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ANNEX A
MODEL DESCRIPTIONS

A-1. RIFE1

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The RIFE1 model has been used in this submission. The structure is shown in Figure A-1.1.

A-1.1. GENERAL

The five white compartments represent dynamic state variables in the forest system. Fluxes of radionuclides introduced into these compartments are represented as series of couple d first order differential equations which are solved numerically and which account for the mass balance of radionuclides within the system.

The shaded compartment represents biological entities which can be considered to be in quasi-equilibrium with the system over the medium- to long-term. Accordingly, aggregated transfer coefficients (T_{agg}) are used to calculate radionuclide activity concentrations in this compartment. This compartment has been used to represent mushrooms (fungi), understorey (berries) and game animals in the calculations carried out for this scenario.

A-1.2. TREES

Pine trees only have been considered in these calculations. Tree growth has been accounted for in the simulations, using the growth data provided in the scenario description.

A-1.3. SOIL

RIFE1 allows simulations of radionuclides in litter, organic soil and mineral soil. Characteristics of litter were given separately in the scenario description. Organic soil in the RIFE.I simulations combines AoF and AoH horizons. For the mineral soil, only the AoA1 and A1 horizons have been considered – this is an arbitrary choice.

A-1.4. FUNGI, UNDERSTOREY AND ANIMALS

As described above, T_{agg} values have been used to calculate activity concentrations in fungi, understorey and animal compartments . These have been obtained from the IAEA booklet of recommended values (Technical Report Series Nº 364). Ranges of values are presented in this handbook and 'best estimates' have been calculated from these ranges for the purposes of these simulations.

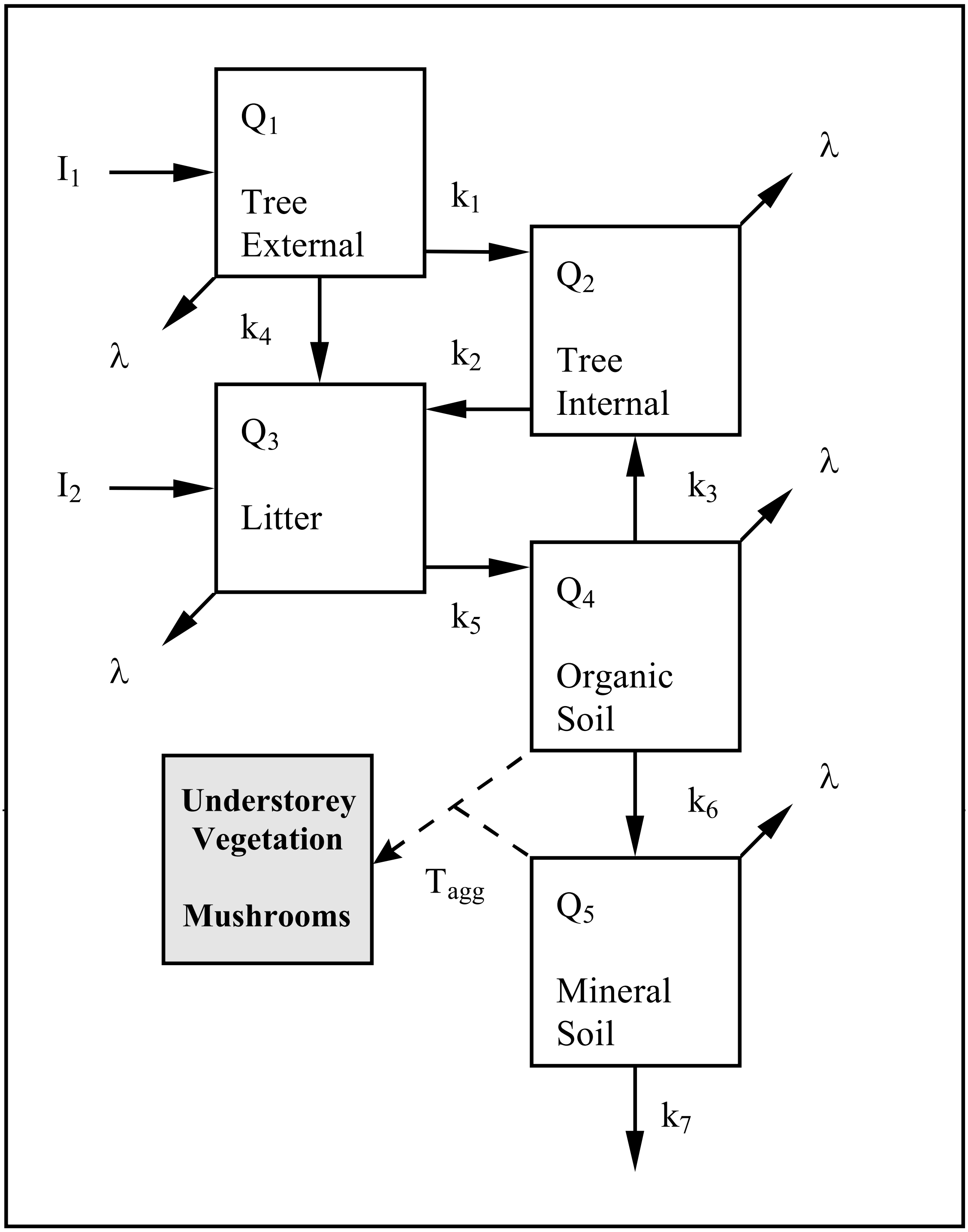

FIG. A-1.1. Structure of the RIFE1 model.

A-2. FORESTLAND

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FORESTLAND is a dynamic model for the prediction of temporal and spatial patterns of the consequences of radioactive contamination of forests ecosystems. The model is focused on migration pathways leading to internal and external radiation doses to the population. FORESTLAND can be applied to both the acute and long-term phases of the contamination created from an aerial radioactive deposition. The present version of the model consists of five individual models:

— FORBIO: A model of the biomass dynamics of trees and the understorey vegetation;

— FORGAME: A dynamic model of the long-term migration of radionuclides in forest food chains, including wild animals;

— FORACUTE: A dynamic model of the migration of radionuclides in forest ecosystems during the acute phase of the contamination;

— FORTREE: A model of the long-term migration of radionuclides in forest trees;

— FOREXT: A dosimetric model for calculation of gamma dose rate in the forest.

— FORDOSE is a model for calculation of the internal and external doses to the population (presently under development).

The structure of FORESTLAND, where outputs of one model are inputs to other models (Figure A-2.1), is specified below.

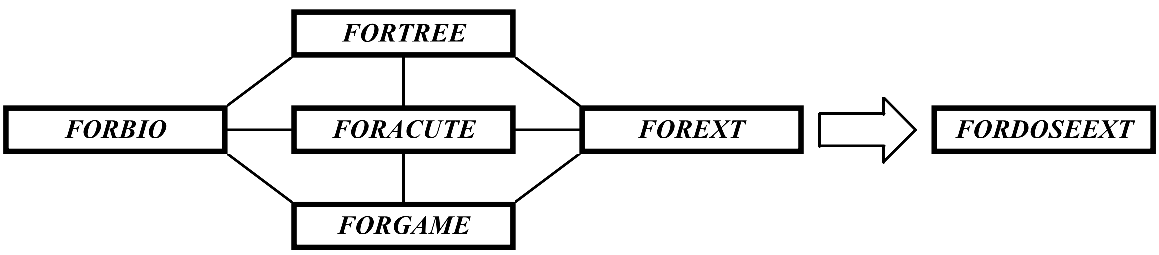


FIG. A-2.1. Interconnection of the individual models within FORESTLAND.

Interconnections between the individual models:

— The model FORBIO provides the migration models (FORTREE, FORGAME and FORACUTE) with input parameters for calculation of several transfer rates. The values of biomass density, in units of kg m^{-2}, estimated with FORBIO are used to obtain the concentration of radionuclides in different forest components, in units of Bq kg^{-1}, from the values of the radionuclide content in these components, in units of Bq m^{-2}, calculated with the migration models.

— The initial distribution of radionuclides in different forest components needed in FORTREE and FORGAME (initial conditions) are calculated with FORACUTE. Alternatively the user can define directly the initial conditions.

— FORACUTE and FORGAME provide the values of activity levels in different forest components needed for calculation of the dose rates with FOREXT. A similar connection between FORTREE and FOREXT (dashed arrow in Figure A-21) is being implemented. FORBIO provides FOREXT with some parameters needed for calculation of the attenuation and scattering of gamma rays.

— Part of the input needed by FORDOSE is generated by the migration models and FOREXT.

A classification of forest ecosystems into four different categories has been adopted in FORESTLAND. Each category corresponds to a different type of tree (coniferous or deciduous) and landscape (automorphic or hydromorphic). A set of model parameters, consisting of a best estimate value and an interval of variation, is estimated for each forest category. A scale of values is defined for each model parameter, which reduces the uncertainties of the parameter values selected for each specific application of the model.

In FORBIO a simple approach for describing seasonal and long-term biomass dynamics of trees and understorey vegetation have been applied. For the understorey vegetation and mushrooms, biomass growth is simulated with a logistic model, while an exponential decrease is assumed during senescence. Differentiation is made between summer and autumn mushrooms and between fruits of berries and the whole plant (animal feeds).

The biomass growth of an individual tree is also described with a logistic model while an exponential equation is used for calculation of tree mortality. A linear differential equation, obtained by combining the equations for growth and mortality, is used for simulating the long-term changes of tree biomass density (kg m^{-2}).

For tree leaves (needles) distinction is made between seasonal and long-term biomass dynamics. The yearly values of leaves (needles) biomass depend of the age of the tree. It is assumed that the contribution of leaves (needles) to the total tree biomass decreases from 10-15 % for a 15 years old tree to 1-2 % for a 100 years old tree. The seasonal variation of the leaf biomass is described with a logistic model during the periods of growth and senescence.

FORACUTE is a dynamic model of the migration of radionuclides during the acute phase of the contamination, lasting a few years after an aerial deposition. The model describes the primary interception of aerial deposited radionuclides by the above ground vegetation and their subsequent redistribution by transfer processes like weathering, secondary interception, translocation in the tree and the understorey vegetation, and root uptake from the upper soil-litter layer. The model also permits evaluating the dynamics of the radionuclides levels in forest products consumed by man, including forest game.

To describe the primary and secondary retention of the radionuclides by the above-ground phytomass, the latter is viewed as a set of four successive filters: the tree leaves (needles), the tree bark, the understorey vegetation and the upper soil-litter layer. The interception by the understorey vegetation is calculated with an exponential function of the biomass density (Chamberlain's equation). A method similar to the one commonly used for evaluating the passage of light though tree crowns is used to simulate the initial retention of radionuclides by trees. It is assumed that the initial retention by trees is proportional to the "projective cover (PC)" of the tree crows. The PC can be calculated from the crown closure (relative area of crowns) and the crown tracery coefficient, which depends on the tree species.

The model FORESTGAME is a dynamic model to predict seasonal and long-term changes of ^{137}Cs activity concentrations in forest food changes (Figure A-2.2). The mathematical formulation of FORESTGAME corresponds with the so-called linear compartment models. A set of 20 coupled differential equations describes the net accumulation of the radionuclide in the compartments over time. Since the model is focused on forest food chains, the migration in tree is described in a simpler way than in FORTREE. The transfer rates corresponding to the processes of root uptake and translocation in trees are, for instance, described with ordinary rate constants. The soil on the contrary is modeled in more detail (18 compartments) with the purpose of describing the influence of roots and mycelia location on root uptake by the understorey vegetation and mushrooms.

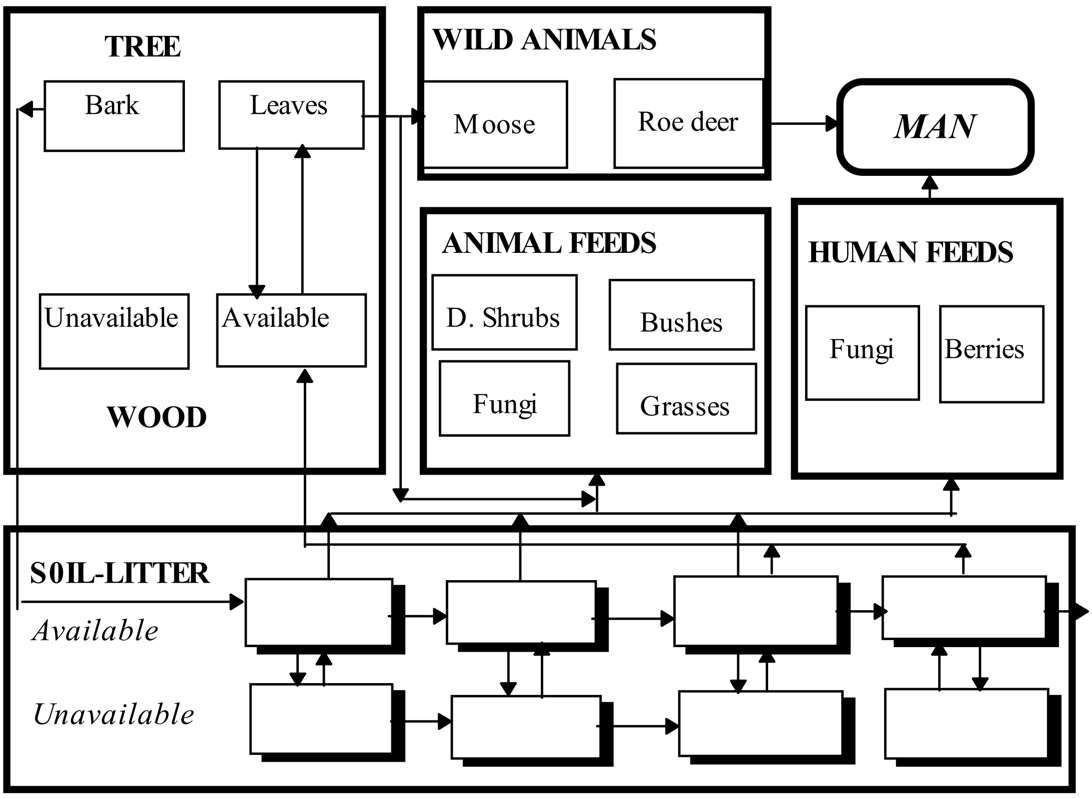


FIG. A-2.2. Conceptual scheme of the FORESTGAME model.

