00E–16	1.68E–15	5.2E–16	2.5E–16	1.8E–16	1.6E–15
Pd-107	5.97E–17	3.70E–17	1.79E–17	2.19E–16	6.1E–17	3.7E–17	1.9E–17	2.2E–16
Ag-108m	2.46E–15	1.24E–15	9.76E–16	7.65E–15	2.5E–15	1.2E–15	9.9E–16	7.8E–15
Sn-126	1.43E–13	1.37E–13	1.63E–14	7.41E–13	1.4E–13	1.4E–13	1.8E–14	7.4E–13
I-129	3.07E–13	1.24E–13	1.04E–13	7.38E–13	3.4E–13	1.3E–13	1.1E–13	8.1E–13
Cs-135	1.34E–13	4.17E–14	6.29E–14	2.67E–13	1.3E–13	3.1E–14	6.3E–14	2.3E–13
Cs-137	8.46E–13	2.64E–13	3.85E–13	1.66E–12	8.2E–13	1.9E–13	4.0E–13	1.5E–12
Sm-151	1.17E–16	7.00E–17	3.17E–17	3.98E–16	1.2E–16	7.2E–17	3.4E–17	4.1E–16
Ho-166m	3.02E–15	1.47E–15	1.11E–15	8.73E–15	3.0E–15	1.4E–15	1.2E–15	9.0E–15
Pb-210	1.17E–12	3.18E–13	5.53E–13	2.00E–12	1.2E–12	3.2E–13	5.4E–13	2.0E–12
Ra-226	2.62E–13	8.87E–14	1.15E–13	5.65E–13	2.7E–13	9.3E–14	1.2E–13	5.9E–13
Ac-227	1.37E–12	7.53E–13	3.88E–13	4.49E–12	1.4E–12	7.5E–13	3.7E–13	4.3E–12
Th-229	9.59E–13	5.23E–13	3.17E–13	3.06E–12	9.8E–13	5.2E–13	3.1E–13	3.2E–12
Th-230	4.23E–13	2.23E–13	1.42E–13	1.32E–12	4.3E–13	2.2E–13	1.4E–13	1.4E–12
Th-232	4.64E–13	2.48E–13	1.54E–13	1.46E–12	4.7E–13	2.4E–13	1.6E–13	1.5E–12
Pa-231	4.11E–13	1.22E–13	1.93E–13	8.28E–13	4.3E–13	1.3E–13	2.0E–13	8.8E–13
U-233	1.92E–14	5.18E–15	1.03E–14	3.73E–14	2.0E–14	5.3E–15	1.1E–14	3.8E–14
U-234	1.85E–14	4.98E–15	9.83E–15	3.59E–14	1.9E–14	5.1E–15	1.1E–14	3.7E–14
U-235	1.77E–14	4.77E–15	9.56E–15	3.50E–14	1.8E–14	4.9E–15	1.0E–14	3.5E–14
U-236	1.77E–14	4.71E–15	9.54E–15	3.41E–14	1.8E–14	4.9E–15	1.0E–14	3.5E–14
U-238	1.69E–14	4.51E–15	9.13E–15	3.26E–14	1.7E–14	4.7E–15	9.6E–15	3.4E–14
Np-237	2.24E–13	2.59E–13	3.91E–14	1.56E–12	2.2E–13	2.6E–13	4.1E–14	1.7E–12
Pu-238	1.20E–13	6.95E–14	4.39E–14	4.16E–13	1.2E–13	6.9E–14	4.6E–14	4.3E–13
Pu-239	1.74E–13	8.06E–14	6.78E–14	4.88E–13	1.8E–13	8.3E–14	6.8E–14	5.1E–13
Pu-240	1.64E–13	7.89E–14	6.28E–14	4.91E–13	1.7E–13	8.0E–14	6.5E–14	5.0E–13
Pu-242	1.72E–13	7.89E–14	6.45E–14	4.92E–13	1.8E–13	8.1E–14	6.8E–14	4.9E–13
Am-241	2.36E–13	1.43E–13	6.59E–14	8.13E–13	2.4E–13	1.5E–13	7.0E–14	8.3E–13
Am-242m	2.20E–13	1.35E–13	6.03E–14	7.70E–13	2.2E–13	1.4E–13	6.4E–14	7.8E–13
Am-243	2.55E–13	1.45E–13	7.64E–14	8.47E–13	2.6E–13	1.5E–13	8.0E–14	8.6E–13
Cm-244	1.33E–13	8.19E–14	3.59E–14	4.55E–13	1.4E–13	8.3E–14	3.6E–14	4.8E–13
Cm-245	2.74E–13	1.53E–13	8.50E–14	8.87E–13	2.8E–13	1.5E–13	8.8E–14	9.1E–13
Cm-246	2.69E–13	1.52E–13	8.36E–14	8.76E–13	2.7E–13	1.5E–13	8.4E–14	9.1E–13

Table 17-2. Probabilistic results from the well module compared with reference results. All units in Sv/year.

