Description of the forest countermeasure model LCMforest in RODOS PV6.0

RODOS(RA3)-TN(04)-03

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Management Summary

This document describes the countermeasure model for forests, LCMforest for RODOS PV6.0. The model is being used together with the forest food chain and dose model FDMF, described in RODOS(RA3)-TN(04)-01.

CONTENTS

1 Introduction

1.1 Objectives of the forest countermeasure model LCMforest

The main objective of the forest countermeasure model LCMforest is simulation and demonstration of the mitigating effects of countermeasures after radionuclide contamination of forested areas. Additional objective is to predict how the availability and delivery of acceptable timber can be improved.

Forest countermeasure model was developed under the project RODOS Migration (Improvement of the practical applicability of RODOS for supporting decisions in operational emergency response to nuclear accidents) under the CEC 5th Framework programme 'Research and Training Programme in the field of nuclear energy' (1998-2002).

1.2 Documentation of LCMforest and the related model FDMF

Forest countermeasure model LCMforest is an extension of the Food Chain and Dose Module for Forests, FDMF, which is an external programme integrated into the RODOS operation environment since the distribution of PV 4.0. The LCMforest can only be used together with FDMF, which provides most of the calculation routines for, and input to LCMforest.

This report contains a detailed description of the background, content and modelling of forest countermeasures in LCMforest. The necessary use of a FDMF run, archived in RODOS system, and specification of individual countermeasures and their implementation for an assessment with LCMforest are also explained.

In section 2 concepts and definitions related to assessment and implementation of countermeasures are presented. The scientific background and practicability of forest countermeasures, and the choice of the measures included in LCMforest are reviewed in section 3. Calculation of countermeasure effects are presented in section 4, and section 5 describes model data and customisation of the database.

Technical details for integration and further development of the software of LCMforest (coded by Michael Ammann) are given in the functional specification document of the LCMforest, RODOS(RA3)-TN(01)06. The related model FDMF is described in the document RODOS(RA3)-TN(04)01, and its functional specifications in the document RODOS(RA3)-TN(01)07. User guides of both models are also available as RODOS documents.

2 Overview of forest countermeasure assessment in LCMforest

2.1 Concepts and definitions

Countermeasures included in LCM_{forest} are measures for reduction of human radiation exposure caused by radionuclide contamination of forests. The model takes into account two d*ose pathways,* ingestion of wild foods, and exposure to external radiation during stay in forest. Countermeasures related to these pathways are restrictions on the use of wild foods, reduction of their activity content, and restriction of access to forests. Measures for improved availability of acceptable timber are also modelled. Reduction of radiocaesium contamination of harvested stem wood is based on soil improvement methods, and optimal timing of felling operations can increase delivery of acceptable timber.

Criteria of intervention indicate the need for intervention after radionuclide contamination of forests. They are *derived intervention levels* of quantities that control human ingestion pathway and external radiation, i.e. radionuclide concentrations of wild foodstuffs and dose rate of external radiation in forests. Intervention level is also specified for concentration of radioactive caesium in timber.

Expected reduction of radionuclide content of edible fraction of food after processing is given by type of wild food for radioisotopes of iodine, caesium, strontium and plutonium. The values of this factor depend on the elements corresponding to radioisotopes, and the actual processing methods.

Expected reduction in radiocaesium contamination of wood is related to soil improvement. This factor depends on methods and local conditions, and needs therefore to be taken into consideration by the user.

The *potential individual dose* is assessed for the entire calculation region and expresses the dose that would be received by an adult due to contamination of forests. The assessment has two components:

- Internal dose, which is directly proportional to the time-integrals of the activity contents in the edible fraction of local wild foodstuffs, and dose conversion factor for a radionuclide and age group. Consumption rate of certain type of wild food (mushrooms, berries or game meat) is applied for the individual species or subgroup of each food type, chosen by the user for a calculation run with FDMF, preceding the calculation of countermeasure effectiveness with LCMforest.
- External dose, which is proportional to time-integral of the kerma rate over time spent in forest, and dose conversion.

The *collective ingestion dose* for each chosen population group will be assessed in a corresponding way, using dietary intakes of radionuclides through wild foodstuffs in the entire calculation region. Here the assumption was made that quantities of products taken from the forest are equal to those consumed. 'Yields' of wild food products cover both harvested wild foods and the fraction unused food resources in forests. The yield cannot mostly be used as a basis for collective doses, because of substantial regional variation in the fraction of picked or hunted food products (Kangas 2001).

Collective external dose is the sum of individual doses received by persons in the calculation area.

The *effectiveness of a countermeasure* will be calculated through the averted external doses from stay in forests and through the ingestion of wild food products due to implementation of a countermeasure. The dose pathways and their relative contributions to the reduction in collective dose will vary by measure and by subgroup of population.

Implementation of countermeasures related to timber will slightly change radiation doses received in forests, and elsewhere after harvesting of timber. Also contamination of wild foods and consequently the ingestion doses, too. None of these secondary implications to human radiation exposure have been included in LCMforest

Averted collective dose is the primary quantity for assessing the effectiveness of a countermeasure applied in a region.

For countermeasures related to the production of timber effectiveness is demonstrated through improved availability of acceptable timber in the region. In addition, through optimised timing of felling operations the utilisation of wood can be improved, which is shown by profitability of production of timber per unit area of forest.

2.2. Use of numerical criteria of intervention

In LCMforest the time of application, duration, and region of implementation of a countermeasure are derived using intervention values for activity concentrations (in wild foods and debarked stem wood), and external dose rate, as relevant for each measure. The area and duration of intervention are derived from an assessment with FDMF, which provides the predictions of time dependent dose rates, contamination of forest products, and collective doses from normal use of forests and forest products. Further, these data are reference values for assessment of the corresponding quantities after implementation of a countermeasure and deriving its effectiveness.

The user of the model can modify values of intervention levels for selected countermeasures through the LCMforest user interface. There is also technically possible to return to calculation of countermeasure effect several times, during a set of successive modifications of intervention levels. This function will support finding an optimal intervention level for a certain dose pathway in a specified contamination situation.

2.3 Choice of model parameters by the user

In stage of initialisation of a run with FDMF the user will select the radioecological region, the day of deposition, type of forest, one species or subgroup of each type of wild foodstuffs, i.e. mushrooms, berries and game meat, and population groups whose exposure to radiation will be assessed. Radionuclides are chosen for atmospheric dispersion model (ADM) before the FDMF run. The results from any previous FDMF run that is archived for LCMforest can be chosen as a reference case for countermeasure assessment with LCMforest.

Through the user interface LCMforest allows the specification of the content and implementation details of each countermeasure selected for calculation. The user can set the expected effect of a food processing method on the reduction of food contamination with the isotopes of caesium, iodine, strontium or plutonium, as chosen for assessment. For all soil improvement measures the user can set the level of reduction in radiocaesium activity concentration in debarked stem wood, the time of application, and the period of time needed to achieve the expected effect. The content of food processing and soil improvement methods can vary, and therefore the values of expected effect may need modification.