Root uptake by the understorey vegetation is described as a function of root distribution in soil, available fraction of ^{137}Cs in soil, the soil-to-plant concentration ratio and the biomass growth rates. The CRs are related only to the available fraction of the radionuclide in soil and have, therefore, the same values for all soil-litter layers.

The intake rate of ^{137}Cs by wild animals (roe deer and moose) is described with a function of the total feed intake, the share of different feeds in the daily animal diet and the activity concentrations in different feeds. It is assumed that the radionuclides incorporated by the animal via ingestion are instantly distributed in the animal body and that the elimination rate from muscles (edible meat) is proportional to the activity levels in this part of the animal body.

FORTREE is a dynamic compartment model of the migration of radionuclides in the tree. The main purpose of the model is interpretation and prognosis of the long-term kinetics of ^{137}Cs activity concentrations in wood. Another endpoint of the model is the seasonal change of activity concentrations in leaves (needles). The basic diagram of the FORTREE conceptual model for deciduous and coniferous trees is presented is presented in Figure A-2.3.

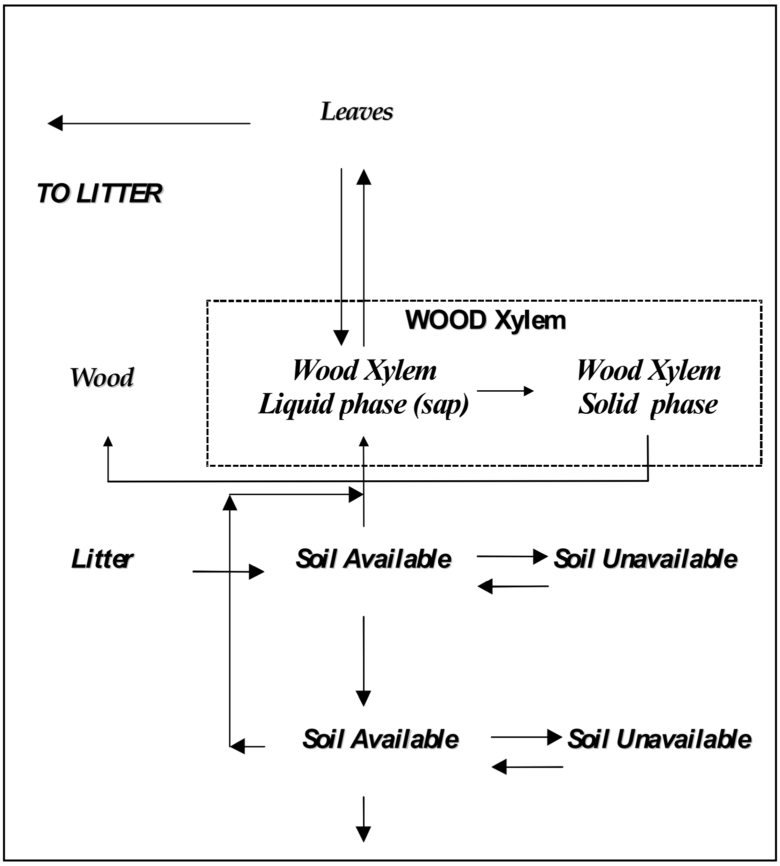
Five compartments are used to describe the change of the quantity of available ^{137}Cs in soil. The first soil layer (0–10 cm) contains the most active parts of the root and is responsible for root uptake during the first several decades after the radioactive contamination. Each soil layer is divided into an available and an unavailable fraction with the purpose of considering sorption/desorption processes leading to fixation and remobilization of the radionuclides.

The tree is described with the following compartments: two compartments for the living part of the wood (liquid and solid phases of the wood xylem), one compartment for the dead (structural) wood, one compartment for leaves (deciduous trees) and four compartments for needles of different age class (coniferous trees).

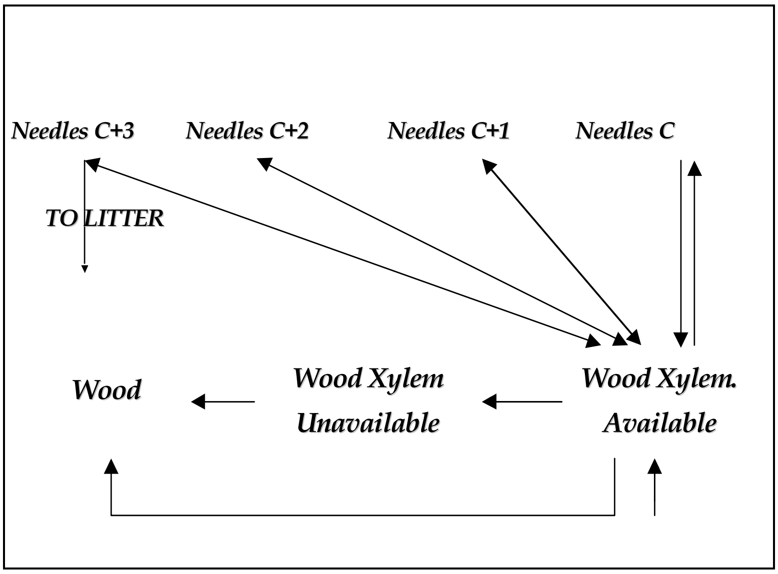
Root uptake is a function of the water flux (transpiration flow) through the xylem during the vegetative period. The main part of this flux is due to evaporation from leaves, which is proportional to the leaves (needles) biomass. The root uptake rates are, therefore, expressed as a function of the leaves (needles) biomass, which depends on tree biomass and age. A conceptual scheme of the FORTREE model is given in Figure A-2.3.

FOREXT is a dosimetric model for calculation of the dose rates in forests contaminated with gamma emitters. Although FOREXT can be used to calculate the exposure rates at any height and for any gamma emitter, in FORESTLAND the model is only adjusted for estimation of the dose rate from ^{137}Cs at 1 m above the soil surface. The vertical column of the forest is divided into 7 successive layers with different average densities. The soil is described with four layers, one for each soil horizon (L, Of, Oh and A). The fifth layer goes from the soil surface to the average height of the understorey vegetation. The frontier between the sixth and seventh layer is set at the average height of the bottom of the tree canopy.

Each layer is considered as a plate source of finite thickness. The activity of each source is calculated from the values of ^{137}Cs activity concentrations in different components of the layer provided either by FORGAME or FORACUTE. The variation of these values with time leads to time variation of the estimated dose rates. The attenuation and scattering of the photons in different layers is taken into account in the dose rate calculations.



Deciduous forest



Coniferous forest

FIG. A-2.3. Conceptual scheme of the FORTREE model.

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A-3.1. THEORETICAL PRESENTATION OF CAESIUM BEHAVIOUR IN A COMPLEX FOREST ECOSYSTEM

Our model (Bergman et al. 1993), focused on redistribution processes in a long-term perspective, belongs to the explanatory category. In our model the major regulators of energy flow, as well as of caesium turnover, are related to primary production and its constraints on the growth capacity. Certain fundamental physiological processes governing the metabolism of living matter in the biotope are also considered. The principal structure of the model is shown in Figure A-3.1.

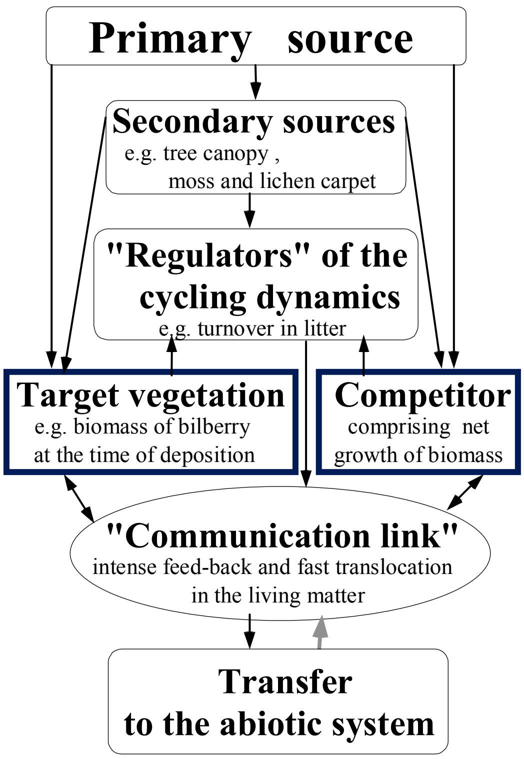

FIG. A-3.1.The principal model structure for interactions and turnover of ^{137}Cs in boreal forest ecosystems.

The model includes qualitatively effects of primary production and growth on turnover of caesium. The dependence on these factors is concluded from the following facts: primary production and its distribution over growth and litterfall constitute major regulators with regard to the dynamics of the redistribution processes of organic matter in the forest. The same conditions should be true for redistribution effects on potassium due to its essential role in the living cell. Potassium and caesium are to a high degree exchangeable in active transport over cell membranes in living tissue. Evidently both elements may serve in the same vital processes. Accordingly, as primary production is of importance for the behaviour of potassium in the forest ecosystem, it should be so for caesium too.

The qualitative system structure of processes, interactions and compartments is thus mainly based on physiological characteristics concerning transport of caesium over cell membranes and intracellular distribution, and the apparently conservative conditions prevailing for caesium in boreal ecosystems (Bergman 1994). Also, quantitative estimates have been made from the latter conditions – *e.g.* the fact that very little of the radioactive caesium deposited over the forest area is lost from the system by run-off, about 90% of the total deposition of ^{137}Cs occurs in the upper organic horizon in podzol areas, and that the availability in the ecosystem, as can be seen from the ^{137}Cs concentration in moose meat, was not significantly different in 1985 (*i.e.* prior to the Chernobyl accident) compared to the period 1986–1990 (Bergman et al. 1991).

The theoretical analysis is based on compartment theory and first order kinetics for the turnover of caesium in a boreal forest. The calculated time dependent change of the ^{137}Cs content in perennial vegetation has been compared to that actually observed at different local study sites with the focus particularly on bilberry.

The primary purpose of applying this model has been to elucidate qualitatively how predictions based primarily on growth and physiological behaviour of caesium corroborate with the main features of the time-dependent change of ^{137}Cs activity according to measurements on perennial vegetation.

A-3.1.1. Redistribution and transfer processes

Estimated transfer factors (Bergman et al 1993) are based on the actual results for the time-dependent redistribution of ^{137}Cs from secondary sources in a Scots pine canopy by throughfall and needlefall (Nylén and Grip 1989, Nylén 1996), in addition to the release to the environment of ^{137}Cs deposited over the moss and lichen carpet. After the Chernobyl accident loss from the system by runoff is less than that due to physical decay – from 1987 and onwards – and is therefore disregarded in the model. The model also includes: a "*competitor*" compartment (*i.e.* indicating the increase in biomass competing for the available caesium) to simulate influence on the redistribution processes of primary production and growth; *target vegetation* (*i.e.* the biomass of the perennial vegetation under study at the time of deposition); litterfall from this compartment; decomposition in a litter compartment; and exchange of caesium between the vegetation compartments and soil. See Bergman et al 1993 for detailed list of transfer factors and model parameters.

Effects of growth

Essential factors for the site specific growth dynamics are:

- Maximum attainable total biomass;
- Dynamics of age dependent net productivity;
- Successional stage and age of the forest stand.

Both in short and long-term perspectives these factors are expected to regulate the redistribution of caesium within and between the biotic components of the system. At sites with a poor nutrient state (e.g. on peat soil) the net biomass increase is very limited, implying relatively small "dilution" effects on the concentration of ^{137}Cs in the vegetation by redistribution of some fraction of it to the new biomass. Similarly in an old forest, where the biomass already has approached rather closely to the maximum capacity of the site productivity, further net increase in biomass is limited – *i.e.* only relatively small changes in the concentration of ^{137}Cs may be expected from growth and subsequent dilution. At sites with good soil conditions possible to support a high biomass, on the other hand, forests at young stages generally exhibit a fast net increase in biomass, which is expected to influence the concentration of *e.g.* ^{137}Cs considerably in the vegetation. Growth functions adapted to simulate the dynamics of net growth representative for many sites in the boreal vegetation zones are illustrated in Figure A-3.2. Growth of the *competitor* compartment (cf. Figure A-3.1) is governed by this time-dependence and scaled to the appropriate level of maximum biomass associated with the soil conditions at the particular sites under study.

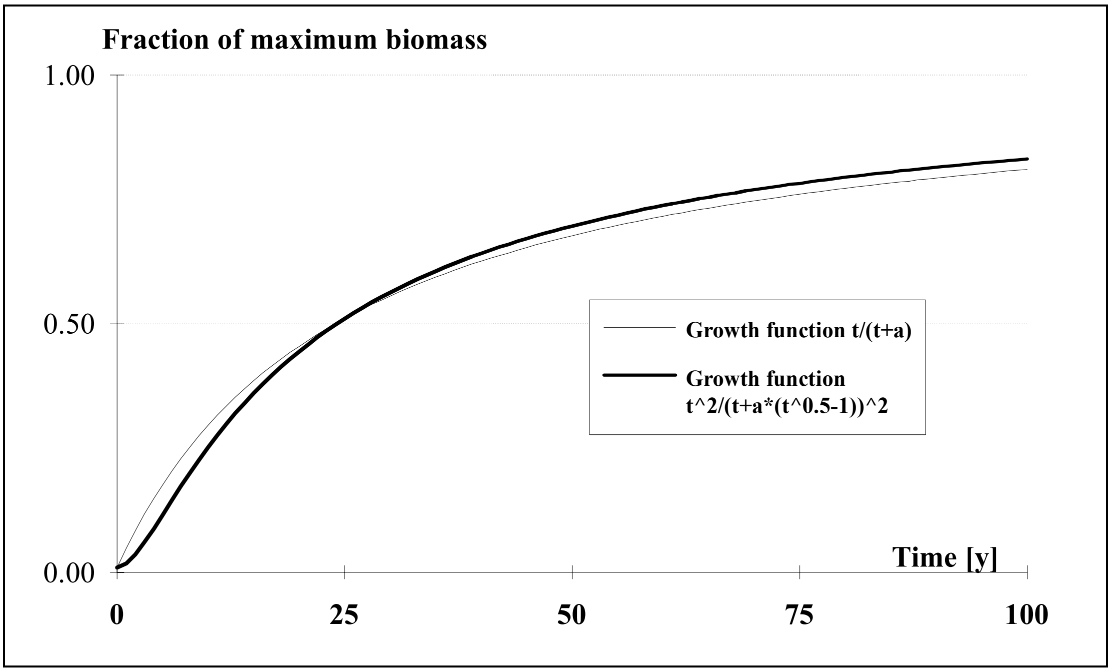

FIG. A-3.2: Fraction of maximum biomass.