Nuclide	Tensit				Reference			
	Mean	**Std.**	**Min**	**Max**	**Mean**	**Std.**	**Min**	**Max**
H-3	1.27E–14	1.92E–15	8.67E–15	1.85E–14	1.3E–14	1.8E–15	8.9E–15	1.8E–14
Be-10	6.23E–13	1.28E–13	4.03E–13	1.10E–12	6.7E–13	1.4E–13	4.0E–13	1.2E–12
C-14	3.29E–13	5.00E–14	2.24E–13	4.82E–13	3.2E–13	4.8E–14	2.3E–13	4.7E–13
Cl-36	9.89E–13	3.01E–13	5.78E–13	2.29E–12	9.8E–13	3.0E–13	5.6E–13	2.5E–12
Co-60	1.45E–12	2.19E–13	9.82E–13	2.09E–12	1.4E–12	2.1E–13	9.8E–13	2.1E–12
Ni-59	7.82E–14	4.07E–14	3.18E–14	2.70E–13	7.9E–14	4.2E–14	3.2E–14	2.7E–13
Ni-63	8.17E–14	1.62E–14	5.16E–14	1.36E–13	8.2E–14	1.6E–14	5.2E–14	1.3E–13
Se-79	3.64E–12	1.97E–12	1.45E–12	1.32E–11	3.6E–12	2.0E–12	1.4E–12	1.5E–11
Sr-90	2.20E–11	4.65E–12	1.35E–11	3.67E–11	1.7E–11	3.4E–12	1.0E–11	2.9E–11
Zr-93	2.62E–13	6.56E–14	1.57E–13	5.21E–13	2.0E–13	6.3E–14	1.1E–13	4.3E–13
Nb-94	4.48E–12	2.20E–12	1.13E–12	1.13E–11	4.6E–12	2.2E–12	1.2E–12	1.1E–11
Mo-93	3.38E–12	1.85E–12	1.40E–12	1.26E–11	2.8E–12	1.5E–12	1.2E–12	1.0E–11
Tc-99	7.57E–13	3.52E–13	3.07E–13	2.16E–12	7.4E–13	3.6E–13	3.0E–13	2.1E–12
Pd-107	3.07E–14	1.36E–14	1.53E–14	9.86E–14	3.1E–14	1.3E–14	1.5E–14	9.2E–14
Ag-108m	1.74E–12	4.03E–13	1.05E–12	3.27E–12	1.8E–12	4.4E–13	1.1E–12	3.5E–12
Sn-126	5.23E–12	2.52E–12	2.33E–12	1.65E–11	5.2E–12	2.5E–12	2.4E–12	1.6E–11
I-129	1.25E–10	8.38E–11	5.41E–11	5.42E–10	1.2E–10	7.7E–11	5.4E–11	5.0E–10
Cs-135	2.59E–12	1.16E–12	1.17E–12	7.64E–12	2.6E–12	1.2E–12	1.2E–12	8.4E–12
Cs-137	7.47E–12	1.11E–12	5.11E–12	1.06E–11	7.9E–12	1.2E–12	5.5E–12	1.2E–11
Sm-151	4.23E–14	6.41E–15	2.94E–14	6.32E–14	4.1E–14	6.1E–15	2.9E–14	6.1E–14
Ho-166m	2.61E–12	5.88E–13	1.36E–12	4.34E–12	2.7E–12	6.2E–13	1.4E–12	4.4E–12
Pb-210	2.46E–10	2.88E–11	1.79E–10	3.27E–10	2.5E–10	2.9E–11	1.8E–10	3.4E–10
Ra-226	1.55E–10	3.32E–11	9.87E–11	2.85E–10	1.6E–10	3.4E–11	1.0E–10	3.1E–10
Ac-227	4.50E–10	6.96E–11	3.10E–10	6.77E–10	4.7E–10	7.0E–11	3.2E–10	7.0E–10
Th-229	5.40E–10	1.99E–10	2.53E–10	1.32E–09	5.1E–10	1.9E–10	2.4E–10	1.2E–09
Th-230	2.76E–10	1.11E–10	1.19E–10	7.03E–10	2.6E–10	1.1E–10	1.1E–10	6.5E–10
Th-232	3.01E–10	1.21E–10	1.30E–10	7.74E–10	2.9E–10	1.1E–10	1.2E–10	7.1E–10
Pa-231	8.95E–10	3.42E–10	4.04E–10	2.23E–09	8.5E–10	3.2E–10	3.9E–10	2.1E–09
U-233	2.93E–11	8.41E–12	1.73E–11	6.65E–11	2.8E–11	7.4E–12	1.7E–11	6.2E–11
U-234	2.83E–11	8.19E–12	1.69E–11	6.48E–11	2.8E–11	7.3E–12	1.7E–11	6.1E–11
U-235	2.70E–11	7.80E–12	1.61E–11	6.48E–11	2.6E–11	6.7E–12	1.6E–11	5.7E–11
U-236	2.69E–11	7.74E–12	1.61E–11	6.26E–11	2.6E–11	6.8E–12	1.6E–11	5.8E–11
U-238	2.56E–11	7.04E–12	1.56E–11	5.62E–11	2.5E–11	6.4E–12	1.5E–11	5.4E–11
Np-237	6.34E–11	1.94E–11	3.79E–11	1.56E–10	6.1E–11	1.9E–11	3.7E–11	1.7E–10
Pu-238	8.71E–11	1.01E–11	6.43E–11	1.16E–10	8.7E–11	1.0E–11	6.4E–11	1.2E–10
Pu-239	2.93E–10	1.19E–10	1.27E–10	7.58E–10	2.8E–10	1.2E–10	1.2E–10	7.5E–10
Pu-240	2.38E–10	8.76E–11	1.14E–10	5.82E–10	2.3E–10	8.7E–11	1.1E–10	5.8E–10
Pu-242	3.07E–10	1.29E–10	1.27E–10	8.17E–10	2.9E–10	1.2E–10	1.2E–10	7.8E–10
Am-241	8.80E–11	1.37E–11	6.09E–11	1.36E–10	9.1E–11	1.4E–11	6.2E–11	1.4E–10
Am-242m	7.37E–11	8.98E–12	5.36E–11	1.00E–10	7.3E–11	9.0E–12	5.4E–11	1.0E–10
Am-243	1.73E–10	6.41E–11	8.32E–11	4.26E–10	1.7E–10	6.5E–11	8.1E–11	4.3E–10
Cm-244	4.14E–11	4.56E–12	3.07E–11	5.41E–11	4.1E–11	4.5E–12	3.0E–11	5.4E–11
Cm-245	2.10E–10	7.90E–11	9.82E–11	5.23E–10	2.1E–10	7.8E–11	9.5E–11	5.2E–10
Cm-246	1.81E–10	6.24E–11	9.12E–11	4.21E–10	1.8E–10	6.2E–11	8.8E–11	4.3E–10

Table 17-3. Probabilistic results from the lake module compared with reference results. All units in Sv/year.