All parameters of LCMforest, both regional and those related to practical methods need to be considered, and modified as required in connection of adaptation of the model to a region not currently covered by the data. (See customisation of the model database in section 5.)

3 Scientific background and selection of forest countermeasures

3.1 About the assessment of countermeasure effect

The post-Chernobyl experience has resulted in several publications on remediation of contaminated forests. This information provides the frame for selecting realistic countermeasure options for LCMforest. It also shows that measures which modify forest ecosystem or the use of forests need careful examination for practicability.

Rather many field experiments have given evidence of reduction of radiocaesium concentrations in forest vegetation after soil improvement. Numerical values of expected reduction of contamination obtained in these studies cannot be applied arbitrarily, or on a site with known differences from the study areas by soil status and vegetation structure. However, the current knowledge base on soil improvement can be used to indicate what can be achieved on various sites, using locally tested methods and estimates for reduction of contamination, where possible.

3.2 Post-Chernobyl restoration of contaminated forests

3.2.1 Summary of findings related to planning of LCMforest

The experience gained and assessment results obtained on contaminated forest sites after the Chernobyl accident were useful for finalising the selection of countermeasures for LCMforest. The suggested measures were based on restrictions on the utilization of forests or forest products, or on modification of the contamination of forest products.

The information used in planning of forest countermeasures to be included in LCMforest contained:

- Comparative assessments on the effectiveness of forest countermeasures performed with an assessment model (Frissel et al. 1996; Shaw et al. 2001)
- Experience on remediation programmes implemented in the former Soviet Union (Panfilov 1999; Linkov et al. 1997; Voigt and Semioschkina, 1999)
- Evaluation of various countermeasure options suggested for contaminated forests (Rafferty and Synnot, 1999; Fesenko and Brown, 1999), and
- Compilation of information to be taken into consideration in planning of intervention strategies for forests contaminated by radionuclides in Northern Europe (Hubbard et al. 2002).

- A review of field experiments giving evidence of the remedial potential of soil improvement methods in forestry (Rantavaara and Aro, 2003),
- Comparison of various exposure pathways and demonstration of regional modelling with a preliminary forest countermeasure model for RODOS (Rantavaara and Ammann, 2002),
- Assessment of remediation costs and profitability of fertilisation after a hypothetical radiocaesium contamination of an advanced pine forest (Rantavaara et al. 2002), and
- Compilation on food processing data (IAEA 1994).

3.2.2 Practicability of countermeasures suggested for forestry

Consideration of practicability of countermeasures to be included in LCMforest was facilitated by communication between two other projects under the same CEC framework programme as RODOS Migration project. Content of practicability was provided for the process of evaluation of rural countermeasures in the project FARMING (Nisbet and Mercer 2002). The criteria of practicability included technical feasibility, capacity, cost, radiological impact, environmental impact and acceptability. The project STRATEGY (Howard et al. 2002) was directed towards documentation, evaluation and assessment of rural countermeasures. Forest countermeasures suggested for LCMforest were also communicated to and reviewed by experts connected with the STRATEGY project.

The practicability of several countermeasures related to forestry has been discussed in some projects of the 4th Framework programme of the CEC in 1996-1999 (Rafferty and Synnot 1998) and in the Nordic Nuclear Safety Research Programme1998-2001 (Hubbard et al. 2002). Some countermeasures and remediation strategies related with forestry and of interest to modellers of LCMforest are commented in the following.

Banning. Fesenko & Brown (1999) and Voigt and Semioschkina (1999) conclude that simple restrictive countermeasures as banning of wild foods are cost-effective and feasible in most circumstances. Banning or restricting the use of wild foodstuffs was one of the most cost-effective methods in the assessments made by Shaw et al. (2001) using the IAEA model. One of the few models developed for forest countermeasure assessment was the model of the International Atomic Energy Agency (Frissel et al. 1996).

Access restriction. External exposure can be reduced by limiting the time spent in forests for recreation, for collecting berries and mushrooms, for hunting and for forestry work. However, external doses related to contaminated forests need to be restricted less often than the use of wild foods when radiocaesium contamination in a location is the same, and the current consumption rates and times spent in forests are considered. Access restriction will also prevent picking of berries and mushrooms, and hunting, if their seasons and access restriction coincide. When the need for intervention of wild foods is assessed, the area will probably be larger than the area of denied access (Hubbard et al. 2002).

Forest management. Remediation by changing species structure and production strategies of forests as in coppice cultivation has been examined (Vandenhove 1999). The method was appraised as production of biofuel instead of timber, and the option was not relevant for LCMforest. Very few countermeasures based on forest management operations were cost-effective when Shaw et al. (2001) were using the total costs of forestry work in evaluation. However, they did not take into account that the investments for reducing contamination of timber often become compensated through improved availability and earlier cutting of acceptable trees compared to situation without intervention.

Removal of forest biomass or topsoil

Decontamination methods by which a fraction of forest biomass or surface soil is removed have not gained general acceptance. Radical removal of the forest biomass and surface layer of forest floor is certainly effective for reduction of contamination and external dose rate on the site. Unfortunately, it is destructive to the forest ecosystem (Rafferty and Synnot 1998) and produces huge quantities of radioactive waste to be disposed of (Lehto et al. 1992). Secondary costs for measures that give back the fertility of forest soil would be substantial, not least for a decline in production of timber during several years. A risk assessment study on Belarussian forests by Linkov et al. (1997) showed this method being of low practicability when contamination level was about 185 kBq ^{137}Cs per square meter.

Some other measures degrading radically the ecosystem are also looked on with reservation, when acceptability to large areas of productive forests is concerned. For instance defoliation of trees has been tested earlier, but is very artificial and has unknown secondary effects (Rafferty & Synnot 1998). Ploughing is a rather radical method for boreal forests, except for being a voluntary choice of a forest owner for its positive changes in very humid forests with a thick humus layer (Hubbard et al. 2002).

Environmental effects. Environmental impact has been of concern in the discussion about remediation of forests in the late 1990's (Amiro et al. 1999). Panfilov (1999) has presented post-Chernobyl measures used in Russia, and no methods changing radically the forest ecosystem were used. Also Fesenko and Brown (1999) appreciated methods closer to traditional forestry.

Sustainable remediation of forests

In LCM_{forest} such countermeasures are included, that would probably be accepted in local and regional management plans and guidance for forestry, considering also multiple uses of forests. Local forest owners are mostly responsible for maintaining acceptable management plans for forests. The countermeasures must not conflict with forest legislation, which in most countries is for sustainable development of forests and protection of natural biodiversity (Hubbard et al. 2002; www.FAO.org/forestry). Also the importance of certification of all stages of production of timber, and increasing consideration of consumer interest will restrict the use of such methods that would degrade the growth conditions in forests.