A-3.1.2. Model predictions

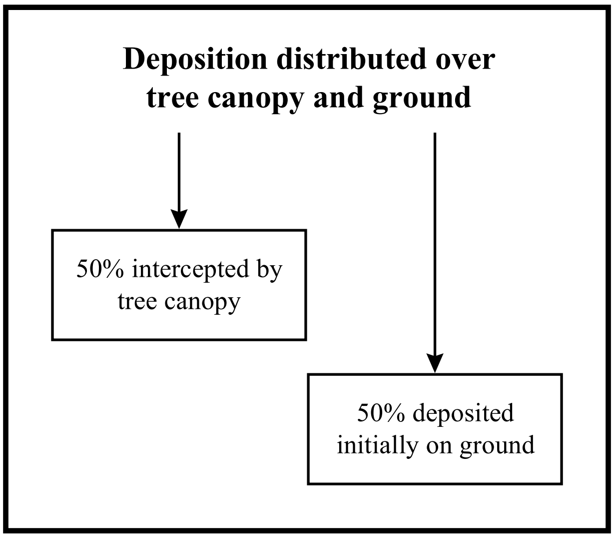

FIG. A-3.3. (cf. Bergman et al. 1993).

The behaviour of deposited ^{137}Cs has been simulated using age of the forest at fallout and nutrient state of the growing site as parameters. Interception in the tree canopy has been chosen to be similar to that which resulted after the Chernobyl accident from wet deposition at the study site (Bergman et al 1988, Nylén and Ericsson 1989, Nylén 1996) and also in coniferous forests at several sites elsewhere in the boreal zones (Bergman1994).

A-3.2. REFERENCES

BERGMAN, R., DANELL, K., ERICSSON, A., GRIP, H., JOHANSSON, L., NELIN, P., NYLÈN T., Uptake, turnover and transport of radioactive nuclides in a boreal forest ecosystem, FOA rapport E 40040 (1988) (in Swedish).

BERGMAN, R., NYLÈN, T., PALO, T., LIDSTRÖM, K., The behaviour of radioactive caesium in a boreal forest ecosystem, In: The Chernobyl fallout in Sweden – Results from a research programme on environmental radiology, Moberg, L. (Ed), Swedish radiation protection institute, 425–456 (1991).

BERGMAN, R., NYLÈN, T., NELIN, P., PALO, T., Caesium-137 in a boreal forest ecosystem: Aspects on the long-term behaviour, Det sjette Nordiske Radio¢kologi Seminar, 1992, Tùrshavn Fêroyar, FOA report C 40284-4.3 (1993).

BERGMAN, R., The distribution of radioactive caesium in boreal forest ecosystems, In: Nordic Radioecology: The transfer of Radionuclides through Nordic Ecosystems to man, Dahlgaard, H. (Ed), Elsevier Sci. Publ. (1994).

NYLÈN, T., ERICSSON, A., Uptake and retention of Cs-137 in Scots Pine, Proc. XVth Congress of IRPA, Progress in radiation protection, Feldt, W. (Ed) (1989).

NYLÈN, T., GRIP, H., The Origin and Dynamics of Cs-137 Discharge From a Coniferous Forest Catchment, accepted in J. Hydrology (1995).

NYLÈN, T., Uptake, turnover and transport of radiocaesium in boreal forest ecosystems, Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden (1996).

A-4. FORESTLIFE

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TO BE ADDED LATER ????

A-5. FORESTPATH

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Linkov , 1995 and Schell et al., 1996a developed the generic model for radionuclide transport in forests, FORESTPATH, which calculates time series of inventories for a specific radionuclide distributed within the following eight compartments: Understorey, Tree, Organic Layer, Labile Soil, Fixed Soil and Deep Soil. To incorporate details of radionuclide migration in the Organic Layer and fungi, the model was developed further (Figure A-3.1). The Organic Layer was represented by three horizons: Ol (litter), Of and Oh (Schell et al., 1996c, Linkov et al., 1999).

In the initial studies (Schell et al., 1996a, Schell et al., 1996b) uncertain model parameters were estimated for the generic model application from the literature, and satisfactory model predictions provided a general view of radionuclide fate and transport. For site-specific applications, the available literature data were limited to the ecosystems close to the site under consideration; site-specific parameters were thus estimated. Nevertheless, this deterministic approach has a limited site-specific application because it does not provide uncertainty estimates for the radionuclide concentrations in the compartments. Therefore, it cannot be used to estimate the confidence intervals for radiation doses required in risk assessment.

In recent studies (Linkov et al., 1997, Linkov at al., 1999) the model uncertainty is treated probabilistically. Results of a literature review show that values for model parameters are very uncertain and can be presented only by broad probability distributions. A triangular shape for the distributions is assumed, characterised by three parameters: minimal and maximal values, and mode.

A-5.1. REFERENCES

LINKOV, I., Radionuclide Transport in Forest Ecosystems: Modeling Approaches and Safety Evaluation, PhD Dissertation, University of Pittsburgh (1995).

LINKOV, I., MOREL, B., SCHELL, W.R. “Remedial policies in radiologically-contaminated forests: environmental consequences and risk assessment” Risk Analysis 17 67 (1997).

LINKOV, I, BURMISTROV, D., KANDLIKAR, M., SCHELL, W.R., Reducing Uncertainty in the Radionuclide Transport Modeling for the Chernobyl Forests Using Bayesian Updating in: Linkov, I., W.R. Schell, eds. “Contaminated Forests: Recent Developments in Risk Identification and Future Perspectives” Kluwer, Amsterdam (1999).

SCHELL, W.R., LINKOV, I., MYTTENAERE, C., MOREL, B., “A dynamic model for evaluating radionuclide distribution in forests from nuclear accidents” Health Physics 70, 318 (1996a).

SCHELL, W.R., LINKOV, I., RIMKEVICH, et al., “Model-directed sampling in Chernobyl forests: general methodology and 1994 sampling program” Science of the Total Environment 180 229 (1996b).

SCHELL, W.R.; LINKOV, I., BELINKAIA, E., MOREL, B., “Application of a dynamic model for evaluating radionuclide concentration in fungi” In: Proc. of 1996 Int. Congress on Radiation Protection, Vienna (1996c) p.2–752.

TABLE A-5.1. FORESTPATH MODEL COEFFICIENTS USED AS ^{137}CS INPUT FOR CONIFEROUS FOREST IN THE IAEA BIOMASS SCENARIO

Parameter	Notation	Distribution	Parameters	
			mode	a – b*
absorption half-time (years)	t_{ab}	triangular	0.6	0.2 – 1
tree biomass (t/ha)	B_t	uniform	140	120 – 160
desorption half-time (years)	t_{ds}	triangular	1.1	0.5 – 10
leaching half-time (years)	t_{lc}	triangular	800	350 – 3000
organic layer removal half-time (years)	_or	8	1-100	3
Ol	_ol		0.6	
Of	_of		1.3	
Oh	_oh		1.7	
radiation half-time (years)	$t_{1/2}$	constant	30.14	na
tree uptake half-time (years)	t_{tu}	uniform	10	1 – 100
tree removal half-time				
short (< 1 weeks)	_tr	triangular	3.6 d	1.4 – 5 d
intermediate (< 1yr)			80 d	21 – 175 d
tree removal half-time long (> 1yr)	t_{tr}		3	1 – 10
understorey removal half-time				
short (< 1 weeks)	_ur		12 d	9 – 19 d
intermediate (<1 yr)			32 d	8 – 64 d
long (>1 yr)	t_{ur}	triangular	0.2	0.1 – 2.8
understorey uptake half-time (years)	t_{uu}	uniform	8	1 – 100

*a is the minimum value and b is the maximum value for triangular and uniform distributions.

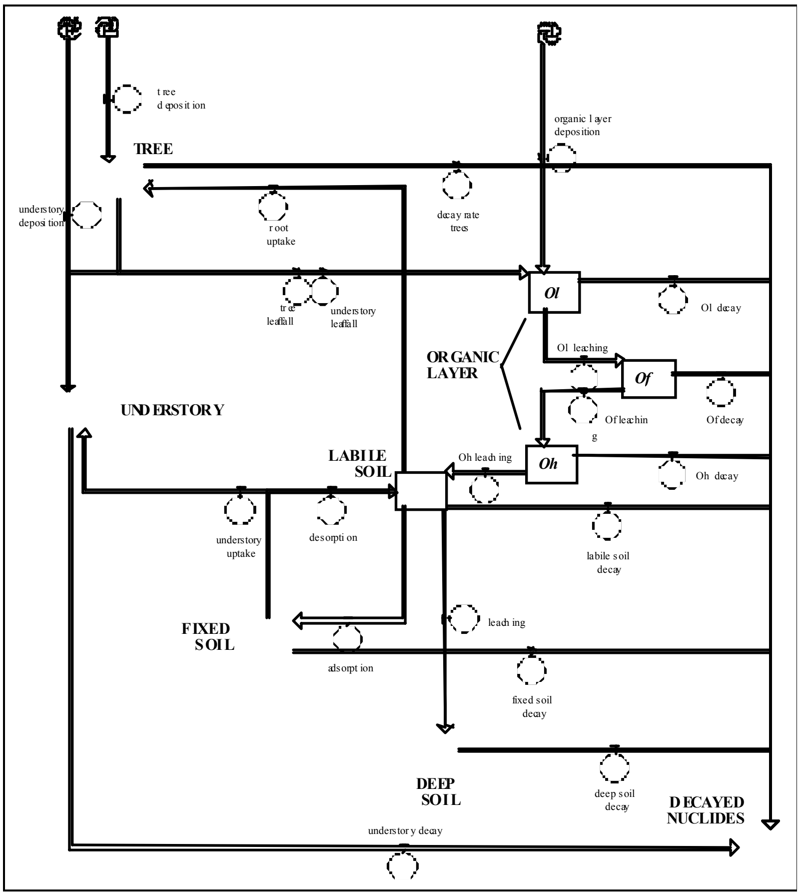

FIG. A-5.1. Diagrammatic representation of the FORESTPATH model.

A-6. ECORAD-C

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The behaviour of the radionuclide is assumed to obey the same regularities as the behaviour of its stable chemical analogue – potassium. Radionuclide dynamics is considered in parallel with the dynamics of phytomass. Radionuclides contained in the vegetation are pooled into two basic compartments: external and internal contamination, with separate analysis of each one. The model was verified using the data obtained during 1986–1994 in the 30 km zone of the accident on Chernobyl NPP.

A-6.1. DRIVING VARIABLE

Atmosphere – the arrival of radioactive matter from the atmosphere.

A-6.2. STATE VARIABLES

The following state variables are included in the model:

Organic matter content (absolutely dry weight) – Xi; content of stable potassium (^{39}K) – Ki; content of ^{137}Cs (Bq on the kilogram of absolutely dry weight): Zi – internal contamination, Yi – external contamination, Ei – total contamination. Soil contamination – Scd. Total contamination of plant and soil cover – Cd. Index i corresponds to the structural parts of plants: 1- distributive pool, 2 – needles, 3 – branches, 4w – trunk wood, 4b – trunk bark, r – large roots, rsm – small roots.

A-6.3. AUXILIARY VARIABLES

Auxiliary variables BEL and SIG are included to account for the influence of temperature and humidity in equations of transfer functions. BEL(a,b,c,d) is a Pirson's curve of I sort. It describes an asymmetric dependency of process from the value of factor a and is bell shaped. It is equal to 0 under a£b or a_d and takes a maximum value 1 under a = c. Parameter e causes a widening of the bell shape. Second variable, given by the formula: SIG(a,b,c) = (a-b)/((c-b)/2-b)+(a-b)), increases from 0 under a£b to 1 under a_c.

Since seasonal (within a year) dynamics is not considered in the given variant of the model, the inventory of organic matter in the components is computed using the following equation: Xi(t+1) = Xi(t) + Pi – Oi, where Xi(t+1) – the biomass of given year, Xi(t) – the biomass of previous year, Pi – the gross increment for a year, Oi – the annual litterfall. Then, potassium inventory in the structural components of the plant cover (Ki) and gross increment (Kpi) are computed: Ki = Xi * Ci; KPi= Pi * Ci, where Ci is the specific content of potassium (g/g of absolutely dry matter) in the component i.

A-6.4. TRANSFER FUNCTIONS

A-6.4.1. External contamination

Interception of ^{137}Cs by needles, branches and trunk bark: fy0i = a(i-1) * (1 – sig(psize, 0, 1000)) * Xi * finp, where a(i-1) is the retaining ability factor, psize is the size of particles (in micrometers) , Xi is the inventory of organic matter in the component, and finp is the contamination density (kBq km^{-2}). Function sig reflects the inverse dependence of fraction retaining ability on the size of fallout particles.

Litterfall: fyis = bi * (Yi – fyi1), where bi is the litterfall factor (the parameter reflecting the rate of self-decontamination of the fraction from the external contamination).