Nuclide	Tensit				Reference			
	Mean	**Std.**	**Min**	**Max**	**Mean**	**Std.**	**Min**	**Max**
H-3	4.45E–18	1.50E–18	1.96E–18	9.83E–18	5.3E–18	1.9E–18	2.3E–18	1.3E–17
Be-10	2.32E–16	1.82E–16	5.71E–17	1.04E–15	2.3E–16	1.8E–16	5.8E–17	1.0E–15
C-14	1.32E–14	9.76E–15	1.04E–15	3.99E–14	1.3E–14	9.8E–15	9.5E–16	4.0E–14
Cl-36	4.62E–16	1.44E–16	2.24E–16	1.00E–15	4.8E–16	1.4E–16	2.4E–16	1.0E–15
Co-60	6.59E–16	3.67E–16	1.06E–16	1.70E–15	6.5E–16	3.0E–16	1.8E–16	1.7E–15
Ni-59	2.58E–17	1.27E–17	8.09E–18	7.69E–17	2.8E–17	1.4E–17	8.0E–18	8.4E–17
Ni-63	4.95E–17	2.84E–17	1.22E–17	1.66E–16	5.3E–17	2.9E–17	1.4E–17	1.7E–16
Se-79	7.07E–15	2.92E–15	2.40E–15	1.67E–14	7.0E–15	3.0E–15	2.4E–15	1.6E–14
Sr-90	5.40E–15	4.03E–15	1.67E–15	2.57E–14	5.6E–15	4.2E–15	1.6E–15	2.6E–14
Zr-93	1.42E–16	8.46E–17	3.72E–17	3.90E–16	1.4E–16	8.6E–17	3.8E–17	4.0E–16
Nb-94	4.27E–15	6.47E–15	3.92E–16	3.89E–14	4.3E–15	6.4E–15	3.6E–16	3.9E–14
Mo-93	7.43E–16	2.97E–16	3.04E–16	2.00E–15	7.5E–16	3.2E–16	2.8E–16	2.2E–15
Tc-99	8.73E–17	4.25E–17	3.49E–17	2.78E–16	8.9E–17	4.5E–17	3.5E–17	3.0E–16
Pd-107	1.02E–17	6.27E–18	3.05E–18	3.60E–17	1.0E–17	7.2E–18	3.0E–18	4.2E–17
Ag-108m	4.20E–16	2.11E–16	1.65E–16	1.30E–15	4.3E–16	2.1E–16	1.7E–16	1.3E–15
Sn-126	2.44E–14	2.34E–14	2.79E–15	1.26E–13	2.4E–14	2.3E–14	2.6E–15	1.2E–13
I-129	5.23E–14	2.06E–14	1.80E–14	1.23E–13	5.7E–14	2.3E–14	1.8E–14	1.4E–13
Cs-135	2.29E–14	7.07E–15	1.05E–14	4.52E–14	2.2E–14	5.2E–15	1.2E–14	3.8E–14
Cs-137	1.37E–13	4.72E–14	5.24E–14	2.83E–13	1.3E–13	2.9E–14	7.2E–14	2.1E–13
Sm-151	1.98E–17	1.18E–17	5.39E–18	6.78E–17	2.0E–17	1.4E–17	4.9E–18	8.3E–17
Ho-166m	5.15E–16	2.49E–16	1.90E–16	1.51E–15	5.2E–16	3.0E–16	1.7E–16	1.7E–15
Pb-210	2.03E–13	5.51E–14	9.65E–14	3.53E–13	2.0E–13	6.0E–14	9.0E–14	3.6E–13
Ra-226	4.47E–14	1.50E–14	1.97E–14	9.39E–14	4.6E–14	2.0E–14	1.8E–14	1.2E–13
Ac-227	2.18E–13	1.24E–13	5.28E–14	7.29E–13	2.2E–13	1.3E–13	5.6E–14	7.5E–13
Th-229	1.63E–13	8.95E–14	5.24E–14	5.14E–13	1.7E–13	1.0E–13	4.6E–14	6.2E–13
Th-230	7.23E–14	3.85E–14	2.41E–14	2.29E–13	7.4E–14	4.5E–14	2.1E–14	2.7E–13
Th-232	7.92E–14	4.19E–14	2.69E–14	2.46E–13	8.1E–14	5.0E–14	2.3E–14	2.9E–13
Pa-231	7.01E–14	2.11E–14	3.38E–14	1.44E–13	7.4E–14	2.5E–14	3.4E–14	1.6E–13
U-233	3.28E–15	8.87E–16	1.77E–15	6.34E–15	3.4E–15	1.1E–15	1.7E–15	8.0E–15
U-234	3.15E–15	8.42E–16	1.70E–15	6.10E–15	3.3E–15	1.1E–15	1.6E–15	7.7E–15
U-235	3.02E–15	8.01E–16	1.65E–15	5.81E–15	3.1E–15	1.0E–15	1.6E–15	7.4E–15
U-236	3.01E–15	8.06E–16	1.63E–15	5.72E–15	3.1E–15	1.0E–15	1.6E–15	7.3E–15
U-238	2.88E–15	7.75E–16	1.55E–15	5.50E–15	3.0E–15	9.7E–16	1.5E–15	7.0E–15
Np-237	3.81E–14	4.40E–14	6.49E–15	2.63E–13	3.8E–14	4.7E–14	5.8E–15	3.0E–13
Pu-238	1.80E–14	1.17E–14	4.77E–15	6.58E–14	1.7E–14	9.9E–15	6.6E–15	5.8E–14
Pu-239	2.97E–14	1.38E–14	1.15E–14	8.60E–14	3.1E–14	1.6E–14	1.1E–14	9.6E–14
Pu-240	2.80E–14	1.36E–14	1.08E–14	8.47E–14	2.9E–14	1.5E–14	1.0E–14	9.4E–14
Pu-242	2.93E–14	1.35E–14	1.10E–14	8.24E–14	3.1E–14	1.5E–14	1.1E–14	9.3E–14
Am-241	4.03E–14	2.46E–14	1.15E–14	1.42E–13	4.1E–14	3.0E–14	9.7E–15	1.8E–13
Am-242m	3.74E–14	2.28E–14	1.02E–14	1.27E–13	3.8E–14	2.8E–14	8.8E–15	1.6E–13
Am-243	4.36E–14	2.48E–14	1.30E–14	1.45E–13	4.4E–14	3.1E–14	1.2E–14	1.8E–13
Cm-244	2.23E–14	1.42E–14	5.04E–15	7.98E–14	2.2E–14	1.6E–14	5.6E–15	9.3E–14
Cm-245	4.68E–14	2.60E–14	1.46E–14	1.51E–13	4.8E–14	3.3E–14	1.3E–14	2.0E–13
Cm-246	4.59E–14	2.58E–14	1.42E–14	1.49E–13	4.7E–14	3.3E–14	1.3E–14	2.0E–13

Table 17-4. Probabilistic results from the peat module compared with reference results. All units in Sv/year.