There are also socio-economic impacts that, among other things, include people's attitudes to decisions (Salt et al. 1999). They are expected being positive as long as both people and forests are protected and cared for.

Forest-owners' right to make a choice between acceptable strategies support the view that an assessment model like LCMforest can be a tool for planning of intervention related to forest management.

3.2.3 Evidence of the effect of intensified processing on wild foodstuffs

Activity content of edible fraction of wild food can be reduced by processing, and the expected effect depends on the method used (IAEA 1994; Rantavaara 1990). As countermeasures such processing methods, should be prioritised that substantially reduce the activity content of edible fraction of food. Methods known to households would most likely be acceptable for households. Most effective is parboiling of mushrooms, which can be applied also for species that do not necessarily need parboiling but are highly contaminated. A consumption survey showed some tendency towards additional parboiling in Finnish households in the late 1990's (Markkula and Rantavaara, 1997). Marinating and light salting are recommended for meat, and the effect can be adjusted by duration of treatment and type of lake solution (Petäjä et al. 1992). Making steam juice or purees (without peels) are among the methods for wild berries (Rantavaara 1990). Expected effect of the method has to be available to the user of LCMforest.

3.2.4 Evidence of the effect of soil management on forest vegetation

Soil improvement. Availability of acceptable timber can be improved with measures of soil improvement. Considerable reduction of the radiocaesium contamination of trees, particularly their debarked woody parts, has been measured in field conditions in boreal coniferous forests. Findings were related to harrowing of forest floor (Rantavaara and Raitio 2002), fertilisation of pine stands and understory birch on various sites (Aro et al. 2002, Kaunisto et al. 2002), effect of fertilisation on underground wood fractions (Aro and Rantavaara, 2002), effect of fertilisation or prescribed burning on radiocaesium in understory vegetation (Levula et al. 2000), and intensive fertilisation of an advanced pine stand (Moberg et al. 1999). Profitability of production of timber with or without soil improvement after a hypothetical contamination was compared by Rantavaara et al. (2002).

3.3 Countermeasures included in LCMforest

3.3.1 Summary of measures

The choice of the countermeasures included in the model was based on the experience and results of evaluation studies on real contamination situations, and the response to the need of radiation protection in them. Soil improvement methods were included after experimental results had been obtained of their effect on forest vegetation. Rather widely certain soil management measures which increase availability of mineral nutrients in soil have shown potential for reduction of the uptake of radiocaesium by forest vegetation.

The countermeasures for reduction of human radiation doses or contamination of forest products in LCMforest are:

- *Banning of wild food* (mushrooms, berries or game meat)
- *Intensified processing of wild food*,
- *Intensified processing or banning of wild food*,
- *Restriction of access* to forested areas

For *improved availability of acceptable timber* soil improvement measures have been grouped under two countermeasures in the model

- Soil preparation
- Fertilisation (or use of soil amelioration agents)

Improved utilisation of acceptable timber is based on assessed trend of radiocaesium concentration in debarked wood. The measure is called

- Timed felling operations.

3.3.2 Comments on soil improvement

Soil improvement decreases contamination of all forest vegetation, and thereby radionuclide contamination of all types of wild foods. It was not included as an option for reduced contamination of wild foods, as a change in species structure of understory vegetation may follow for some years. Grasses may temporarily dominate the field vegetation and cause a temporary decline in the harvest of berries.

Effect of soil improvement on tree growth can be substantial during rotation period. It compensates rather well the investment in the soil management operation. However, the cost for countermeasure has not been reduced by the incremental growth in LCMforest. The benefit it provides has not been taken into account in the stem biomass either, as it had unnecessarily complicated calculations and increased demand for data.

The actual growth data is needed in the model for assessments related to contamination of wood. The source of the data was the national forest inventory, which covers all types of boreal forests independent of their management history (Finnish forest research Institute, 1996).

Soil preparation by harrowing of forest floor is an example on soil preparation with at least moderate effect on root uptake of caesium. Careful patchy harrowing of the topsoil will increase the mobility of nutrients and thereby reduce radionuclide uptake by vegetation. Practicability is site-specific.

3.3.3 Population groups and averted radiation doses

FDMF includes the following groups of population: adult members of the public, children 5 years old, hunters, pickers of wild berries and mushrooms, forest workers, and vegetarians The countermeasures included in LCMforest do not call for additional subgroups of population. Forest workers can be exposed to external radiation during implementation of forest management measures related to intervention. Access restrictions protect them as in their normal work in forests, as members of the public.

End users of timber are an unidentified group whose radiation doses will be reduced through reduced content of radioactive caesium in timber. The radiation doses would be reduced in proportion to reduction in contamination of wood. Realistic modelling of the whole dose pathway from forest to the end users of debarked wood is possible at regional level. Individual doses received from the use of wood were estimated in the project TEMAS of the 4th Framework programme of the CEC (Gutiérrez et al., 1999). The methodology and modelling of dose calculation from radionuclides in building materials, also applicable for isotopes of caesium in wood, is included in the report of Markkanen (1995).

4 Calculation of countermeasure effect in LCMforest

4.1 LCMforest in relation to FDMF

The forest model FDMF (Fig. 1) provides functions and parameters for quantification of the need for intervention and assessment of countermeasure effects through LCMforest.