Radioactive decay: fyid = dc * yi, where dc – part of ^{137}Cs, decaying per a year.

The contribution of structural parts to the distributive pool: fyi1 = ci * Yi, where ci is the proportion of external ^{137}Cs contained in the fraction i entering the pool.

A-6.4.2. Internal contamination

Deductions of ^{137}Cs from fractions into the distributive pool: fzi1 = hi * Zi, where hi is the part of internal ^{137}Cs contained in the fraction i entering the pool. The distribution of ^{137}Cs from the pool into the fractions is assumed to be directly proportional to the K content in the fraction: fy1zi = Y1 * Ki / Ksum, where Ksum is the total K content in vegetation. ^{137}Cs uptake by plants from soil:

$$fsp = a6 * a7 * bell(ny, 1, 5, 100, 5) * Scd,$$

where a6 is the factor of the ecosystem moistening (hydromorphism) , a7 is the factor of maximum biological availability of ^{137}Cs for some type of soil, bell is the function depending on the dynamics of ^{137}Cs biological availability on the time passed from the moment of fallout. Distribution of ^{137}Cs entered from soil into plants by fractions: in this case it is assumed that the distribution takes place proportionally to the content of potassium in the gross increment of some fraction: fsi = fsp * KPi / KPsum, where KPsum is the total content of K in the gross increment of vegetation. Removal of the accumulated ^{137}Cs from the plants to soil with litterfall: this value is assumed to be directly proportional to the litterfall mass: fis = Zi * Oi / Xi. The export of a proportion of ^{137}Cs into the distributive pool before the litterfall is taken into account for the needle compartment.

TABLE A-6.1. PARAMETER VALUES

		Units
a1	0.141	m^2 kg^{-1} y^{-1}
a2	0.089	m^2 kg^{-1} y^{-1}
a3	0.056	m^2 kg^{-1} y^{-1}
a4	0.9	y^{-1}
a5	0.22	y^{-1}
a6	1	y^{-1}
a7	0.0017	y^{-1}

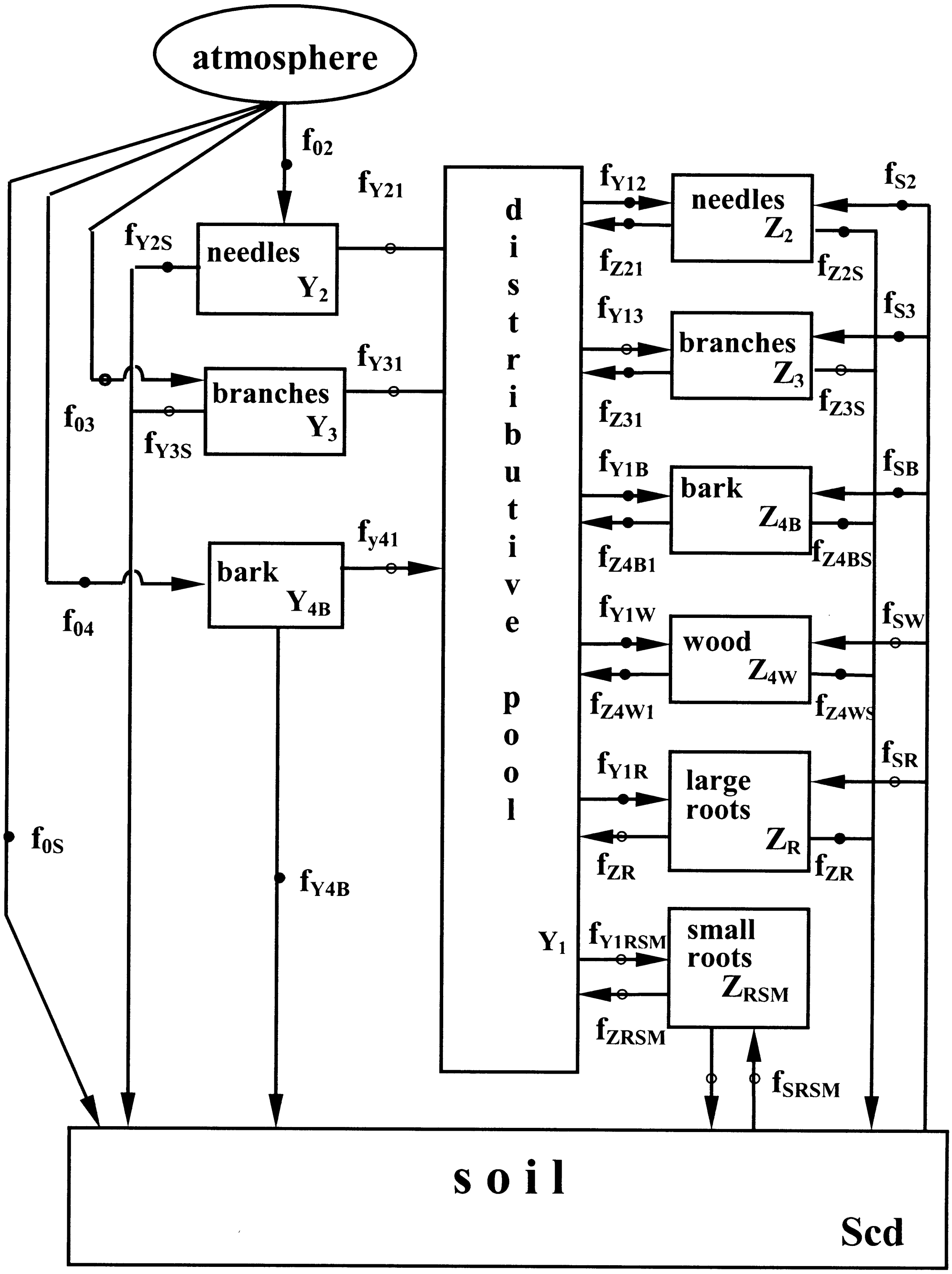

FIG. A-6.1. Flow diagram of ECORAD-C.

A-7. FINNFOOD

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The model for biological endpoints was based on observed constancy of uptake of radiocaesium by forest food products during the post-Chernobyl period in North European conditions rather similar to those defined for the scenario. The ^{137}Cs concentrations have been calculated using the formula:

$$^{137}Cs\ concentration = (Deposition\ in\ ground\ layer\ corrected\ for\ radioactive\ decay) \times Transfer\ factor\ (TF)$$

The concentrations in all food products are given for the date August 1. The activity content of trees was not considered.

Transfer factors, TF ($m^2\,kg^{-1}$ fw)	
Moose	0.01
Roe deer	0.05
Boletus edulis	0.0045
Cantharellus cibarius	0.012
Leccinium scabrum	0.021
Russula sp.	0.06
Suillus luteus	0.014
Fragaria vesca	0.004
Rubus idaeus	0.0014
Vaccinium myrtillus	0.0048

TF values are derived from the data of STUK, except for roe deer, which was taken from the IAEA Handbook of parameter values (Technical Report Series 364).

A-8. RODOS

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Food and Dose Module for Forests (FDMF) integrated after revisions in RODOS version PV4.0

A-8.1. SOFTWARE

RODOS (Real time On-line DecisiOn Support) is a software system for giving decision support for off-site emergency management in Europe. RODOS consists of subsystems for estimation of present and future distributions of activity concentrations, for quantifying benefits and drawbacks of various combinations of protective actions and countermeasures, and for evaluation of countermeasure strategies. The subsystem for estimation of activity concentrations consists of foodchain and dose modules for terrestrial and aquatic ingestion pathways. Currently, a module for modeling forest foodchains and doses, FDMF, is being developed in collaboration of IPSN and STUK. After completion, the module was integrated into the RODOSversion PV4.0.

The Foodchain and Dose Module for Forest ecosystems is composed of four submodules, for deposition, forest dynamics, external exposure and ingestion doses received through mushrooms, berries and game. Deposition calculation can be carried out for fifteen nuclides out of 69 at a time. The ingestion dose calculation is performed for nine radionuclides (I-131, Cs-134, Cs-137, Sr-89, Sr-90, Pu-238, Pu-239, Pu-240, Pu-241).

The main input parameters of this model are the time integrated concentration of radionuclides in air ($Bq.s.m^{-3}$), for dry deposition, and the total wet deposition ($Bq.m^{-2}$) and rainfall. Three forest types with different characteristics (heights, biomass and tree species) may be defined by the user. Calculations are performed for arbitrary geographical regions in Europe. The main output quantities are the concentration of radionuclides in forest gifts (mushrooms, berries and game) ($Bq\ kg^{-1}$ fresh weight), the external exposure to forest workers and to the public, and the ingestion dose for the average population, mushroom and berry collectors as well as hunters.

A-8.2. MODELS

A-8.2.1. Deposition modelling

Dry deposition to all forest compartments is calculated from time integrated concentration in air using deposition velocities and leaf area indices for vegetation compartments (crown, trunk, understorey). Wet deposition is modelled using interception fractions for each department. Interception fractions are calculated using a modified version of the formula suggested by [Müller, Pröhl 1993].

$$fw = LAI \, . \, c_f \, . \, S_i / R \, . \, [1-\exp(-\ln 2 \, . \, R / pS_i)],$$

where LAI is the leaf area index at time of deposition, c_f the fraction of tree covered area, S_i retention coefficient, R rainfall during deposition event, and p a coefficient characterising the storage capacity of each compartment. For compartments other than crown, c_f is chosen equal one, and p equal to three as in [Müller, Pröhl 1993]. Wet deposition is calculated successively for crown layer, trunk layer, understorey and soil.

A-8.2.2. Forest dynamics

After the deposition event, transfer processes distribute radionuclides between the compartments. The removal and transfer processes are described by differential equations. The processes considered currently are weathering from vegetation, litterfall from trees, foliar absorption, and uptake from soil. In the initial phase after deposition, also runoff is considered. Radionuclides deposited on soil become available to the root uptake with delay. Root uptake is controlled by nuclide specific rates. Bioavailable radionuclide (here: radiocaesium) fraction in soil is reduced by fixation and vertical migration. During ground frost and snow cover most transfer processes are essentially slower than in the growth period.

The radionuclides metabolised through foliar absorption are distributed in crown. The needle year classes exposed directly to deposition are considered in values of weathering rates for the crown in the first four years. Outputs of the forest dynamics submodule to dose calculation routines are the total activities in the compartments crown, trunk, understorey, vegetation and soil, in Bq/m^2. Tree is divided into crown and trunk below the crown for purposes of external dose calculation.

A-8.2.3. Activity concentrations in forest products

For the first ten days after deposition, the activity concentration in mushrooms is related with deposition to understorey and translocation and afterwards using transfer factors from soil.

Until the end of the first year after deposition berries are supposed to be contaminated by translocation of radionuclides from understorey via foliar absorption and for all later times using transfer factors from soil

In the first year after deposition we consider that game animals are contaminated through ingestion of contaminated understorey feed, and afterwards transfer factors from soil are used.

A-8.3. MODEL – DATA COMPARISON

A-8.3.1. Activity concentrations in mushrooms, berries and game meat (IPSN)

IPSN calculated activity concentrations in mushrooms, berries and game using the forest food chain dose calculation module (FDMF) of RODOS.

Some values of transfer coefficients are as follows:

Cantharellus cibarius, Boletus edulis	$0.05\ m^2.kg^{-1}$	(fresh weight)
Xerocomus badius, Suillus luteus	$0.5\ m^2.kg^{-1}$	(fresh weight)
Bilberry	$0.03\ m^2.kg^{-1}$	(fresh weight)
Roe deer	$0.1\ m^2.kg^{-1}$	(fresh weight)

Calculation of foodstuff concentrations received input from the dynamic module of radionuclide transfer in forest ecosystems developed by STUK. This module was still under development and differs somewhat from the (also preliminary) version used by STUK. This intercomparison exercise was an opportunity for us to test our modules and to improve the predictions.

A-8.3.2. Trees and understorey vegetation (STUK)

The components of the crown (needles, branches, and wood and bark of the stem) were considered when estimating parameters for the crown. Stem under the canopy is another tree compartment of FDMF. The distribution of ^{137}Cs in tree after deposition was derived from data for North European pine forests (Mälkönen 1974; Nygrén et. al 1994; Raitio & Rantavaara 1994).

The endpoints calculated for the BIOMASS scenario are concentrations in different tree fractions defined considering the whole tree. They were derived from FDMF normal outputs with a procedure analogous with that used in estimation of input parameters for crown and trunk. Activity concentrations in berries were derived from those of undesrstorey dwarfs.

Input parameters in FDMF were adjusted for the 50 years old pine growing at the site described in the test scenario.

The parameters related to the forest scenario were:
Crown height: 11m
Trunk height: 11m
Crown density: 2.01 kg m^{-3}
Trunk density: 1.43 kg m^{-3}
Weathering rate for crown (includes litterfall):
0.016 d^{-1}(first 60 days);
2.89 E-3 d^{-1}(following 10 months);
6.93 E-5 d^{-1}(later)
Weathering rate for trunk:
0.050 d^{-1}(first 60 days);
0.004 d^{-1}(following 10 months);
7.0 E-6 d^{-1}(later)
Runoff rate: 0.006 d^{-1} in April-October, applied until a fraction of 0.03 is reached
Foliar absorption rate: 0.013 d^{-1} (during the first 15 days)
Soil fixation and migration rate: 9.5 E-5 d^{-1}

A-8.4. REFERENCES

MUELLER, H., PROEHL G., ECOSYS-87: A dynamic model for assessing radiological consequences of nuclear accidents, Health Phys. **64** (3) (1993) 232–252.

MÄLKÖNEN, E., Annual primary production and nutrient cycling in some Scots pine stands, Comm. Inst. For. Fenn. 84.5, Helsinki (1974).

NYGREN, P., HARI, P., RAUNEMAA, T., KULMALA, M., LUOKKANEN, S., HOLMBERG, M., NIKINMAA, E., Behaviour of ^{137}Cs from Chernobyl fallout in Scots pine canopy in southern Finland, Can. J. For. Res. **24** (1994) 1210–1215.