Nuclide	Tensit				Reference			
	Mean	**Std.**	**Min**	**Max**	**Mean**	**Std.**	**Min**	**Max**
H-3	*	*	*	*	3.6E–16	4.2E–16	6.1E–17	2.7E–15
Be-10	8.35E–13	8.64E–13	1.04E–13	5.17E–12	8.6E–13	1.7E–12	7.7E–14	9.8E–12
C-14	6.17E–15	8.93E–15	1.94E–16	5.93E–14	6.5E–15	1.3E–14	1.7E–16	9.8E–14
Cl-36	2.33E–11	2.54E–11	2.10E–12	1.58E–10	2.2E–11	3.0E–11	1.7E–12	2.0E–10
Co-60	2.86E–13	4.02E–13	1.46E–14	2.34E–12	2.8E–13	4.5E–13	1.0E–14	2.7E–12
Ni-59	2.72E–13	2.40E–13	4.73E–14	1.49E–12	2.7E–13	3.9E–13	4.1E–14	2.5E–12
Ni-63	1.55E–13	1.64E–13	1.11E–14	9.94E–13	1.6E–13	2.4E–13	8.0E–15	1.6E–12
Se-79	1.97E–09	2.04E–09	2.30E–10	1.26E–08	1.7E–09	2.4E–09	1.7E–10	1.7E–08
Sr-90	1.79E–11	2.14E–11	1.65E–12	1.33E–10	1.8E–11	2.6E–11	1.3E–12	1.8E–10
Zr-93	4.31E–13	4.27E–13	5.16E–14	2.61E–12	4.4E–13	5.6E–13	3.8E–14	3.5E–12
Nb-94	1.96E–12	2.35E–12	1.59E–13	1.50E–11	2.0E–12	3.3E–12	1.4E–13	2.4E–11
Mo-93	2.55E–12	2.48E–12	3.31E–13	1.52E–11	2.5E–12	3.6E–12	2.6E–13	2.6E–11
Tc-99	3.99E–13	1.22E–12	1.60E–15	7.86E–12	4.2E–13	1.5E–12	9.4E–16	1.1E–11
Pd-107	6.42E–14	6.47E–14	9.11E–15	3.88E–13	6.4E–14	9.0E–14	7.6E–15	7.1E–13
Ag-108m	1.88E–11	2.44E–11	1.03E–12	1.46E–10	1.9E–11	2.9E–11	8.8E–13	2.3E–10
Sn-126	8.46E–11	8.55E–11	1.15E–11	5.20E–10	8.6E–11	1.3E–10	8.7E–12	9.1E–10
I-129	2.98E–11	2.87E–11	4.17E–12	1.79E–10	3.0E–11	4.1E–11	3.3E–12	2.8E–10
Cs-135	2.65E–12	2.27E–12	4.93E–13	1.42E–11	2.7E–12	3.3E–12	3.7E–13	2.2E–11
Cs-137	3.49E–12	3.95E–12	2.45E–13	2.47E–11	3.5E–12	6.4E–12	1.9E–13	2.9E–11
Sm-151	5.61E–15	6.04E–15	5.39E–16	3.62E–14	6.0E–15	1.0E–14	4.4E–16	8.1E–14
Ho-166m	1.87E–12	1.98E–12	1.49E–13	1.17E–11	1.9E–12	2.8E–12	1.2E–13	2.0E–11
Pb-210	1.60E–11	2.24E–11	7.18E–13	1.38E–10	1.6E–11	3.0E–11	5.7E–13	2.3E–10
Ra-226	1.15E–09	1.23E–09	1.35E–10	7.55E–09	1.2E–09	2.1E–09	1.1E–10	1.6E–08
Ac-227	6.25E–11	6.91E–11	5.08E–12	4.20E–10	6.2E–11	9.2E–11	3.5E–12	6.5E–10
Th-229	6.75E–09	6.83E–09	6.29E–10	4.34E–08	7.0E–09	1.1E–08	5.1E–10	8.6E–08
Th-230	3.89E–09	3.93E–09	3.66E–10	2.32E–08	4.0E–09	6.4E–09	3.0E–10	5.0E–08
Th-232	4.28E–09	4.34E–09	4.27E–10	2.66E–08	4.4E–09	7.1E–09	3.4E–10	5.5E–08
Pa-231	3.42E–09	4.27E–09	2.21E–10	2.48E–08	3.5E–09	5.6E–09	2.0E–10	4.3E–08
U-233	6.03E–12	1.15E–11	8.00E–14	6.56E–11	6.1E–12	1.3E–11	5.7E–14	8.7E–11
U-234	5.88E–12	1.12E–11	7.25E–14	6.69E–11	5.9E–12	1.2E–11	5.5E–14	8.4E–11
U-235	5.27E–12	9.47E–12	7.52E–14	5.95E–11	5.4E–12	1.1E–11	5.1E–14	7.6E–11
U-236	5.50E–12	1.09E–11	7.19E–14	6.78E–11	5.5E–12	1.1E–11	5.2E–14	7.8E–11
U-238	4.86E–12	8.79E–12	6.99E–14	5.30E–11	5.1E–12	1.0E–11	4.8E–14	7.2E–11
Np-237	1.09E–10	1.06E–10	1.55E–11	6.57E–10	1.1E–10	1.5E–10	1.2E–11	1.0E–09
Pu-238	3.68E–11	4.15E–11	2.79E–12	2.53E–10	3.7E–11	5.4E–11	1.8E–12	3.6E–10
Pu-239	4.12E–10	6.29E–10	1.17E–11	3.84E–09	4.1E–10	8.1E–10	8.4E–12	6.4E–09
Pu-240	3.62E–10	5.13E–10	1.14E–11	3.25E–09	3.6E–10	6.7E–10	8.3E–12	4.9E–09
Pu-242	4.14E–10	6.20E–10	1.04E–11	3.88E–09	4.1E–10	8.3E–10	8.1E–12	6.8E–09
Am-241	2.01E–10	2.29E–10	1.43E–11	1.40E–09	2.0E–10	3.2E–10	1.3E–11	2.6E–09
Am-242m	6.35E–11	7.28E–11	4.47E–12	4.39E–10	6.3E–11	1.0E–10	4.1E–12	8.1E–10
Am-243	1.77E–09	1.97E–09	1.36E–10	1.22E–08	1.8E–09	2.8E–09	1.1E–10	2.5E–08
Cm-244	5.49E–12	6.28E–12	3.88E–13	3.80E–11	5.5E–12	8.3E–12	3.6E–13	6.1E–11
Cm-245	9.33E–10	1.18E–09	4.58E–11	7.14E–09	9.8E–10	1.7E–09	4.4E–11	1.2E–08
Cm-246	7.76E–10	9.37E–10	4.34E–11	5.73E–09	8.1E–10	1.4E–09	4.0E–11	1.0E–08