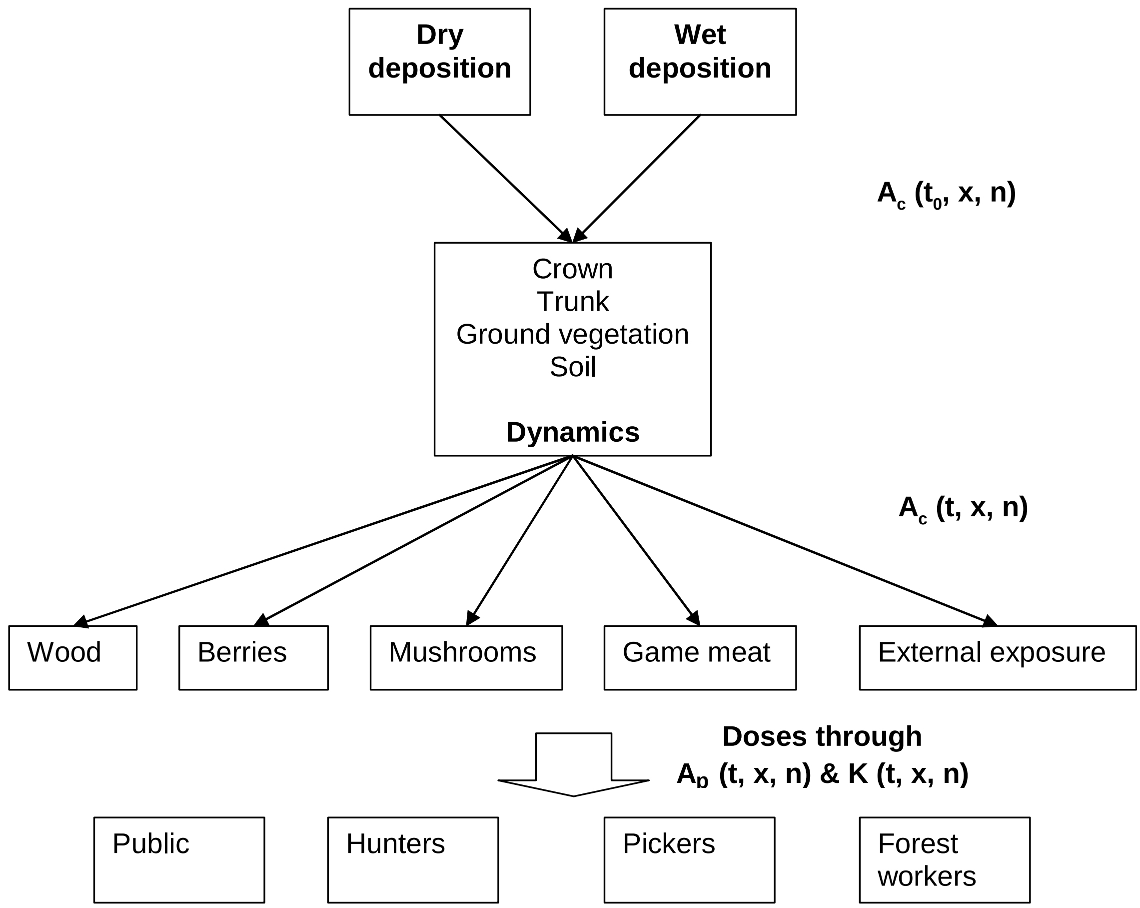

Figure 1. Main compartments and data flow in the model FDMF:

- $A_c(t_0, x, n)$: Activity concentration in compartments (c) crown, trunk, understory and soil at time t_0 (initial condition for dynamic module).
- $A_c(t, x, n)$: Activity concentration in compartments crown, trunk, understory and soil at time t.
- $A_p(t, x, n)$: Activity concentration in products: mushrooms, berries, game meat and debarked wood at time t.
- K(t,x,n): Kerma-rate in air.

The forest model FDMF provides the data for time-dependent contamination of forest products, contributions of all selected nuclides to collective ingestion doses of the population groups defined for a calculation run with FDMF, and external dose rates in forests for the entire calculation area. Such data is a necessary set of reference data for estimation of the need for intervention based on intervention criteria.

Data provided by FDMF is also used for calculation of the countermeasure effect in terms of averted collective dose, and costs for implementation of a measure. For calculation of these quantities the input from LCMforest contains specification of content and implementation of each countermeasure. The choices made in the initialisation phase of FDMF concerning region, forest type, species of various types of wild foods, and population groups are the same for the whole assessment of countermeasure effectiveness with LCMforest and FDMF.

4.2 Specification of countermeasure options of LCMforest

Radiation exposure received by people through contaminated forests can be reduced with measures at different stages of the dose pathways related to the use of forests or forest products (wild foods and timber) (Fig. 1). With countermeasures included in the LCM_{forest} the user of the model can either restrict the use of forests and forestry products, reduce the contamination of wild foods, or reduce contamination of timber and improve utilisation of acceptable timber. When defining a countermeasure related directly to human exposure the user can alter such regional parameters as consumption rates, processing factors of wild foodstuffs, and the length of time spent in forests:

- Due to *banning of foodstuffs* or *access restriction* certain components of radiation dose received from forests are set to zero for a period of time. For banning the consumption of a type of wild food, and for access restriction the time spent in forest is set to zero.
- For assessment of the effect of intensified *processing of food* the actual processing factor in the algorithm of dietary intake, included in the module for ingestion dose in FDMF will be modified.
- A reduction factor is used for quantification of the effect of *soil improvement* with fertilisation or soil preparation on the radiocaesium concentration in wood. The reduced activity concentration in wood is calculated applying a reduction factor on activity in wood after the given time period needed to achieve the expected reduction. The time of application and the time needed

to achieve the expected reduction in wood contamination are given.

- For *improved utilisation of acceptable timber* the user will accept or modify the default value for interest rate. The intervention level is given as activity concentration. To obtain the reduced contamination in wood in the same unit, the stem biomass as a function of age of trees is included in the database.

In addition to several regional parameters the user can also modify the default values of intervention criterion for all countermeasure options in the model.

4.3 Calculation of countermeasure effects

4.3.1 Begin of countermeasure assessment

The algorithms used in FDMF are modified for some parameters, and these changes provide the primary input of LCMforest to calculation of averted collective doses and costs. An archived run with FDMF has to be chosen as a reference case.

4.3.2 Restricted access to forests

Access to and staying in forest for any reason, e.g. for forestry work, or free time activity, is limited according to a given dose rate criterion. The user modifies or accepts the default value for time normally spent in forest by a group of population.

Averted radiation dose through external dose is calculated an adult individual representing the whole population in the region, and to a forest worker by reducing the times spent in forest in the equation (1).

$$D_g^{ext} = \int_t^{t'} oc_g \, mc_g \dot{D}^{ext} dt' \qquad (1)$$

Where

$\dot{D}^{ext}$ is the potential effective dose-rate (nSv h^{-1}); oc_g is the average time spent in forest (d a^{-1}) for a population group g; mc_g is a mass correction factor for calculation of effective dose for members of group g. (The database includes monthly values for oc_g to allow consideration of the seasonal exposure, but in the current model programme seasonal data has not been considered.)

The period of intervention and the value of time spent in forests (oc_g) reduced or set at zero for each subgroup will define the averted dose from equation (1).

No *costs for intervention* are estimated concerning people living or working in the area, loss of earnings of forest workers, or reduced sale of wild foods. During harvest season the access restrictions prevent harvesting wild food. The dose implications and costs for not using local wild food products are given under the method 'Banning of wild food products'.

4.3.3 Banning of wild food products

Banning means that collection of certain type of mushrooms or berries is temporarily restricted or their use is prohibited, or hunting in an area is restricted either selectively or as a whole. The method aims at reducing the collective ingestion dose through reduced or zero consumption during a period of time. Begin and duration of banning will be derived from the time dependent activity concentrations of isotopes of iodine, caesium, strontium and plutonium, that are exceeding the intervention levels which are set for food items and isotopes in question. The measure also aims at preventing high ingestion doses of population groups with exceptional dietary habits.

The measure will reduce intake rate F_g (Bq d^{-1}) of a radionuclide for each of the subgroups g in equation (2)

$$F_g = \sum_p cr_{gp} C_p^{proc} \tag{2}$$

Where

cr_{gp} is consumption rate (kg d^{-1}) of product p for a member in group g;
C_p^{proc} denotes activity concentration in product p (Bq kg^{-1} fresh weight) at time of consumption (i.e. after normal processing).