RAITIO, H., RANTAVAARA, A., Airborne radiocaesium in Scots pine and Norway spruce needles, Sci. Tot. Env. **157** (1994) 171–180.

A-9. FORM (IAEA MODEL)

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A-9.1. DESCRIPTION OF IAEA FOREST MODEL W995_1_2 (APPLIED TO SCENARIO 1)

The IAEA forest model has been developed as a decision tool for the evaluation of countermeasures for contaminated forests. It consists of three parts: an ecological part, a dose assessment part and a financial part.

It considers in the first place countermeasures as immediate cutting and postponement of cutting. The dose resulting from harvested wood by industrial or domestic applications is included. The latter dose is the main problem of caesium-contaminated wood.

Furthermore measures are considered as no consumption of forest products, no admittance into forests, fertilisation, etc.

The model covers a period of 100 year. A detailed description of an earlier, simpler, version was described by Frissel et al, 1995.

A-9.1.1. Contributors to the model (alphabetical order)

- M. Crick (Initiator): Parameter sensitivity studies
- M.J. Frissel: Soils, uptake from soil, wood, computer programming
- E. Holm: Dose calculations, industrial applications
- C. Robison: Economical part
- G. Shaw: Tree, computer programming

The present version of the model includes the dose assessment part, but not the financial part. The model description is limited to the radioecological part.

A-9.1.2. Description

The structure of some versions of the model is shown in Figure A-9.1. The model is very easy to adapt to specific needs.

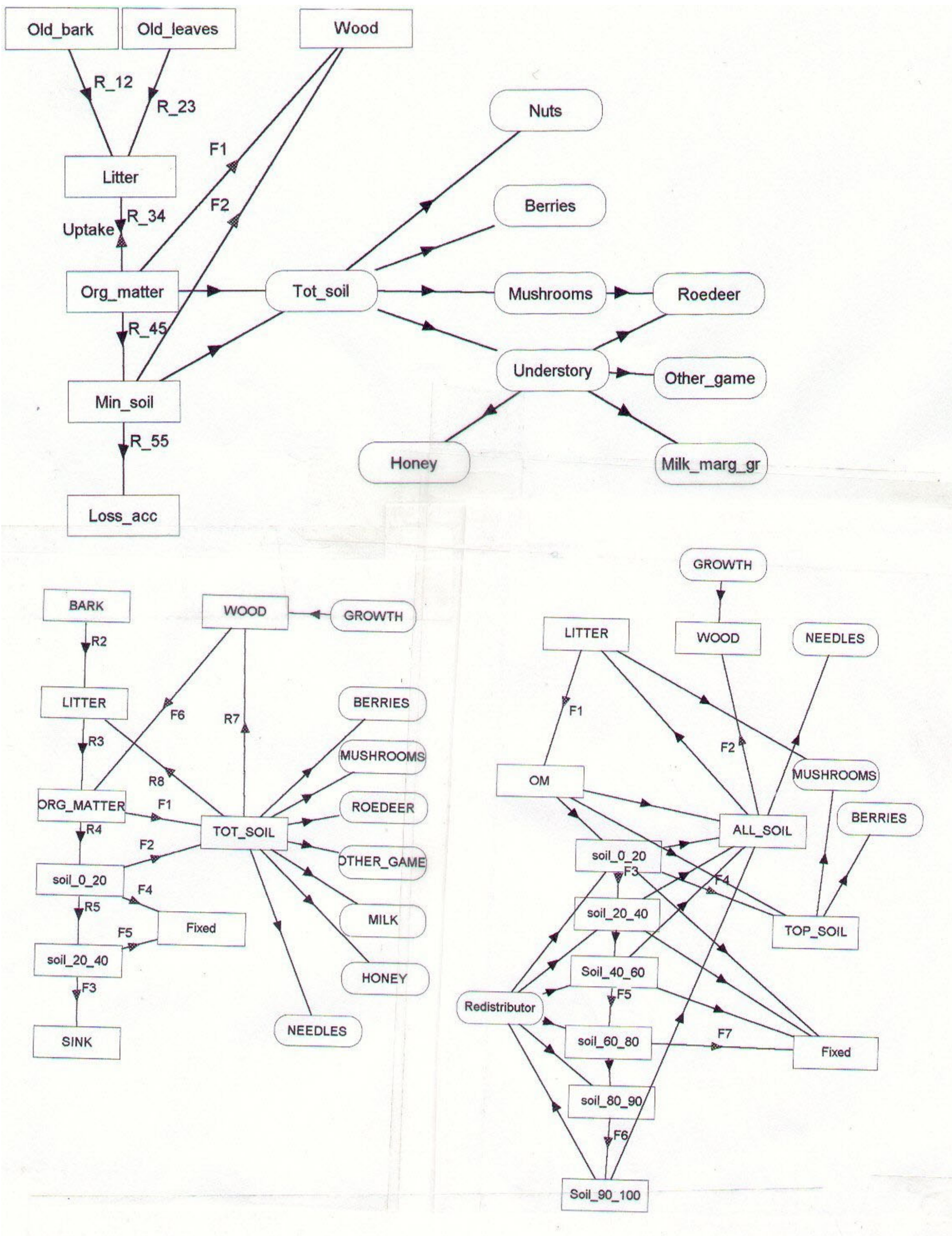

FIG. A-9.1. The IAEA Forest Model.

Top: The ecological part of the model as developed in 1995.
Bottom left: Model as adapted for Scenario 1 (forest Ukraine).
Bottom right: Model as adapted for Scenario 2 (waste deposit).

The model contains the following radioecological components:

The *dynamic* compartments, which provide the core of the model. They have the form:

$$C_t = C_{t-1} + R*dt \,,$$

where C_t is the current concentration in a compartment and C_{t-1} the concentration in the foregoing year, and R is the transfer rate between two compartments and dt is the time increment.

The *dynamic* compartments are: Cs in wood, bark, litter, organic matter, mineral surface soil, deep soil, fixed Cs and a sink.

The flow of Cs between the compartments is calculated by rate equations. The rate controlling parameters are the transfer of Cs from: Bark-to-litter, litter-to-OM, OM-to-surface soil, surface soil-to-deep soil, deep soil-to-sink and mineral soil-to-fixed Cs. The surface mineral soil layer covers the 0 –20 cm layer, the deep layer the 20 –40 cm layer. The deep layer is added to have a possibility to model uptake from this layer. The sink or loss-accumulator is added to allow a material balance for control purposes.

The uptake rate of Cs by wood is annually calculated for the annual wood growth increment, from the Cs pool in the OM and mineral surface soil layer and the use of a transfer factor. This quantity is added to the Cs which is already present in the wood from foregoing years. The production of wood is a function of the age of the tree., a typical example of a weight calculation is:

IF(age<60, G=0.0375*age^2.12, G= 220+ (age-60)*11.9

The key equation for the concentration of Cs in wood is:

$$Cs_{(wood,t)} = (Cs_{(OM+min\ surf\ soil)} *TF*dt*dG + Cs_{(wood,\ t-dt)} *G_{(t-dt)})/G_t$$

where

$Cs_{(wood,t)}$	= average Cs concentration in wood at time t, Bq/kg
$Cs_{(OM+min\ surf\ soil)}$	= Cs in OM and surface mineral soil layer at time t, Bq/m2
TF	= Transfer factor, m^2/kg
dt	= time increment, usually 1 year
dG	= growth of wood during time increment, kg
$Cs_{(wood,\ t-dt)}$	= average Cs in wood at time (t-dt), Bq/kg
$G_{(t-dt)}$	= weight of wood at time (t-dt), kg
G_t	= weight of wood at time t, kg

Because of the free choice of time of cutting and consideration of the specific growth rate, the wood contamination programming is rather complicated.

The translocation of Cs between annual wood increments is not considered. There is a parameter included which accounts for Cs loss from wood to OM, this process is called biodecay.

There is no compartment for leaves/needles or newly formed bark. For assessment calculations these compartments are not relevant. Instead, the amounts taken up by leaves, needles and new bark are immediately added to the litter pool. With a time step of one year, this is for deciduous forests very correct, for coniferous forests it leads to a conservative estimate of the dose.

To allow a comparison with other models, the concentration in leaves/needles is calculated in the same way as the concentration in other forest products. This is clearly shown in the flowchart. The initial contamination of the leaves is not considered

The bark compartment is only used to store Cs upon the initial contamination. Transfer is to litter only, transport from bark to wood is not included.

Because the litter production is expressed as Bq/kg, and the litter compartment accounts for the total Cs in the layer, the litter yield is an input parameter.

Cs fixation (i.e. irreversible absorption in soil) is considered by a first order rate process.

The model includes the following *non-dynamic* compartments: Mushrooms, berries, honey, nuts, milk, game, roedeer, grass and leaves/needles. The Cs concentrations in these compartments are calculated from the amount of Cs present in OM + mineral surface soil layer by multiplication by a simple aggregated transfer factor. For mushrooms also the litter compartment is considered.

Because there is no canopy compartment the initial distribution of a radioactive contamination is for the greater part assumed to be present in the litter layer, smaller fractions are allocated to bark, OM and mineral surface soil.

A-9.2. PARAMETER SELECTION

Most parameters were selected during the development of the model by Shaw and Frissel in 1995 and are often based on IAEA Handbook on Transfer parameters (TR 364). The soil to plant parameters for wood, leaves/needles, grass and berries are based on generic soil system reference values (Table A-9.1). These values have to be multiplied by conversion factors for specific crop groups (Table A-9.2, Frissel 1999).

The site description is not clear as far as the nutrient status is concerned. From a comparison of calculations and observed data it appears that the expected parameter values for soils with a low nutrient status show the best fit.

A-9.3. ADAPTATIONS FOR VERSION W995_2_1 (SCENARIO 3)

To adapt the IAEA model to the requirements of the waste deposit scenario two modifications were introduced.

A-9.3.1. The redistributor

The main water flow is downwards, even capillary rise will therefore not result in an upward flow of material. Diffusion is extremely slow and therefore not relevant.

The main mechanism that causes an upward transport of radionuclides in a soil is mechanical mixing due to the presence of animals. Mechanical mixing may be much more important in soil then is generally recognised, Long term studies show that the migration of Pu and Am in the upper soil layers (say upper 50 cm) is almost equal to the migration of Cs and Sr. Yet the solubility of Sr and Cs is much larger than of Pu and Am. It has been assumed that the mixing is caused soil animals.

TABLE A-9.1. EXPECTED REFERENCE TRANSFER FACTORS OF CS. REFERENCE VALUES EXPRESSED AS (Bq/kg DRY CROP)/(Bq/kg SOIL IN THE UPPER 20 cm OF SOIL)

Nutrient status	Soil type			Reference tf's of Cs for accidental releases	
				Expected value	Range
high nutrient status, pH >4.8	all soils			0.05	0.02 - 0.1
medium nutrient	Clay and loam soils			0.1	0.05 – 0.5
status, pH >4.8	Sand, peat and other soils			0.2	0.1 – 0.5
	Clay soils			0.5	0.2 – 1
	Sand and other soils			0.7	0.2 – 2
		pH >4.8		0.7	0.2 – 2
low nutrient status	Peat soils	pH <4.8	Normal moisture	1.4	0.4 – 4
OR pH < 4.8			Wet, gley	8	2 – 20
	Soils with exchangeable K <0.05 meq/100 g			5	2 – 10

TABLE A-9.2. RECOMMENDED CONVERSION FACTORS

Recommended conversion factor	Cereals	Grass	Fruit*	Leaves of woody species as tea and thyme**
Cs	1	4.5	5	20
Standard deviation for Cs	11	4		

*Values for berries may be higher

** Also applied to needles and newly formed wood.

The redistributor assumes that a certain fraction (typical value 0.03 per year) of the activity in the 90-100 cm layer is distributed over the other layers. (typical fraction values for the upper 10 cm layers 0.2, for the layer 80-90 0.84). Application of these values gives a distribution which is more or less in agreement with the observed data as provided in the scenario

A-9.3.2. Uptake from various layers

The uptake is assumed to depend on rooting depth of the tree, which in turn is a function of the age of the tree. The various uptake fractions are listed in Table A-9.3. The choice is arbitrarily and not supported by any reported observation.

TABLE A-9.3. UPTAKE FRACTIONS AS A FUNCTION OF AGE AND SOIL DEPTH

	Soil depth					
Period y	0–20 cm	20–40 cm	40–60 cm	60–80 cm	80–90 cm	90–100 cm
0 – 10	1	0	0	0	0	0
11 – 20	0.5	0.5	0	0	0	0
21 – 100	0.3	0.3	0.05	0.05	0.01	0.01

A-9.4. REFERENCES

FRISSEL, M.J., SHAW, G., ROBISON, C., HOLM, E., CRICK, M., Model for the long term countermeasures in forests, in "Radioecology and the restoration of radioactive-contaminated sites (F.F. Luykx and M.J. Frissel, Eds) Kluwer Academic Publishers (1995).

FRISSEL, M.J., Updating soil to plant transfer factors of Cs and Sr, available as Internal Working Document (1999).

A-10. FORWASTE

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A-10.1. THE MODEL STRUCTURE

A conceptual scheme of the model is given on Figure A-10.1. The model comprises two blocks – TREE and SOIL. The block SOIL consists of compartments corresponding to successive layers of soil. Number and thickness of soil layers depend on modelling objective and availability of input soil characteristics. Thickness and weight of the upper layer increase with time as a result of leaves (needles) fallout. The block TREE consists of compartments corresponding to different parts of tree. Tree parts characterised by biomass - age functions. Active roots biomass is given separately for each soil layer. For a given modelling problem some compartments can be combined. For example, radionuclide exchange between TRUNK and EXTERNAL WOOD in a young tree is quite fast and there is no reason to consider these two compartments separately. From the other hand, some part of tree can be presented in the model in more details. In particular, the compartment NEEDLES can be divided into several compartments according to the age.