* No value obtained due to absence of inputdata.

Table 17-5. Probabilistic results from the agricultural land module compared with reference results. All units in Sv/year.

Nuclide	Tensit				Reference			
	Mean	**Std.**	**Min**	**Max**	**Mean**	**Std.**	**Min**	**Max**
H-3	1.21E–15	1.08E–15	1.82E–16	6.73E–15	1.3E–15	1.8E–15	1.8E–16	1.3E–14
Be–10	1.25E–14	1.43E–14	4.35E–16	8.75E–14	1.3E–14	2.1E–14	3.3E–16	1.5E–13
C-14	2.08E–17	2.69E–17	1.61E–18	1.79E–16	2.0E–17	3.0E–17	1.5E–18	2.2E–16
Cl-36	4.33E–13	4.24E–13	5.70E–14	2.61E–12	4.0E–13	5.6E–13	4.0E–14	4.0E–12
Co-60	3.92E–18	2.13E–17	2.80E–21	1.09E–16	5.0E–18	2.5E–17	2.7E–21	2.3E–16
Ni-59	1.05E–14	1.32E–14	3.65E–16	7.74E–14	1.1E–14	1.6E–14	3.2E–16	8.8E–14
Ni-63	6.24E–17	1.60E–16	3.41E–19	9.35E–16	7.6E–17	2.4E–16	2.8E–19	1.3E–15
Se-79	1.77E–12	1.92E–12	1.70E–13	1.18E–11	1.6E–12	2.4E–12	1.4E–13	1.5E–11
Sr-90	2.53E–14	3.23E–14	5.99E–16	1.89E–13	2.8E–14	4.8E–14	5.2E–16	3.1E–13
Zr-93	3.07E–15	3.39E–15	1.44E–16	2.04E–14	3.0E–15	4.2E–15	7.7E–17	2.6E–14
Nb-94	2.27E–13	1.96E–13	3.06E–14	1.14E–12	2.4E–13	2.9E–13	2.6E–14	2.2E–12
Mo-93	8.79E–13	8.85E–13	9.06E–14	5.51E–12	8.7E–13	1.1E–12	6.7E–14	8.2E–12
Tc-99	6.21E–14	9.99E–14	1.75E–15	6.14E–13	5.9E–14	1.4E–13	1.4E–15	6.5E–13
Pd-107	2.60E–15	2.41E–15	2.86E–16	1.48E–14	2.7E–15	3.6E–15	2.3E–16	2.5E–14
Ag-108m	1.54E–14	2.33E–14	3.34E–16	1.50E–13	1.8E–14	3.2E–14	3.3E–16	1.9E–13
Sn-126	1.11E–12	1.04E–12	1.20E–13	6.25E–12	1.2E–12	1.7E–12	1.0E–13	1.2E–11
I-129	4.80E–11	5.60E–11	2.83E–12	3.36E–10	5.0E–11	7.9E–11	2.3E–12	4.9E–10
Cs-135	2.95E–13	3.71E–13	6.32E–15	2.17E–12	3.1E–13	5.2E–13	5.4E–15	3.5E–12
Cs-137	1.30E–16	3.34E–16	6.18E–19	2.04E–15	1.7E–16	5.0E–16	6.5E–19	3.8E–15
Sm-151	5.74E–19	9.75E–19	1.31E–20	5.81E–18	7.0E–19	1.3E–18	9.7E–21	9.8E–18
Ho-166m	2.79E–14	2.79E–14	1.84E–15	1.70E–13	3.4E–14	5.0E–14	2.1E–15	3.5E–13
Pb-210	2.61E–15	6.42E–15	8.58E–18	4.09E–14	3.4E–15	1.1E–14	9.6E–18	7.7E–14
Ra-226	6.44E–12	6.83E–12	4.82E–13	4.32E–11	7.2E–12	1.1E–11	4.2E–13	7.4E–11
Ac-227	5.93E–16	1.17E–15	1.00E–17	7.25E–15	7.4E–16	1.9E–15	1.1E–17	1.2E–14
Th-229	4.08E–12	7.44E–12	7.21E–14	4.89E–11	4.6E–12	1.1E–11	6.4E–14	7.9E–11
Th-230	2.80E–12	5.09E–12	4.47E–14	3.11E–11	3.0E–12	7.5E–12	4.2E–14	5.2E–11
Th-232	3.14E–12	5.71E–12	5.02E–14	3.58E–11	3.4E–12	8.5E–12	4.7E–14	5.9E–11
Pa-231	5.95E–12	1.03E–11	1.24E–13	5.97E–11	6.1E–12	1.2E–11	9.8E–14	6.9E–11
U-233	3.74E–13	4.12E–13	2.74E–14	2.60E–12	3.7E–13	5.4E–13	2.2E–14	3.9E–12
U-234	3.61E–13	4.00E–13	2.62E–14	2.51E–12	3.6E–13	5.3E–13	2.1E–14	3.8E–12
U-235	3.43E–13	3.79E–13	2.49E–14	2.33E–12	3.4E–13	5.0E–13	2.0E–14	3.6E–12
U-236	3.42E–13	3.87E–13	2.41E–14	2.50E–12	3.4E–13	4.9E–13	2.0E–14	3.6E–12
U-238	3.14E–13	3.48E–13	2.30E–14	2.16E–12	3.1E–13	4.5E–13	1.9E–14	3.3E–12
Np-237	2.03E–12	2.45E–12	1.07E–13	1.54E–11	2.1E–12	3.3E–12	7.8E–14	2.2E–11
Pu-238	2.66E–16	5.60E–16	5.13E–18	3.39E–15	3.6E–16	1.0E–15	5.8E–18	6.0E–15
Pu-239	1.04E–12	1.87E–12	2.46E–14	1.16E–11	1.2E–12	2.8E–12	2.6E–14	1.8E–11
Pu-240	6.60E–13	1.27E–12	1.62E–14	7.34E–12	7.7E–13	1.9E–12	1.7E–14	1.2E–11
Pu-242	1.18E–12	2.15E–12	3.18E–14	1.41E–11	1.3E–12	3.2E–12	2.9E–14	2.0E–11
Am-241	5.79E–14	8.97E–14	1.41E–15	5.59E–13	6.9E–14	1.3E–13	1.2E–15	1.1E–12
Am-242m	5.61E–15	9.59E–15	1.26E–16	5.84E–14	6.6E–15	1.3E–14	1.1E–16	1.1E–13
Am-243	2.33E–12	2.78E–12	9.63E–14	1.67E–11	2.6E–12	4.0E–12	7.3E–14	2.8E–11
Cm-244	3.24E–18	5.78E–18	5.76E–20	3.75E–17	4.1E–18	8.1E–18	4.9E–20	4.8E–17
Cm-245	9.29E–13	1.40E–12	2.22E–14	8.99E–12	1.0E–12	1.7E–12	1.7E–14	1.0E–11
Cm-246	6.48E–13	1.02E–12	1.55E–14	6.33E–12	7.1E–13	1.2E–12	1.2E–14	7.4E–12