Averted radiation doses are derived through reduced intake rates to the public and its subgroups, depending on the content of food ban.

Averted external doses are calculated to hunters (in the case of a ban on game meat) and to berry and mushroom pickers (in the case of a ban on mushrooms and/or berries), and due to reduced access to forests to members of the public. It is worth noticing that wild foods can be banned also in an area where access to forests need not be restricted.

The model parameters to be modified are consumption rates for foods and time spent in forests by subgroups of population.

Costs for reduced wild food consumption are calculated. It means in practice often compensation of unacceptable wild foods with other foodstuffs. Costs are calculated in LCMforest on the basis of market price of wild foodstuffs, given in the database for berries, mushrooms and game meat.

4.3.4 Intensified processing of wild foods

For reduction of dietary intake of radionuclides wild foodstuffs can be processed more effectively than normal in cooking. Parboiling of various species of mushrooms for removal of most of their activity content rather than only following normal guidance will substantially reduce the fraction of activity remaining in edible food. Replacing use of fresh berries with use of processed berries has similar but lower effect on intake. Decontamination of game meat is possible in private households and food industry by marinating or soaking the uncooked meat in dilute solution of NaCl.

The user of the model can modify or accept processing factors suggested for different methods. The value of activity concentration in wild food at the time of consumption, calculated from equation (3) will be reduced through processing factors that refer to activity content remaining in edible fraction of food received from one kilogram of unprocessed (raw) foodstuff:

$$C_p^{proc} = pf_p\, C_p^{raw} \qquad (3)$$

Where

C_p^{proc} activity content (Bq kg^{-1} f.w.) in the processed product *p*; pf_p is the food processing factor for product *p;*

C_p^{raw} activity concentration (Bq kg^{-1} f.w.) in product *p* at time of consumption before food preparation. Consumption rates in FDMF are given for unprocessed food, and an apparent inconsistency between definition of pf_p and the unit of C_p^{proc} in equation (3), due to missing correction of mass of processed food, does not cause a mistake in calculation of dietary intake.

Combination of banning and processing of wild foodstuffs. Processing can be taken into account as an action that will improve availability of wild foodstuffs. The model provides an area of banning, where the processing of a type of wild food is not sufficient to comply with the need for intervention. The costs for unnecessary processing of highly contaminated wild foodstuffs can thus be eliminated.

4.3.5 Soil preparation

Radiocaesium contamination of growing trees can be reduced with soil improvement in the long term, during the next few years after soil improvement. The effect is rather long lasting. The change is calculated applying a reduction factor to the actual content in stem wood after the period needed to achieve the expected reduction. The time of application after the day of deposition, and the length of period of continuous decrease in wood contamination are given by the user.

Soil preparation will mix radionuclides in topsoil and thereby reduce the level of external radiation from ground. External doses from overstory will also be reduced in the long term. However, the emphasis is on timber, and the model does not currently provide the potential reduction in external dose.

Costs for soil management measures will be based on working time, use of equipment and machines, and fuel. Through improved growth some compensation of costs will normally be received, but the implementation of the measure and its costs are defined as costs for intervention. The forests in the region would not necessarily need the same type of management in normal conditions. Unit cost for soil preparation or fertilisation is given in € per hectare of forest land.

4.3.6 Fertilisation

A stand would normally be fertilised when tree growth is slow due to weakened nutrient status. Application in connection of reforestation is less effective than later, for young or advanced stands. Timing options will be suggested to the user of the model. Uptake of caesium will be reduced by 50% or 75% in the next few years, depending on dosage, and growth rate of trees will be increased for several years. The given reduction factors are suggested to be accepted or modified by the user of the model. Activity content is calculated by modifying the result of equation (4), and activity concentration is obtained through the stem biomass per unit area of forest land, given by age of tree.

4.3.7 Timed tree felling operations

A slow dynamic change of activity content in the wood compartment is normally observed in trees during tens of years: increase first and decrease later; the closer to maturity the trees are, the slower the change in activity concentration. Depending on the age of a stand, *i.e.* the remaining length of the rotation period at time of deposition, the theoretical maximum of activity content will be reached before harvesting, or not. Forest model is used for finding an appropriate time for carrying out the felling operation.

Timed felling means advanced or delayed cutting of trees to avoid harvesting of timber that would not be acceptable due to contamination in excess of the used intervention level. Acceptable timber will be harvested before or after the period of intervention, as close to the normal stage of growth as possible. Period of intervention is derived from the time-dependent contamination of wood and the set level of intervention. Activity concentration in wood, A_W, is defined by the equation (4), and given for unit area of forest land by the dynamic sub-module of the FDMF:

$$\frac{dA_W}{dt} = -\lambda^{rad} A_W + \lambda_{RW} A_R \qquad (4)$$

In barked stem wood only activity originating in soil is assumed to be found. The source is soil compartment R containing bio-available radionuclides. λ^{rad} refers to radioactive decay. Stem wood density in forest (in kg m^{-2}) as a function of tree age, given in the database, is used for calculation of activity concentration (Bq kg^{-1}).

Goal of operation is an efficient use of resources of acceptable timber in forests through modified timing of felling operations. Model shows regional differences in length of periods of acceptable contamination in wood and facilitates planning of timed felling.

[Additional dose to workers could in principle be derived for operations carried out earlier than in normal forestry, and reduced doses will be received by workers in opposite case through a decline in external radiation in forests. These calculations are not included in the model.]

No additional *costs for the felling work* are calculated in LCMforest. Reduced stem biomass due to other than normally timed felling will be taken into account in *the price of harvested stem wood*. Through the actual volume or mass of stem per unit area of forest land at the time of advanced, normal or delayed felling, the unit price of wood is assessed. The net present values of wood are calculated for the three options for the day of contaminating deposition. The default interest rate, 3%, can be modified by the user in stage of initialisation of an LCMforest run.

For cost estimation the biomass of barked stem wood per surface area of land is provided by age of trees. The harvested timber can contain logs and pulpwood , whereas harvesting losses, potential wood fuel, were assumed to remain on the forest site. Fractions of different timber in different age categories vary by species. The unit prices included in the model database (€ kg^{-1}) have been estimated considering all these factors.

4.4 Results from LCMforest

According to a choice of regional parameters for FDMF and the selected countermeasures and their parameters for LCMforest the resulting quantities presented for **all selected countermeasure options** are:

- averted collective doses of specified population groups (table),
- direct costs from, or due to implementation of a countermeasure (table),
- the quantity used as criterion of intervention in all locations of the entire region (map at the time of maximum values),

- time dependent values of the quantity used as criterion of intervention plotted for the location of maximum value at the time of maximum need for intervention in the region, and
- begin, duration and end of banning (map).