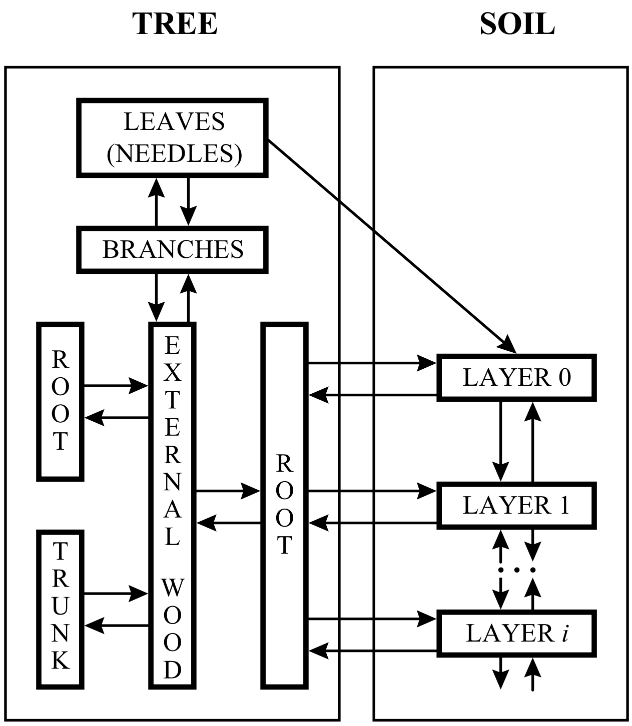

FIG. A-10.1. The model scheme.

A-10.2. RADIONUCLIDE FLUXES BETWEEN COMPARTMENTS

Uptake of radionuclides by tree roots is described in existing mathematical models as an irreversible process [1]. However, it was shown that radiocaesium introduced in the tree trunk is partially transferred to the root system and, further, to the soil around roots [2]. This means that trees uptake radiocaesium reversibly and able to release it to soil. Data on ^{137}Cs content in pine roots at different depths indicates that radionuclide downward transport via roots can be an important mechanism of redistribution of radioactive contamination in soil. In the Chernobyl NPP vicinity activity concentration of ^{137}Cs in pine roots in the lower soil layers is almost the same as in the upper one, in spite of several order of magnitude difference in soil contamination [7,8]. Based on these observations we describe root uptake of radionuclides as a reversible process and consider tree root system as one compartment.

Radiocaesium transfer from the root exchange complex to the underground part of plants is relatively fast. Characteristic time of this process for grassy plants is about 1 day [5]. The model considers the root uptake rate to be limited by the rate of radionuclide diffusion and convection through the soil layer adjacent to roots:

$$F_{i,w} = \left(\frac{D_E}{l_+} + V_T\right)\rho_i R_i B_R \sigma \left(\frac{S_i}{m_i} - \frac{W}{CR_i B_W}\right) \tag{1}$$

where:

D_E is the radionuclide effective diffusion coefficient in soil, m^2/s;
V_T is the velocity of radionuclide transport with the water taken up by roots, m/s;
ρ_i is the density of the i-th layer of soil, kg/m^3;
R_i is the fraction of active roots in the i-th layer of soil;
σ is the specific surface of active roots, m^2/kg;
B_R, B_w and m_i are dry masses of active roots, wood and the i-th layer of soil respectively, kg/m^2;
W and S_i are the radionuclide content in wood and in the i-th layer of soil respectively, Bq/m^2;
CR_i is the ratio of the radionuclide concentration in wood to that in the i-th layer of soil when the flux from the layer to wood is equal to that from wood to the layer;
l_+ is the thickness of the soil layer which is depleted in radionuclide as a result of its transfer from soil to roots, m.

The reverse flux from tree to soil occurs by diffusion only:

$$F_{w,i} = \frac{D_E}{l_-}\rho_i R_i B_R \sigma \left(\frac{S_i CR_i}{m_i} - \frac{W}{B_W}\right) \tag{2}$$

where:

l_- is the thickness of the soil layer which is enriched in radionuclide as a result of its transfer from roots to soil, m.

Values of l_+ and l_- are, generally, different and time-dependent. Then the effective flux is directed from soil to tree, almost equilibrium activity concentration in tree can be reached as a result of radionuclide transfer from a relatively thin layer of soil adjacent to roots. Then the reverse flux prevails, equilibrium can be established only after spreading of released radionuclide through the whole root zone volume. Therefore, l_+ is normally smaller than l_-.

Fluxes within tree are assumed to be reversible and described by first order kinetic equations. Relative concentrations of ^{137}Cs in different tree parts are approximately constant for a given species all over the Chernobyl zone [4, 6, 7]. This indicates that radiocaesium transfer within tree is quite fast and activity distribution between tree parts is close to equilibrium. The only exception is, probably, radionuclide exchange between external wood and trunk for a tree after a certain age.

Radionuclide flux from tree crown to the soil surface (F_{LS}, Bq/m^{2}y) is calculated as follows:

$$F_{LS} = (\phi f_L + r I_R)L/B_L \tag{3}$$

where

ϕ	is the ratio of radionuclide concentration in litterfall to that in leaves (needles) as a whole;
f_L	is the litterfall rate, kg/m^{2}y;
L	is the radionuclide content in leaves (needles), Bq/m^2;
B_L	is the biomass of leaves (needles), kg/m^2;
r	is the ratio of radionuclide concentration in the crown water to that in leaves (needles), kg/L;
I_R	is the average precipitation rate, L/m^{2}y = mm/y.

Radionuclide fluxes between soil layers are described by first order kinetic equations. Rate constants are estimated, if possible, from experimental data on radionuclide vertical distribution in soil. Given no experimental data, rate constants are calculated as a function of effective diffusion coefficient and convective transport velocity. Effective diffusion coefficient and convective transport velocity are, in turn, estimated using all available information about meteorological conditions, soil properties and radionuclide speciation.

The main distinctions of this model from existing models are:

— root uptake of radionuclide is considered to be a reversible process;

— root system depth distribution are given as a function of time;

— the model allows, from the one hand, to estimate the tree role in radionuclide vertical migration in soil, and, from the other hand, to predict radioactive contamination of tree as a function of radionuclide vertical distribution in soil.

— Model calculations shows that radiocaesium transfer from the surface radioactive waste disposal site via root system of pine can lead to significant contamination of the soil surface layer.

A-10.3. REFERENCES

[1] AVILA R., MOBERG L., HUBBARD L., Modelling of radionuclide migration in forest ecosystems, a literature review, Swedish Radiation Protection Institute Report 98:07, Stockholm, SSI, 36 p (1988).

[2] OLSON, J.S., Distribution of roots and radiocaesium migration in them in a mesophilic forest in Tennessee, In: Methods of investigation of productivity of root systems and organs of rhizosphere, Leningrad, Nauka, 143–149 (1968) (in Russian).

[3] SAK M.M., Accumulation of radionuclides by pine roots in forests of different types, In: Abstracts of Radiobiological Congress, Kiev, September 1993, Puschino, p. 880 (1993) (in Russian).

[4] SCHEGLOV, A.I., Biochemistry of technogenic radionuclides in forest ecosystems, Moscow, Nauka, 268 p. (1999) (in Russian).

[5] SOKOLIK, A.I., DEMKO, G.G., GOROBCHENKO, N.E., YURIN, V.M., Main mechanisms of ^{137}Cs root uptake, Radiation Biology, Radioecology, **37** 5, (1997) 787–795 (in Russian).

[6] IPATEV V.A., BRAGINSKY, V.F., BULAVIK, I.M., et al., “Forest. Man. Chernobyl”, Gomel, 454 p (1999) (In Russian).

[7] DVORNIK, A., ZHUCHENKO, T., Model FORESTLIFE and prediction of radioactive contamination of forests in Belarus, In: Linkov, I., Schell, W.R. (Eds), Contaminated forests, NATO Science Series **58**, Kluwer Academic Publishers, Dordrecht, The Netherlands (1999) 185–194.

A-11. LOGNAT

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ITALY

LOGNAT is written in software STELLA II and is a simple compartment-type model assessing the transfer of Cs-137 from an initial event (deposition at t=0) in function of time (years). The variable state is indicated in Bq m^{-2}. Main assumptions o the model are:

(1) The model calculates the circulation of Cs-137 in a closed system (forest), assuming an initial deposition in the litter, holorganic and leaves compartment as input values.

(2) No losses (sink) from the system are accounted for.

(3) Corrections are considered for decay, assuming ^{137}Cs half-life of 30 yrs (k = 0.023).

(4) Transfer between compartments are expressed as first order kinetics, in form of dimensionless parameters (fraction of total amount, 1/yr).

(5) Transfer parameters have been derived from experimental data (litter decomposition, soil and leaves sampling, *etc.*) and literature.

(6) The forest biomass evolution at long-term scale (*i.e.* 50 years) during simulations is calculated as growth rate function of the standing biomass.

(7) Uptake rates are considered in function of the standing biomass and productivity. Uptake rate is expressed as a fraction parameter per standing biomass unit (1/ (yr * kg of biomass)).

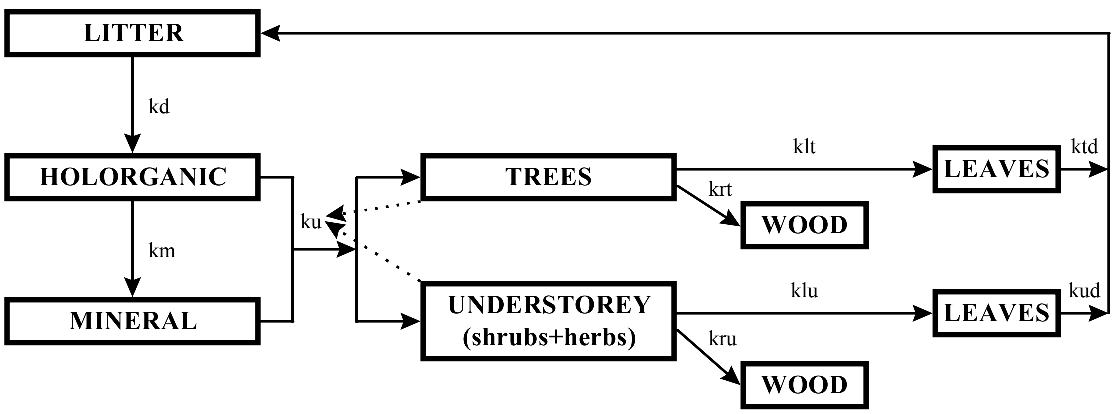

FIG. A-11.1. Model LOGNAT structure.

ANNEX B
HYPOTHETICAL SCENARIO FOR MODEL-MODEL INTERCOMPARISON STUDY
MODEL-MODEL INTERCOMPARISON SCENARIO

B-1. BACKGROUND

The source term for this scenario is hypothetical, but the forest data is based on data for a real forest. The data for this scenario were collated by Ms. N Sancharova, Russian Institute of Agricultural Radiology, Obninsk, Russian Federation.

B-2. SOURCE TERM

Spike release and deposition of ^{137}Cs as dry aerosol. Total initial deposition at the top of the canopy is 50 kBq m^{-2}.

Deposition date: 1st May

B-3. TOPOGRAPHY AND CLIMATE

Deposition is to a uniform area of forest on level ground. The average annual temperature is 5.3 ^{o} C. January is the coldest month (-8.5^{o} C), and July the warmest (+19.4 ^{o} C) (Table B-1). The period of average daily temperatures above +10 ^{o} C is 140-150 days. The maximum snow cover occurs from the second week of February to the first week of March and reaches 30 cm. The snow cover melts in late March, early April. The annual precipitation varies from 550 to 790 mm. About 70-75% of the total annual precipitation falls during the warm period, from April to October. Small amounts of precipitation of up to 1 mm day^{-1} contribute about 40% of all precipitation during a year.

TABLE B-1. AVERAGE CLIMATIC CHARACTERISTICS OF THE AREA

Month	Rainfall, mm	Temperature, ^{o} C
January	25	- 8.5
February	26	- 6.8
March	38	- 3.7
April	44	+4.2
May	51	+14.5
June	70	+17.9
July	79	+19.4
August	71	+18.1
September	53	+12.9
October	50	+3.8
November	40	-1.9
December	33	- 6.3
Annual	580	+5.3

B-4. SOIL CHARACTERISTICS

The main type of soil is soddy-podzolic loamy sand formed from fluvio-glacial sand accumulation. The soils belong to the automorphic group and have a density of 1.2 g cm^{-3}. The main soil mineral is quartz and its content varies from 80 % to 95 % (in the 0.05 – 0.01 mm fraction). The clay content is between 0.5% and 1%. More than 95.3% of the soil consists of particles exceeding 0.01 mm (physical sand). The soils of the area are characterised by low natural fertility and unfavourable hydrophysical properties: high water permeability and low water-holding capacity, this causing rapid deep infiltration of melted snow, while considerable quantities of water are evaporated from the upper layers.

TABLE B-2. LITTER AND SOIL CHARACTERISTICS

Horizon	Depth cm	Soil bulk density g cm^{-3}	pH_{H2O}	pH_{KCl}	Cation exchange capacity Meq 100 g^{-1}	Organic matter %
A_OL *	0-2	0.12	4.5	3.7	76.2	42.58
A_OF *	2-3	0.12	4.9	3.6	74.9	34.03
A_OH *	3-3.5	0.16	5.2	4.0	27.3	22.34
A_OA_1	3.5-5	0.47	5.3	3.9	7.2	2.1
A_1	5-16	0.92	5.2	4.1	4.6	0.78
A_1A_2	16-24	1.16	5.1	4.2	3.7	0.80
B	24-40	1.72	4.9	4.4	2.7	0.05

* Forest litter, mor - moder type

B-5. TREE CHARACTERISTICS

The dominant species is pine (*pinus sylvestris*) with sparse examples of birch. The rising generation includes pine (*pinus sylvestris*) and birch (*betula pendula*). The average age of the pine trees is 50 years. The birch trees are 40 - 50 years old. The average age of the trees at the time of contamination is 50 years. The average height of the trees is 20-25 m. The average density of wood biomass is between 120 and 160 metric tonnes per hectare. The growth rates of pine and birch trees, expressed as yearly increases of the diameter and the height, are presented in Table B-3.