Table 17-6. Probabilistic results from coast module compared with reference results. All units in Sv/year.

Nuclide	Tensit				Reference			
	Mean	Std.	Min	Max	Mean	Std.	Min	Max
H-3	3.05E–18	1.43E–18	9.13E–19	8.31E–18	3.2E–18	1.5E–18	9.9E–19	9.0E–18
Be-10	3.93E–16	3.91E–16	3.44E–17	2.07E–15	3.9E–16	3.9E–16	3.3E–17	2.1E–15
C-14	1.61E–15	2.35E–16	1.11E–15	2.30E–15	1.7E–15	2.4E–16	1.2E–15	2.4E–15
Cl-36	1.61E–16	6.27E–17	5.98E–17	3.63E–16	1.6E–16	6.4E–17	6.3E–17	3.9E–16
Co-60	4.94E–16	2.48E–16	1.12E–16	1.32E–15	5.1E–16	2.5E–16	1.1E–16	1.3E–15
Ni-59	2.24E–17	9.68E–18	5.52E–18	5.18E–17	2.2E–17	9.6E–18	4.7E–18	5.0E–17
Ni-63	5.23E–17	2.23E–17	1.27E–17	1.20E–16	5.2E–17	2.2E–17	1.1E–17	1.1E–16
Se-79	1.41E–14	4.34E–15	6.64E–15	2.73E–14	1.4E–14	4.3E–15	6.8E–15	2.6E–14
Sr-90	1.34E–15	6.69E–16	3.32E–16	3.63E–15	1.3E–15	6.7E–16	3.2E–16	3.6E–15
Zr-93	9.03E–17	5.18E–17	1.55E–17	2.45E–16	9.0E–17	5.3E–17	1.6E–17	2.5E–16
Nb-94	2.11E–16	1.67E–16	2.44E–17	8.39E–16	2.1E–16	1.7E–16	2.1E–17	8.9E–16
Mo-93	9.29E–17	5.68E–17	1.64E–17	3.27E–16	9.2E–17	5.4E–17	1.5E–17	3.1E–16
Tc-99	1.72E–17	1.37E–17	1.70E–18	6.61E–17	1.7E–17	1.4E–17	1.4E–18	6.9E–17
Pd-107	1.21E–18	8.27E–19	1.95E–19	4.46E–18	1.2E–18	8.4E–19	2.0E–19	4.4E–18
Ag-108m	1.11E–15	5.08E–16	3.05E–16	2.65E–15	1.1E–15	5.0E–16	2.9E–16	2.6E–15
Sn-126	9.93E–16	8.33E–16	1.47E–16	4.56E–15	9.9E–16	8.3E–16	1.4E–16	4.4E–15
I-129	1.82E–14	8.65E–15	5.46E–15	5.34E–14	1.8E–14	8.8E–15	6.0E–15	5.6E–14
Cs-135	7.78E–16	2.33E–16	3.58E–16	1.53E–15	7.8E–16	2.4E–16	3.6E–16	1.5E–15
Cs-137	4.77E–15	1.35E–15	2.28E–15	9.08E–15	4.8E–15	1.4E–15	2.3E–15	9.2E–15
Sm-151	5.83E–18	4.38E–18	8.59E–19	2.36E–17	5.9E–18	4.5E–18	7.3E–19	2.4E–17
Ho-166m	1.39E–16	1.12E–16	1.71E–17	6.06E–16	1.3E–16	1.1E–16	1.4E–17	6.0E–16
Pb-210	8.51E–14	2.56E–14	4.05E–14	1.65E–13	8.5E–14	2.6E–14	4.0E–14	1.7E–13
Ra-226	1.57E–14	6.39E–15	4.92E–15	3.46E–14	1.6E–14	6.4E–15	4.9E–15	3.6E–14
Ac-227	1.76E–13	1.68E–13	1.59E–14	8.86E–13	1.8E–13	1.7E–13	1.5E–14	9.1E–13
Th-229	1.25E–14	1.04E–14	1.00E–15	4.94E–14	1.3E–14	1.1E–14	8.4E–16	4.9E–14
Th-230	5.38E–15	4.46E–15	4.36E–16	2.13E–14	5.4E–15	4.5E–15	3.6E–16	2.1E–14
Th-232	5.90E–15	4.88E–15	4.79E–16	2.36E–14	5.9E–15	5.0E–15	3.9E–16	2.3E–14
Pa-231	1.27E–14	1.25E–14	1.13E–15	6.56E–14	1.3E–14	1.2E–14	1.1E–15	6.8E–14
U-233	2.58E–15	1.13E–15	7.46E–16	5.90E–15	2.6E–15	1.1E–15	7.5E–16	5.9E–15
U-234	2.48E–15	1.09E–15	7.38E–16	5.66E–15	2.5E–15	1.1E–15	7.2E–16	5.7E–15
U-235	2.37E–15	1.04E–15	6.86E–16	5.40E–15	2.4E–15	1.0E–15	6.9E–16	5.4E–15
U-236	2.38E–15	1.05E–15	6.98E–16	5.48E–15	2.4E–15	1.0E–15	6.9E–16	5.4E–15
U-238	2.27E–15	1.00E–15	6.79E–16	5.24E–15	2.3E–15	1.0E–15	6.6E–16	5.2E–15
Np-237	1.98E–15	1.95E–15	1.85E–16	1.06E–14	2.0E–15	2.0E–15	1.8E–16	1.1E–14
Pu-238	5.02E–15	2.15E–15	1.40E–15	1.12E–14	5.1E–15	2.2E–15	1.4E–15	1.1E–14
Pu-239	6.36E–15	2.93E–15	1.58E–15	1.44E–14	6.4E–15	2.9E–15	1.5E–15	1.5E–14
Pu-240	6.34E–15	2.90E–15	1.59E–15	1.42E–14	6.3E–15	2.9E–15	1.5E–15	1.5E–14
Pu-242	6.10E–15	2.81E–15	1.53E–15	1.38E–14	6.1E–15	2.8E–15	1.4E–15	1.4E–14
Am-241	1.63E–14	9.36E–15	2.78E–15	4.45E–14	1.6E–14	9.4E–15	2.6E–15	4.6E–14
Am-242m	1.53E–14	8.71E–15	2.67E–15	4.07E–14	1.5E–14	8.8E–15	2.5E–15	4.3E–14
Am-243	1.64E–14	9.43E–15	2.83E–15	4.46E–14	1.6E–14	9.5E–15	2.6E–15	4.6E–14
Cm-244	3.90E–15	2.61E–15	6.84E–16	1.51E–14	4.0E–15	2.7E–15	7.5E–16	1.5E–14
Cm-245	1.65E–14	1.21E–14	2.89E–15	6.22E–14	1.6E–14	1.2E–14	2.7E–15	6.5E–14
Cm-246	1.64E–14	1.21E–14	2.86E–15	6.26E–14	1.6E–14	1.2E–14	2.7E–15	6.4E–14