For information about all LCMforest runs a table of values set for intervention levels will be given.

LCMforest provides the following quantities, **specific to individual countermeasure options**

Banning of wild food:

- Costs for wild foodstuffs that are unacceptable for normal consumption.

Intensified processing of wild food:

- Begin, duration and end of banning after processing (maps).

Intensified processing ***or*** *banning of wild food*:

- The predicted area of banning after processing (begin, duration and end). Processing is only carried out in locations where it will reduce activity concentrations of all selected isotopes below their intervention levels (maps).
- Costs for processing (table). Costs will be lower than in the previous method which includes processing of all wild foods in the area of intervention.

Restriction of access to forests:

- Begin, duration and end of access restriction (maps).
- Costs for unused wild foods in the area of banning are given, if the user has included ingestion pathway in the countermeasure option.

Improved availability of acceptable timber, i.e. soil preparation or fertilisation:

- Intervention area in terms of begin, duration and end of banning of wood after the soil improvement has reduced wood contamination to expected level;
- difference of duration of banning without soil improvement and with application of a soil improvement measure.
- For information: the given parameters for expected effect in reduction of radiocaesium activity of stem wood, the time of application after the day of contaminating deposition, and the time needed to achieve the expected reduction in contamination of wood.

Improved delivery of acceptable timber/ Timed felling operations:

- Net present value of debarked timber (€ per hectare) on the day of deposition is given on maps for wood harvested at the predicted times: in advance of the normal time, at normal time, or delayed.
- The banning area for wood planned to be harvested at normal time (begin, duration and end) (maps);
- minimum number of years in advance of or after the normal harvesting time, when acceptable timber can be harvested (maps).

5 Model data

5.1 About data in Annex 1

The types of data which LCMforest needs for specification of countermeasure options and their implementation are rather few when compared to the database of the forest food chain and dose model FDMF. The data that is specific to LCMforest is given in Annex 1 of this report. For practical reasons, in the software also data for LCMforest is included in the database of FDMF.

The format of tables in Annex 1 reminds the actual database in the model software. However, tables have been abridged by cutting and combining the fractions of data sets whenever the values are copied from another region or parameter values for caesium are suggested as default values for other nuclides.

Currently the model database includes parameters for Central and Northern Europe. Food processing methods can be close to similar in different parts of Europe. An obvious need for local data is for soil improvement methods. The database includes values for typical age of a type of forest at the time of deposition and at the time of felling, price of wood, and stem biomass by the age of a stand.

Several default values of LCMforest parameters, provided by the database, can be modified through the user interface of the LCMforest.

5.2 Criteria of intervention

Default values for intervention levels of activity concentrations in foodstuffs are the same as maximum permitted levels in CEC regulation No. 3954/87 (1987). For external dose rate an intervention value for access restriction from STUK guidance (2001) is referred to (100 $\mu Sv\ h^{-1}$ suggested as default). Due to lack of an agreed international guidance for radionuclide contamination of wood at the time of delivery of the model software a default value of 500 $Bq\ kg^{-1}$ for a 50% dry matter content, was suggested for isotopes of caesium. The user of LCMforest can modify the default intervention values for all countermeasures.

5.3 Stem biomass by age of a stand

Age-dependent stem biomass is needed for calculation of the price of wood per unit area of forest land in LCMforest. The same data is used in FDMF for calculation of activity concentration in wood. Therefore the data is given in the model description report of the FDMF (RODOS(RA3)-TN(04)01). The information from the Eighth National Forest Inventory in Finland was used to derive the average stem volume and biomass by development class of forests in kg per m^2

(Finnish Forest Research Institute, 1996). All quantities related to debarked stem wood or wood of growing stands, also prices of wood are given for 50% dry matter (DM) content of wood. Thereby interpretation of model outputs dealing with wood, either of growing trees or harvested logs is simple.

5.4 Data for measures reducing contamination

Input interface of LCMforest provides the user the default values for expected effect of the countermeasures intended for reduction of the contamination of forest products. The methods are intensified processing of wild foods, and soil improvement that covers several methods for reduction of contamination of wood before harvesting. All these measures are dependent on element, type of forest product, and the method used for reduction of activity.

5.4.1 Intensified processing of wild foods

Processing factors for foodstuffs were chosen from experimental data from the late 1980's and early 1990's (IAEA 1994; Rantavaara 1989). The content of such factors, to be used in dose assessment calculation, is a *remaining fraction* of activity content found in a portion of edible food. This fraction has been calculated from the activity content in raw material needed for preparation of the portion of edible food mentioned above.

5.4.2 Soil improvement

The user of LCMforest can change the content of a measure for soil improvement as far as it is analogous to the described methods that reduce the root uptake of radioactive caesium in the long term. The model needs the value of *expected reduction* (in percent) in radioactive caesium activity of debarked stem wood, the *time needed to achieve the expected effect*. Reduction in contamination refers to the activity concentration of wood without soil improvement. The model allows the user define also the time of application. The user is assumed to know these details of the method to be applied in a region.

The titles of the measures given under soil improvement do not restrict the choice of the actual method. Concerning a tailored soil improvement option it is essential to know the numerical value of achievable effect, i.e. the *maximum achievable reduction* of radiocaesium activity in debarked stem wood, and the timing of the reduction.

For countermeasures based on forest management operations *the time of application* need not be quickened before a realistic, optimised site specific intervention plan is prepared for different types of forests in the contaminated area. To remind users of results of the need for sufficient time for planning the default application time is one year after the day of deposition.

Dependence on forest type defined in FDMF database has to be considered when effectiveness of a countermeasure is defined. For instance the effect of dosage of fertilisers, or new soil amendment agents, on the reduction of wood contamination needs to be examined locally. For mineral soils a reduction of 50% is realistic when normal management doses of fertilisers are used, or most of the forest floor is harrowed (Rantavaara and Raitio 2002; Aro et al. 2002). Dosage in excess of normal management for growth of trees has been categorised as intensive, and reduction factor of 75% is somewhat lower than the maximum of observed values (Moberg et al. 1999). For soil improvement with unknown, presumably moderate effect, as partial harrowing of forest floor, a reduction of 25% can be achieved in most circumstances in seven years or less after partial treatment of forest floor. One reason for not emphasising the effect of soil preparation too much is the practical difficulty in harrowing forest floor without damaging a growing stand. Clear cutting and regeneration of forest would allow soil preparation in the whole area of a stand, but LCMforest does not include forest regeneration.

5.5 Costs for implementation of countermeasures

All costs for implementation of countermeasures are regional. In Annex 1 costs derived for Finland are sometimes copied as default values for Central Europe, but authentic information for different regions should be used. The main source of information was annual statistics for forestry (Finnish Forest Research Institute, 2001).

5.5.1 Reduction of radiation exposure or contamination

The data for estimation of costs for, or due to implementation of countermeasures is described in the following.