TABLE B-3. GROWTH RATES OF AN AVERAGE INDIVIDUAL TREE

Age of trees, years	Height, m/y	Diameter, cm/y	Mass of wood, kg
20	0.34	0.36	12.6
30	0.34	0.34	40.3
40	0.3	0.33	89.5
50	0.25	0.31	161.8
60	0.22	0.28	250.6
70	0.17	0.26	352.4
80	0.15	0.24	475.2
90	0.13	0.22	600.3
100	0.1	0.2	731.4
110	0.08	0.17	852.1
120	0.06	0.13	959.7
130	0.05	0.1	1053.7

TABLE B-4. DYNAMICS OF WOOD MASS FOR AN AVERAGE INDIVIDUAL TREE AND PER UNIT AREA

Age of trees, years	Individual trees (kg)	Per unit area (metric tons ha^{-1})
20	10.8	43
30	34.4	75
40	76.5	119
50	138.3	165
60	214.1	204
70	301.1	235
80	406.1	235
90	513.0	257
100	625.0	275
110	728.2	290
120	820.1	303
130	900.4	317

B-6. UNDERSTOREY CHARACTERISTICS

The total biomass of understorey is about 1.0 kg m^{-2} (10 t ha^{-1}) d.w., including small trees of the rising generation. Shrubs include rowan-tree (*Sorbus aucuparia*), alder black (*Alnus nigra*), buckthorn alder (*Frangula alnus*). The prevailing species of dwarf-shrubs are red raspberry (*Rubus idaeus*) and blackberry (*Rubus trivialis*). The main species of mushrooms are *Boletus edulis*, *Leccinum scabrum*, *Cantharellus cibarius* and *Russula* species.

Grasses are rather sparse. The prevailing species are *Pteridium aquilinum* (fern), *Pyrola rotundifolia*, *Equisetum pratense*, *Calamagrostis epigeios*, *C. arundinacea*, *Deschampsia caespitosa*, *Melica nutans*, *Chamaenerion angustifolium, Majanthemum bifolium.*

Mosses cover 90 % of the area. The prevailing species are true mosses (Bryales).

TABLE B-5. BIOMASS OF BERRIES AND MUSHROOMS

Species	Biomass (kg ha^{-1})	
	Fresh weight	Dry weight
Berries:		
Red raspberry (*Rubus idaeus*)	67	7.4
Bilberry (*Vaccinium myrtillus*)	56	6.2
Wild strawberies (*Fragaria vesca*)	15.6	1.7
Mushrooms:		
Suillus luteus	59.7	5.7
Boletus edulis	28.6	2.7
Russula cyanoxantha	17.1	1.6
Cantharellus cibarius	19.1	1.8

B-7. FOREST GAME

The main game species are moose (0.08 animals per km^2), and roe deer (0.06 animals per km^2).

B-8. ENDPOINTS

Participants were required to make predictions of ^{137}Cs activity concentrations in the following forest materials:

- bole wood, Bq kg^{-1};
- total wood (*i.e.* trunk plus branches), Bq kg^{-1};
- needles, Bq kg^{-1} (annual average);
- other parts of tree, especially bark, Bq kg^{-1};
- soil profile, including litter, Bq kg^{-1} [separate results should be given for each soil layer if possible, as well as for the total organic layer (AoL+AoF+AoH) and the total mineral layer ($A_oA_1+A_1+A_1A_2+B$)];
- animals, Bq kg^{-1} (annual average for moose and red deer);
- vegetation, Bq kg^{-1} (mushrooms, berries, shrubs and grass).

Activity concentrations were expressed as Bq kg^{-1} **fresh weight** (except for the soil profile).

Participants did not have to report on all the endpoints, but could choose the endpoints they wanted from the list above. Pine (*Pinus sylvestris*) was the main tree of interest, but participants could report on both pine and birch (*Betula pendula*). Similarly, participants could report generically on mushrooms, berries, shrubs and grasses, or on specific species of these.

Each chosen endpoint was considered as:

- a function of time (1 year intervals from 1 to 20 years after the start date).

Calculations were be based on:

- best estimates of parameter input values.

Some modellers also reported results as 95% confidence intervals as well as best estimates.

ANNEX C
MODEL-DATA INTERCOMPARISON STUDY

C-1. GEOGRAPHICAL LOCATION

Ukraine, Zhitomir region, Luginsky district, near v.Rudnya-Povcha, about 130 km to south-west of Chernobyl (51º09'N and 28º35'E).

C-2. SOURCE TERM

Spike release and deposition of Cs-137 as dry aerosol. Initial deposition on 1 May 1986 was 555 kBq m^{-2}

C-3. TOPOGRAPHY AND CLIMATE

The average annual temperature is +7.9°C. February is the coldest month (-2.8°C), and July the warmest (+19.8°C) (Table C-1). The period of average daily temperatures above +10°C is 160 days. The maximum snow cover occurs from the second week of February to the first week of March and reaches 15-20 cm. The snow cover melts from the third week of March to the second week of April. The annual precipitation varies from 550 to 710 mm. About 70-75% of the total annual precipitation falls during the vegetative period, from April to October. Small amounts of precipitation of up to 1 mm/day contribute about 50% of annual precipitation. Heavy showers (more than 3mm per rainfall event) are especially typical for summer months.

TABLE C-1. AVERAGE CLIMATIC CHARACTERISTICS OF THE AREA

Month	Rainfall, mm	Temperature, °C
January	24.2	-1.7
February	45.2	-2.8
March	44.1	1.0
April	62.1	7.7
May	57.9	11.7
June	63.5	17.2
July	82.5	19.8
August	56.3	17.7
September	32.1	13.7
October	56.8	7.7
November	29.3	2.8
December	23.0	0.2
Annual	577.0	+7.9

C-4. SOIL CHARACTERISTICS

The main soil type is a soddy podzol developed in sandy loam deposits of fluvio-glacial origin. The average annual depth of groundwater level about 130 cm. The soil is formed from fluvio-glacial sandy-loam deposits. It belongs to the automorphic group and has an average bulk density per 10-cm stratum of 1.15-1.25 g cm^{-3}. The main soil mineral is quartz and its content varies from 60 to 85% (in the 0.05-0.01 mm fraction). The clay content is 0.5%. The soil of the experimental plot No 15 (61) is characterised by low natural fertility and unfavorable hydrophysical properties: high water permeability and low water-holding capacity, thus causing rapid deep infiltration of melted snow, while considerable quantities of water are evaporated from the upper layers. This soddy-podzolic soil is favourable for the growth of boreal tree and plant species – *Pinus sylvestris*, *Vaccinium myrtillus etc.*

Description of soil profile: forest litter thickness reaches 10-15 cm, humus is rough, moder-type. Forest litter mainly consists of needles of *Pinus sylvestris* and residues of mosses (Bryales). Ah-horizon is grey-black, sandy-loam, its thickness is 8-10 cm, with large amounts of roots of dwarf-shrubs, grasses, and rhizoids of mosses. E-horizon (eluvial) is light grey, sandy; its thickness varies from 5 to 10 cm without any roots of plants. Bh-horizon (illuvial) is ferrugineo-brown, loam, dense, with middle diameter roots of *Pinus sylvestris*. Its thickness varies from 5 to 10 cm. The Bi-horizon is yellow brown, sandy-loam or sandy, and exceeds the depth of the ground water. It contains separate big roots of *Pinus sylvestris*.

TABLE C-2. LITTER AND SOIL CHARACTERISTICS

Horizon	Depth, cm	Soil bulk density, g/cm^3	pH $_{H2O}$	pH $_{KCl}$	Cation exchange capacity meq/100g	Organic matter, %
Ol*	0 – 2	0.026	5,7	5,2	63,5	83,2
Of*	2 – 6	0.050	5,5	5,0	48,8	75,4
Oh*	6 – 8	0.093	5,4	4,7	42,3	59,1
Ah	8 – 18	1.10	5.2	4.6	3,7	4,2
E	18 – 26	1.30	5.4	4.2	1,3	0,9
Bh (i)	26 – 36	1.61	5.6	4.7	1,7	1,8
Bi	36 - 130	1.53	5.7	4.5	0,9	0,1

* Forest litter, humus-moder-type

TABLE C-3. BULK DENSITY OF SEPARATE STRATUM OF FOREST LITTER AND 2-CM STRATUMS OF MINERAL PART OF THE SOIL

Soil horizon	Depth, cm	Bulk density, g/cm^3
Ah	0 – 2	0.683
	2 – 4	0.975
	4 – 6	0.982
	6 – 8	1.220
	8 – 10	1.174
E	10 – 12	1.340
	12 – 14	1.340
	14 – 16	1.346
	16 – 18	1.345
Bh (i)	18 – 20	1.450

C-5. TREE CHARACTERISTICS

The dominant species is pine (*Pinus sylvestris*) with sparse birch (*Betula pubescens*). The rising generation includes the same species of trees. The average age of the pine trees is 50 years. The birch trees are about 25-30 years old. The total amount of pine is 1180 trees, the average height of the pine trees is 22 m, diameter 20 cm. The average density of wood biomass is 297.2 metric tonnes per hectare (in fresh weight). The growth rates of pine trees, expressed as yearly increases of the height and the diameter, are presented in Tables C-4 and C-5.

TABLE C-4. GROWTH RATES OF AN AVERAGE INDIVIDUAL TREE

Age of trees, years	Height, m/y	Diameter, cm/y	Mass of wood (trunk with branches), kg (fresh weight)
20	0.42	0.41	26.6
30	0.45	0.40	82.5
40	0.37	0.37	183.8
50	0.30	0.35	297.2
60	0.24	0.31	432.8
70	0.19	0.28	584.8
80	0.16	0.26	747.8
90	0.15	0.24	1006.9
100	0.12	0.22	1341.2
110	0.11	0.21	1565.3
120	0.10	0.18	1759.4
130	0.07	0.14	1943.6

TABLE C-5. DYNAMICS OF WOOD MASS FOR AN AVERAGE INDIVIDUAL TREE AND PER UNIT AREA

Age of trees, years	Individual trees (wood with bark) kg (fresh weight)	Per unit area (metric tonns/ha) (fresh weight)
20	21.6	107
30	71.4	206
40	156.4	297
50	269.9	370
60	397.4	422
70	541.0	467
80	695.6	504
90	941.0	550
100	1258.2	591
110	1472.5	627
120	1658.2	650
130	1833.6	675

C-6. UNDERSTOREY CHARACTERISTICS

Vegetation belongs to floristic association Molinio-Pinetum J.Mat. 1981, Union Dicrano-Pinion Libl. 1933, Ordo Vaccinio-Piceetalia Br.-Bl. 1939 em K.Lund 1967, Class Vaccinio-Piceetea Br.-Bl. 1939. This association is wide spread in Central Polessie of Ukraine (about 40% of total forest cover). The understorey vegetation layer is dense, with a projective cover of 70-75%, representing Vaccinium myrtillus (60-65%), Vaccinium vitis-idaea (5-10%), Vaccinium uliginosum (1-3%), Molinia caerulea (1-3%), Melampyrum pratense (1%), Dryopteris carthusiana (1%), separate plants – Ledum palustre, Equisetum sylvaticum, Luzula pilosa, Lysimachia vulgaris, Calluna vulgaris, Potentilla erecta et al. Moss cover is dense (with projective cover 90-98%), consisting of Pleurozium schreberi (60-65%), Dicranum polysetum (30-33%), Polytrichum commune (1-5%).

The total biomass of understorey vegetation is about 1,3 kg m^{-2} (13,0 t/ha, d.w.), including small trees of the rising generation, and shrubs of Sorbus aucuparia and Frangula alnus (about 0.1 kg m^{-2}) d.w. Biomass of mosses is 1,0 kgm^{-2}, dwarf-shrubs (mainly Vaccinium myrtillus – 0.12-0.14 kg m^{-2}). The main species of mushrooms are Xerocomus badius, Cantharellus cibarius, Russula paludosa, Suillus luteus, Boletus edulis.

TABLE C-6. BIOMASS OF BERRIES AND MUSHROOMS

Species	Biomass (kg/ha) Aboveground phytomass, (d.w.)	Berries (f.w.)	Berries (d.w.)	Mushrooms, fruitbodies (d.w.)
Berry species				
Vaccinium myrtillus	1200	320	31,8	
V.vitis-idaea	20	–	–	
V.uliginosum	2	–	–	
Mushrooms				
Suillus luteus	–	–	–	0.1
Cantharellus cibarius	–	–	–	0.2
Russula paludosa	–	–	–	1.3
Xerocomus badius	–	–	–	2.0
Boletus edulis	–	–	–	0.1

C-7. FOREST GAME

The main game species is roe deer (0.03 animals per km^2).

C-8. ENDPOINTS

Participants were required to make predictions of ^{137}Cs activity concentrations in the following forest materials:

— Wood, Bq/kg dry weight;

— Annual shoots, Bq/kg dry weight;

— Annual Needles, Bq/kg dry weight;

— Total bark[*] , Bq/kg dry weight;

— Soil profile, Bq/kg dry weight;

— Roe deer , Bq/kg in muscles (fresh weight), September-October;

— Mushrooms, Bq/kg dry weight;

— Bilberries, Bq/kg dry weight.

Participants did not have to report on all the endpoints, but could choose the endpoints they wanted from the list above. Participants could report generically on mushrooms and berries, or on specific species of these.

Each chosen endpoint was considered as a function of time (1 year intervals from 1986 to 1998). Calculations should have been based on best estimates of parameter input values. Results should have been reported as either as 95% confidence intervals, or as best estimates.

[*] Total bark is defined as the internal plus external bark. Internal bark is the cambium; *i.e.* the physiologically active part between the external bark and the wood.