Appendix H

Updates to SR 97

This appendix lists updates reported for /Bergström et al, 1999/. See section 7.2 for updates used in the probabilistic simulation of the well module.

Table 18-1. The following equations have been updated.

Reads in /Bergström et al, 1999/	Update
Coastal and lake module, page 42 and 33: $TC_{sed,w} = e^{(-k\cdot\frac{D_m}{\sqrt{a\cdot 10^{-6}}})}$	Corresponds to *TC₁₂* in Table 11-7 for coast, and *TC₁₃* in Table 11-4 for lake module. $TC_{sed,w} = e^{(\frac{-k\sqrt{a}}{1000\cdot D_m})}$
Coastal module, page 42: $TC_{sed,d} = \frac{SR}{M_{sed}} - TC_{sed,w}$	Corresponds to *TC₃₂* in Table 11-7. $TC_{sed,d} = \max(\frac{SR}{M_{sed}} - TC_{sed,w}, 0)$
Lake module, page 34: $TC_{sed,d} = \frac{(SR - PP\cdot f_{sed})\frac{P_a}{100}}{M_{sed}} - TC_{sed,w}$	Corresponds to *TC₄₃* in Table 11-4. $TC_{sed,d} = \max\left(0, \frac{(SR - PP\cdot f_{sed})\frac{P_a}{100}}{M_{sed}} - TC_{sed,w}\right)$
Concentration in cereals and root-crops, page 144: $U_i = C_s \cdot B_i + \sum_{0}^{n} I_n \cdot TL \cdot C_w$	The change in this equation comes from that the remaining water on vegetation (parameter *I*) is only sampled once and then multiplyed with the number of irrigations instead of beeing sampled separetely for each irrigation event (n samples). Corresponds to Equation (13). $U_i = C_s \cdot B_i + n \cdot I \cdot TL \cdot C_w$
Concentration in vegetables, page 144: $U_v = C_s \cdot B_v + \frac{C_w}{Y_w} \cdot \frac{I}{t_{tot}} \cdot \sum_{n} \int_0^{t_n} e^{-\lambda t_n} dt$	Corresponds to Equation (14). $U_v = C_s \cdot B_v + \frac{C_w}{Y_w} \cdot \frac{I}{t_{tot}} \cdot \sum_{i=1}^{n} \int_0^{t_n} e^{-\lambda t} dt$ $t_i = i\frac{t_{tot}}{n}, \quad i = 1,2,\ldots,n$

Table 18-2. The following nuclide specific parameters have been updated.

Reference in /Bergström et al, 1999/	Updated
Translocation factors, Table A-5	No distribibution reported, shuld be triangular distribution

Table 18-3. The following nuclide independent parameters have been updated.