Banning of wild food. The market price in € per kg is given for mushrooms, berries or game meat for amounts not consumed in areas where contamination is in excess of intervention level of some of the nuclides considered. For wild foods the assumed market prices tend to be somewhat lower than prices based on costs for the efforts needed to acquire wild foodstuffs from forests. For economics of multiple uses of forests such cost estimation is delivered annually.

Intensified processing of wild food. Cost for working time and use of energy are summed for each type of food, considering the method of cooking of mushrooms, berries or game meat.

Intensified processing *or* banning of wild food. Cost depends on the level of contamination of wild food products, which divides the region into areas of banning or intensified processing, and costs are assessed accordingly.

Restriction of access to forested areas: No actual costs for implementation, as losses of earnings are estimated. When ingestion pathway is linked with the countermeasure, the model takes into account the costs for eventual banning of wild foods.

Improved availability of acceptable timber through various soil improvement measures has been grouped under two countermeasures. For *soil preparation* costs for work in € per hectare are given. For *fertilisation* (or use of soil amelioration agents) the total costs for performance of the measure (work and materials) are given in € per hectare. The costs for implementation of soil improvement measures are calculated assuming that the measures are performed for purposes of intervention, i.e. costs are for intervention, not for normal forest management.

5.5.2 Improved delivery of acceptable timber

Timed felling operation is a measure that allows comparison of three felling options with LCMforest, when the normal felling time coincides with the period when contamination of wood is in excess of the intervention level(Rantavaara et al. 2002):

1. normal timing of tree cutting of the forest type chosen for the reference prediction with FDMF,
2. advanced cutting, just before the wood becomes contaminated in excess of the intervention level, and
3. delayed harvesting soon after the contamination has declined below intervention level after reaching the top content of radioactive caesium

LCMforest provides the price of debarked stem wood by age of trees for all three cutting times in € per hectare. For all these cutting times the fractions of stem wood acceptable for log-wood or mass industry are different. The prices per kg stem wood in the database are averages weighted for the fractions of different quality of wood in stems of trees of different age. Different timing of felling has effect on the quantity of wood, the unit price of wood and on losses through delayed realisation of the investment to the forest.

Unit delivery prices of wood (€ per ha) harvested at three optional times are converted to *net present values* of the price of wood. The reference day is the time of contaminating deposition. Through the user interface the default value of discount rate, 3%, can be changed.

Unit delivery prices have been provided in Annex 1 for stem wood harvested from different types of forests, defined in FDMF. The choice of the unit of wood price in the database, € per kilogram was exception from the practice of forestry, but supports the use of intervention levels given as activity concentrations. The cost for felling work has not been estimated, as felling is normal and necessary work in forestry, and LCMforest supports timing of felling that is as close to normal as possible.

5.6 Customisation of the database

Customisation of FDMF database is important also for LCMforest, because it covers all necessary, forest type specific and human data. Essential for reliability of model results are also the radioecological parameters for dynamic processes that are specific to local forest types.

The countermeasures included in LCMforest should be acceptable and effective in the conditions for which the model is customised. The modification of the database composed of text files is technically simple. Advice for customisation is given in more detail in the functional specification document of LCMforest, RODOS(RA3)-TN(01)06.

Providing regionally valid data for the countermeasure effect and timing is essential. Adaptation of LCMforest to regions not covered by the current database should be based on the knowledge on the use of forests and wild foods, characteristics of forests, and radioecological conditions in the region. The insufficient quality or representativeness of these types of data can be the main source of uncertainty of LCMforest results. Regional forest management tradition and wild food tradition may need consideration to find out realistic and acceptable methods of both soil improvement and intensified processing of wild foodstuffs.

It is an advantage to find sources of descriptive data for forests that are collected in the region at regular intervals by forestry experts. The structure of the direct costs for implementation of countermeasures should be clear, and secondary costs referred to if possible.

Soil improvement methods known to forest owners can vary locally by site conditions and by regional forest management practices. Their effects on radionuclide uptake by trees, particularly wood, should be known and related with the aims of using LCM_{forest}. The actual content of a measure having long term reducing effect on the uptake of radionuclides from soil can well vary, as the database only provides the factor showing maximum reduction and length of period corresponding to achieving full effect of reduction in contamination of wood.

The database of LCM_{forest} should correspond to the locally relevant content of countermeasures and their implementation. For optimisation of intervention strategies prices of forest products and work and other costs for forestry operations should be provided.

6 Discussion

The forest countermeasure model LCMforest was developed for RODOS decision support system to provide predictions of the effectiveness of countermeasures applied after radionuclide contamination of forests. Normal use of forests and forest products gives a reference for changes due to intervention. Radiation exposure from people's voluntary outdoor activities and work in forests, use of terrestrial wild foods, and delivery of timber are covered by the model.

The current version of LCMforest calculates the effectiveness of a countermeasure mainly as averted collective dose for various population groups. Results from implementation of a countermeasure are also shown as reduction in intervention area and duration of banning. Acceptable timber can be harvested in a larger production area, or timing of tree felling can be optimised with the model. Model results displayed through the RODOS Graphics System indicate the scale of the contamination problems and the potential of the selected countermeasures to mitigate hazards of radiation.

For purposes of radiation protection the assessment of countermeasures like access restriction, and banning of wild foods will support decision making immediately after the contaminating deposition. In addition to model predictions the measured contamination level of forests should be provided to support early decisions on intervention.

Contamination of wild foods can be assessed for selected isotopes of caesium, iodine, strontium and plutonium. Mushrooms are divided into groups by uptake of radioactive caesium, and individual species of berries and game animals can be chosen for a model run. Different types of wild food, namely mushrooms, berries and game meat have their typical regional harvesting and hunting seasons. It the LCMforest database is customised concerning seasons, species and groups of products, the model results support planning of targeted and timed banning of wild foods. Thereby unnecessary losses of wild foods can be avoided.

In production of timber the model predictions are aimed to direct planning of intervention towards practicable strategies. At local level the users of model results can probably achieve the best content of intervention through multidisciplinary collaboration in issues of radioecology and forest management. Thereby site conditions, forest type, radiation protection and potential ways of utilisation of forests in the future can be taken into account. Measurement checks are important for assurance of contamination level of timber before harvesting.

Management of growing stands with two main types of soil improvement, fertilisation and soil preparation is included in the model. Content and effect of methods can vary by site conditions and regional forest management tradition. Therefore, the local forestry experts are capable and needed to tell the dosage and timing of application on different sites. The effect of a measure for soil improvement can be significant also when applied a few years after the contaminating deposition, depending on development stage of a stand.

Regeneration stage of forests was not included in the model, although often more fundamental soil improvement would then be possible than in later stages of rotation. However, optimal timing of soil improvement aimed at reduction of radionuclide contamination of timber is later, and shown by selection of forest types in the model database. LCMforest can not cover the earliest stages of rotation for the time scale reasons either. The model calculates radionuclide transfer in forests for fifty years after contaminating deposition, which does not include the whole rotation in northern Europe.