Reference in /Bergström et al, 1999/	Update
Irrigation events, Table 3-1 and Table 3-2	Reported T (3, 5, 7) distribution, should be U(3, 7)
Weather half-life, Table 3-1 and Table 3-2	Reported T (10, 15, 20) distribution, should be LT (10, 15, 20)
Fuel load, Table 3-17	Reported T (0. 5, 1.0, 2.0) kg d.w./h Updated to match the units used in equation for dose from inhalation on page 145. Fuel load = T (0.5/3600, 1.0/3600, 2.0/3600) kg d.w./s
Dust concentration in air, Table B-3	Reported T (3E-5, 1E-4, 3E-4) distribution, should be LT (3E-5, 1E-4, 3E-4).
Retention of irrigation water Table 3-2	Reported T (0.0001, 0.0003, 0.0005), should be T (0.001, 0.003, 0.005),
Well dilution volume, page 30	Reported 2000 m^3/year, should be T (1800, 2000, 2200)
Soil removal by weeding, Table 3-2	Reported T (0.3, 0.4, 0.5), set to zero in simulations.

Appendix I

Utility blocks

This appendix lists current Tensit utility blocks, Table 3-1.

Table 19-1. Current Tensit utility blocks presented with name and description.

Name	Description
Scatter (plot)	Plots the vector contents of a signal in a Matlab plot window. It includes a useful a legend with name tags acquired from the TENSIT block. This helps to indentify different species in a plot.
Export	Stores the content of a signal in Matlab workspace. It has a helpful feauture that assigns the worspace variable name it produces to be the same as the block name of the Export block. For instace drag and conect an Export block to your model and rename it to CompartmentA, then you will have a variable named CompartmentA in the Matlab workspace after simulation.
(List) Init Commands	When this building block is added to a model it outputs the inititalization commands of all submodel masks occuring in the the model to the Matlab prompt when runned.
(List) Mask parameters	When this building block is added to a model it outputs the mask paramaters of all sub model blocks occuring in the the model to the Matlab prompt when runned.
(List) Mask set_param	When this building block is added to a model it outputs string commands to set the mask paramaters to their current settings for all sub model blocks occuring in the the model to the Matlab prompt when runned.
(List) TC parameters	When this building block is added to a model it outputs paramaters of all Constant blocks with a name starting with TC occuring in the the model to the Matlab prompt when runned.

Inside view of conversion blocks *Mole2Bq*, Figure 19-1*,* and *Bq2 Mole,* Figure 19-2. Note that these blocks assume the simulation time unit to be in years.

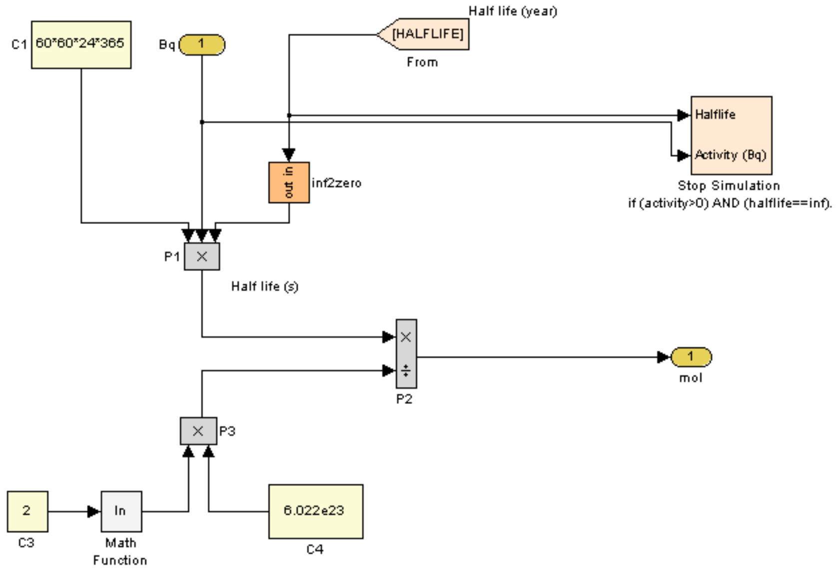

Figure 19-1. *Inside the Bq2mole block. This block converts activity in Bq to moles. There is an automatic error checking function included in the Stop Simulation block. Information about species halflife is available trough the From block, which in turn links to the TENSIT block.*

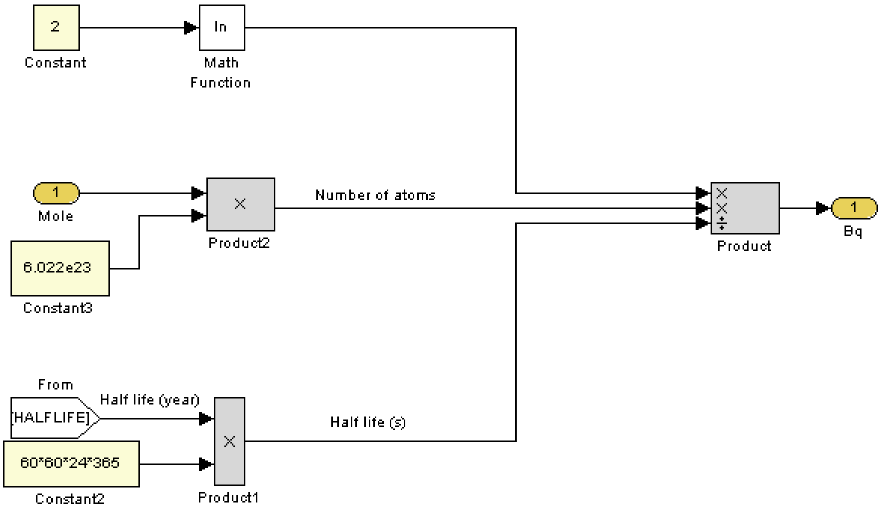

Figure 19-2. *Inside view of the Mole2Bq block. This block converts moles of species into equivalent activity in Bq. Information about species halflife is available trough the From block, which in turn links to the TENSIT block.*

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