Normal practices of good forest management take into account an appropriate development stage of a stand for different management operations. This principle has been used in defining the types of forests for FDMF and timing of countermeasures in LCMforest. Thereby acceptability of measures suggested for forestry will be improved. Demands for data are also more realistic than using an approach where countermeasures are applied at arbitrary stages of rotation.

Countermeasures included in LCMforest are chosen for productive forests and forests that are visited by the public for free time activities. Interest in urban forests has increased in general discussion and among forestry experts. Maybe more tailored and costly countermeasures not included in the current LCMforest should be assessed for implementation in densely populated areas. LCMforest could be used for sizing also such methods, which are worth consideration in the future modelling of forest countermeasures.

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Annex 1: Calculation parameters of LCMforest

Note 1: Identification codes, if not given in this Annex, are found in Annex 1 of the model description of FDMF: RODOS(RA3)-TN(04)-01.

Note 2: All costs have been estimated for Finnish conditions, and the same values are given for Central Europe by default.

1 Cost for banning of wild food

Note: Production loss is approximated by market price.

Reg_id (1) Central Europe, (230) Finland
Prod_id -- (1) mushroom, (2) berry, (3) game meat
Cost -- Production loss (euro per kg)

Reg_id	Prod_id	Cost
1	1	2.4
1	2	2.0
1	3	7.0
230	1	2.4
230	2	2.0
230	3	7.0

2 Additional cost for intensified processing of wild food

Reg_id (1) Central Europe, (230) Finland
Prod_id (1) mushroom, (2) berry, (3) game meat
Cost euro per kg

Reg_id	Prod_id	Cost
1	1	0.3
1	2	0.3
1	3	0.5
230	1	0.3
230	2	0.3
230	3	0.5

3 Typical forest management costs

Note: Data is region dependent. Region 1 has been given by default the same values as for region 230.

Reg_id (1) Central Europe, (230) Finland
Method_id (1) Harrowing, (2) Fertilisation
Cost Management costs in euro/m^2

Reg_id	Method_id	Cost
1	1	0.0155
1	2	0.0188
230	1	0.0155
230	2	0.0188

4 Typical age of varios types of forests, and normal age at cutting

Reg_id (1) Central Europe, (230) Finland

Forest_id according to table 'forest_id.dat'
Age typical age (in decades between 1 and 10) of forest

Reg_id	Forest_id	Age of a forest type	Typical age at felling
1	1	6	8
1	2	6	8
1	3	6	8
230	1	5	10
230	2	5	10
230	3	2	10

5 Nuclide groups related to maximum permitted levels for foodstuffs

Nuclide Symbolic nuclide name
Group_id Nuclide group ID:
1 strontium, 2 iodine, 3 plutonium and transplutonium,
4 caesium and other radionuclides with $T_{1/2}$ > 10 days

Nuclide	Group_id
Na-24	0
Mn-54	4
Co-57	4
Co-58	4
Co-60	4
Kr-85m	0
Kr-85	0
Kr-87	0
Kr-88	0
Rb-86	4
Rb-88	0
Sr-89	1
Sr-90	1
Sr-91	1
Sr-92	1
Y-90	0
Y-91	4
Zr-95	4
Zr-97	0
Nb-95	4
Mo-93	4
Mo-99	0
Tc-99m	0
Ru-103	4
Ru-105	0
Ru-106	4
Rh-105	0
Ag-110m	4
Sb-127	0
Sb-129	0
Te-127m	4
Te-127	0
Te-129m	4
Te-129	0
Te-131	0

Te-131m	0
Te-132	0
Te-133m	0
Te-133	0
Te-134	0
I-129	2
I-131	2
I-132	2
I-133	2
I-134	2
I-135	2
Xe-133	0
Xe-135	0
Xe-138	0
Cs-134	4
Cs-136	4
Cs-137	4
Cs-138	4
Ba-140	4
La-140	0
Ce-141	4
Ce-143	0
Ce-144	4
Pr-143	4
Nd-147	4
Np-239	3
Pu-238	3
Pu-239	3
Pu-240	3
Pu-241	3
Am-241	3
Cm-242	3
Cm-244	3
Cm-245	3
Cm-248	3

6 Price of wood

Note 1: The price is given for wood with 50% dry matter content.

Note 2: Currently no data for Region 1 is included in the database.

Reg_id: (1) Central Europe, (230) Finland
Forest_id: according to table 'forest_id.dat'
Age: age (years, in decades from 1 to 14) of harvested wood
Price Delivery price (euro/kg)

Reg_id	Forest_id	Age	Price
1	1, 2, 3	1-14	0.0
230	1	1	0.029
230	1	2	0.029
230	1	3	0.029
230	1	4	0.029
230	1	5	0.051
230	1	6	0.051
230	1	7	0.053
230	1	8	0.053
230	1	9	0.054
230	1	10	0.054
230	1	11	0.055
230	1	12	0.055
230	1	13	0.055
230	1	14	0.055
230	2	1	0.041
230	2	2	0.041
230	2	3	0.047
230	2	4	0.047
230	2	5	0.054
230	2	6	0.054
230	2	7	0.055
230	2	8	0.055
230	2	9	0.056
230	2	10	0.056
230	2	11	0.057
230	2	12	0.057
230	2	13	0.057
230	2	14	0.057
230	3	1	0.029
230	3	2	0.029
230	3	3	0.029
230	3	4	0.029
230	3	5	0.051
230	3	6	0.051
230	3	7	0.053
230	3	8	0.053
230	3	9	0.054
230	3	10	0.054
230	3	11	0.055
230	3	12	0.055
230	3	13	0.055
230	3	14	0.055

7 Summary of default values the user can modify through user interface

Quantity	**Value**	**Unit**
Intervention value for external dose rate	100	$\mu Sv\ h^{-1}$
Intervention value for activity concentration of isotopes of Cs in debarked stemwood (50% dry matter content)	500	$Bq\ kg^{-1}$
Intervention values for activity concentration in wild foodstuffs[1] for isotopes of		
- iodine	2000	
- caesium (and others with $T_{1/2} > 10$ d)	1250	
- strontium	750	
- plutonium and transplutonium elements	80	
Remaining fraction of Cs after intensified processing of		
- mushrooms	0.10	-
- berries	0.50	-
- game meat	0.30	-
Expected effect of soil improvement on the reduction of radioactive caesium in debarked stemwood, categorised as		
- moderate	25	%
- medium	50	%
- intensive	75	%
Time of soil preparation or fertilisation after the day of deposition	365	d
Time needed to achieve the expected effect on reduction of Cs in debarked stemwood	2555	d
Interest rate	3	%

1) The maximum permitted levels from CEC Council regulation No.3954/87.

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