TABLE C-7. EXPERIMENTAL DATA FOR MODEL-DATA INTERCOMPARISON STUDY

(Provided by A Orlov, Polesskaya Forest Scientific Research Station, Zhitomir, Ukraine)

Specific activity of ^{137}Cs in samples on experimental plot ¹ 15 (61)

Type of sample	Specific activity of ^{137}Cs in samples, Bq kg^{-1}						
	1991	1992	1993	1994	1995	1996	1997
Pine-tree (d.w.)							
Bark external (d.w.)	6667	5080	4030	3977	3511	3090	3500
	5974	5163	5204	3973	4901	3960	3800
	5488	6740	3975	4950	4443	4140	2750
Mean	**6043**	**5661**	**4403**	**4300**	**4285**	**3730**	**3350**
Bark total (d.w.)	6510	4500	5170	4700	4490	3700	4690
	6030	6360	4470	3720	347	4600	3180
	5910	6750	5990	5380	539	4660	4640
Mean	6150	5870	5210	4600	1792	4320	4170
Bark internal (bast) (d.w.)	5670	7700	7295	6890	6754	6946	11694
	7140	5810	6230	6780	9315	10553	7701
	4950	8090	7343	6130	6485	9642	10176
Mean	5920	7200	6956	6600	7518	9047	9857
Wood (without bark)	1284	1424	1394	1280	1409	2726	2300
	2017	948	1561	1409	1663	2529	2252
	1694	1369	1191	1670	1407	3178	3068
Mean	**1665**	**1247**	**1382**	**1453**	**1493**	**2811**	**2540**
Annual shoots (d.w.)	21776	38631	10316	17903	17611	54681	47380
	23708	31692	10689	12956	11873	63621	63510
	15935	37311	12739	19757	15069	45555	76610
Mean	**20473**	**35878**	**11248**	**16872**	**14851**	**54619**	**62500**
Annual needles (d.w)	19250	27951	11554	17816	13062	38299	50610
	20280	42029	15340	13277	20042	47282	41010
	23740	36172	15397	15737	16522	38688	38370
Mean	**21090**	**35384**	**14097**	**15610**	**16542**	**41423**	**43330**
Berries (f.w.)							
Vaccinium myrtillus	7450	6380	5813	4960	4684	7899	7420
	7480	5760	6477	9871	7469	5303	3740
	14530	3500	6551	5591	9676	3740	6760
	11800	6760	8296	9502	5333	8257	3920
	8990	9050	7833	7261	7163	4744	5960
Mean	**10050**	**6290**	**6994**	**7437**	**6865**	**5988.6**	**5560**
All abogr phytom (d.w)	32905	48930	42200	34800	37120	42755	25250
	60055	57036	67300	44860	51540	40145	26369
	59755	68779	35100	23800	51710	31040	40604
	56070	51359	32600	33070	42510	34340	51883
	80852	57499	63700	35260	29410	42526	56670
Mean	57927	56720	48180	34358	42458	38161.2	40155.2
Mushrooms							
Xeroc badius (d.w.)	3189000	6530000	6141000	3777000	5260000	5910000	5660000
	4337400	2950000	6231000	5100000	1170000	4800000	4450000
	3755100	2310000	1571500	2130000	1700000	1160000	1120000
	7112800	2580000	4334200	2095000	5650000	3970000	4640000
	1932600	6040000	25050	6062000	3830000	1940000	1520000
Mean	4065380	4082000	3660550	3832800	3522000	3556000	3478000

TABLE C-7. CONTINUED

Specific activity of ^{137}Cs in samples on experimental plot ¹ 15 (61)							
Type of sample	Specific activity of ^{137}Cs in samples, Bq kg^{-1}						
	1991	1992	1993	1994	1995	1996	1997
Suillus luteus (d.w.)	4583500		1870000	3060000		4059000	3303000
	3553800		3790000	4910000		3399000	2148000
	3032600		4360000	2560000		2676000	4785000
Mean	**3723300**		**3340000**	**3510000**		**3378000**	**3412000**
Canth cabarius (d.w.)	1294500		1411000		109000	555300	
	912700		984000		89000	1279800	
	1304700		1130000		144000	878200	
	1400000		1126000		97000	1016200	
	1266000		794000		110000	887500	
Mean	**1235580**		**1089000**		**109800**	**923400**	
Boletus edulis (d.w.)	895300			809300			861200
	317200			457400			518700
	672100			483200			513700
Mean	**628200**			**583300**			**631200**
Russ paludosa (d.w.)	1705600	1624200	1758400	1341500	959300	2420000	1516000
	762700	961200	372100	584800	2626900	1236000	1531000
	1849600	2159500	2083000	2835100	1397600	655000	2164000
	1664800	1193700	931900	2589300	1930700	1816000	747000
	3284800	477500	2038600	1278300	1229000	1592000	372000
Mean	**1853500**	**1283220**	**1436800**	**1725800**	**1628700**	**1543800**	**1266000**
Roe-deer (muscles)	63550	62330	-	60355	-	55330	56280
Soil profile (d.w.)							
Ol	9985	11141	10835	10599	6780	7007	5797
	11871	6324	7975	6278	9310	9820	7291
	7649	10375	8295	7393	7400	5676	9532
Mean	**9835**	**9280**	**9035**	**8090**	**7830**	**7501**	**7540**
Of	87352	128201	81215	84221	61300	51675	58080
	125199	74984	96726	116016	71360	48783	50360
	88580	94514	116434	85153	59640	40704	51160
Mean	**100377**	**99233**	**98125**	**95130**	**64100**	**47054**	**53200**
Oh	59906	66690	66620	46485	65090	49055	111840
	48263	36480	48370	53060	75150	64584	78720
	47246	55380	45660	66685	42730	73156	81540
Mean	**51805**	**52850**	**53550**	**55410**	**60990**	**62265**	**90700**
Ah 0-2 cm	7733	4620	5230	7218	8030	5842	6180
	5513	6422	7910	6254	5020	8310	4660
	4349	7948	4650	5620	8100	10031	8030
Mean	**5865**	**6330**	**5930**	**6364**	**7050**	**8061**	**6290**
2-4 cm	2402	1794	2300	2026	1790	1907	3790
	1432	1869	2294	1781	2950	2216	2460
	1926	2592	1310	2586	2070	3098	2210
Mean	**1920**	**2085**	**1968**	**2131**	**2270**	**2407**	**2820**
4-6 cm	374	615	522	516	644	1204	1202
	339	365	392	287	726	793	1778
	562	619	346	520	535	718	1370
Mean	**425**	**533**	**420**	**441**	**635**	**905**	**1450**

TABLE C-7. CONTINUED

Specific activity of ^{137}Cs in samples on experimental plot ¹ 15 (61)							
Type of sample	Specific activity of ^{137}Cs in samples, Bq kg^{-1}						
	1991	1992	1993	1994	1995	1996	1997
6-8 cm	224	225	291	249	369	766	1037
	192	210	168	236	510	526	962
	133	315	231	268	351	457	836
Mean	**183**	**250**	**230**	**251**	**410**	**583**	**945**
8-10 cm	155	135	191	138	250	258	358
	141	165	170	211	222	382	360
	178	222	116	152	188	377	398
Mean	**158**	**174**	**159**	**167**	**220**	**339**	**372**
10-12 cm	140	131	137	69	161	289	209
	195	146	169	73	121	304	216
	106	92	93	110	177	166	223
Mean	**147**	**123**	**133**	**84**	**153**	**253**	**216**
12-14 cm	167	140	105	199	156	234	196
	125	195	163	127	148	206	190
	158	145	206	175	236	181	109
Mean	**150**	**160**	**158**	**167**	**180**	**207**	**165**
14-16 cm	45	34	37	38	139	201	95.9
	25	42	52	36	114	283	75.9
	35	53	61	58	77	182	121
Mean	**35**	**43**	**50**	**44**	**110**	**222**	**97.6**
16-18 cm	42	39	51	47	154	248	51.3
	36	36	48	35	109	235	42.5
	42	24	51	56	97	231	60.4
Mean	**40**	**33**	**50**	**46**	**120**	**238**	**51.4**
18-20 cm	28	23	51	15	52	282	210
	22	22	42	13	91	158	345
	19	15	27	20	97	232	399
Mean	**23**	**20**	**40**	**16**	**80**	**224**	**318**

ANNEX D
SECOND MODEL-MODEL INTERCOMPARISON STUDY (SCENARIO 3)

D-1. SOURCE TERM

The source term is a continuous release of ^{137}Cs from loosely tipped radioactive waste disposed in a number of trenches that are now covered by soil caps. Trees grow on the site, with the roots penetrating through the soil caps directly into the waste. We would like to know the activity concentration of ^{137}Cs in various parts of the trees up to 200 years after they have regenerated naturally on the trench caps.

It is assumed that the radioactive waste is disposed in a minimally engineered facility consisting of 10 trenches (two rows of five units) orientated perpendicular to the groundwater flow (see Figure D-1). The trenches are adapted from a previous IAEA study on Quantitative Acceptance Criteria for Near Surface Disposal of Radioactive Waste [1]. Relevant parameters for the waste and the trenches are as follows (also see Figure D-1):

10 trenches (two rows of five units)

Dimensions of trench:
- internal length = 100 m
- internal width = 15 m
- internal depth = 6 m
- distance between two trenches (edge to edge) = 20 m.

Total area of the site = 195 × 260 m (i.e. 5.07E+4 m^2)

Homogeneous waste backfilled with native, sandy soil:
- total porosity = 0.5
- waterfilled porosity = 0.4
- hydraulic conductivity = 10^{-5} $m.s^{-1}$
- total bulk density = 500 $kg.m^{-3}$
- activity concentration of ^{137}Cs in waste = 1 kBq kg^{-1} dry weight.

Radioactive decay of ^{137}Cs can be assumed in calculations. It should also be assumed that the potential bioavailability of ^{137}Cs within the waste material is the same as that in the mineral soil layer.

Cap made of natural material (i.e. made of compacted, sandy soil):
- thickness = 1 m
- kinematic and total porosity = 0.3
- hydraulic conductivity = 10^{-7} $m.s^{-1}$
- bulk density = 1500 $kg.m^{-3}$

Soil properties:
- unsaturated zone thickness (temperate) = 2 m below base of disposal unit
- average moisture content of the unsaturated zone = 0.15
- kinematic and total porosity = 0.3
- bulk density = 1700 $kg.m^{-3}$
- hydraulic conductivity = 10^{-5} $m.s^{-1}$
- hydraulic gradient = 1 in 50
- thickness of the saturated zone = 15 m
- longitudinal dispersivity = distance to outlet / 10 (m)
- transverse dispersivity = distance to outlet / 50 (m).
- water table: 2 m below the bottom of the cap that covers the waste

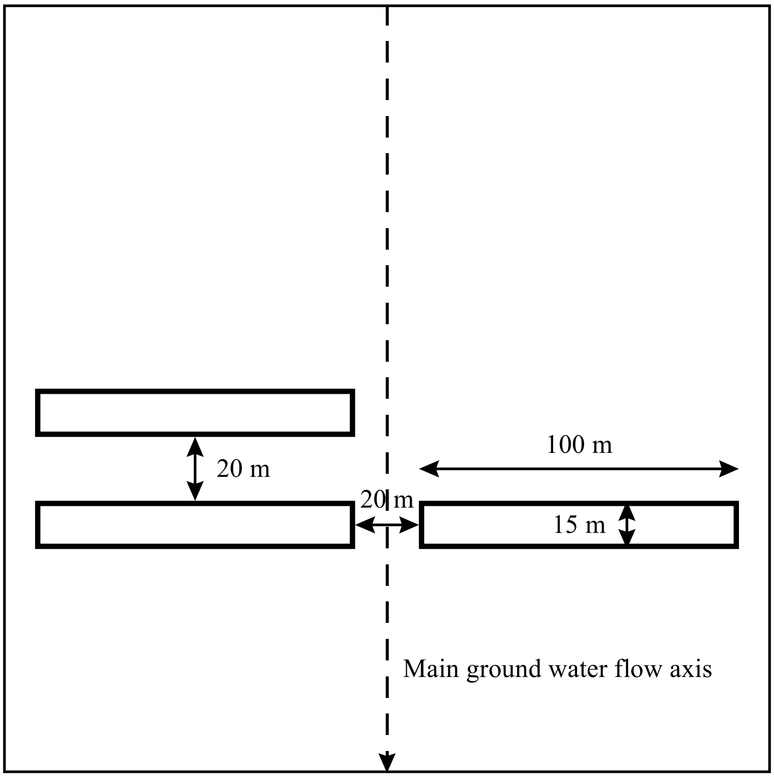

FIG. D-1. Trench disposal facility.

D-2. CLIMATE

temperate precipitation = 1000 mm.y^{-1} (yearly averaged)
temperate actual evapotranspiration = 400 mm.y^{-1}

Closure of facility May

D-3. TREE CHARACTERISTICS

There are no trees at time zero (i.e. when the trench cap is put in place), but there is natural regeneration of vegetation, including tree saplings, within the first year after closure. The dominant tree species is pine (*Pinus sylvestris*) with sparse examples of birch. Two hundred years after closure the average height of the trees is 20–25 m. The average density of wood biomass on the trenches is between 10 and 20 kg m^{-2}. No information on tree growth rates is available over this period.

The roots of the trees penetrate through the soil caps directly into the waste. It should be assumed that the potential bioavailability of ^{137}Cs within the waste material is the same as that in the mineral soil layer. The distribution of the roots with depth at various tree ages is given in Tables D-1 and D-2. The following general observations on the distribution of tree roots with depth should also be kept in mind:

— pine root growth rate decreases with age;

— pine roots reach half a maximum depth after 10-15 years;

— roots distribution of trees older than 40-60 years does not change significantly with time.

TABLE D-1. ROOTS DISTRIBUTION FOR 12 YEARS OLD PINE

Horizon	Layer, cm	Roots dry weight, g/tree	
		large roots (d>1mm)	Small roots (d<1 mm)
A_1	1-11	140,7	64,3
A-B	11-21	230,2	38,0
	21-31	48,5	22,4
B_1	31-41	27,3	14,1
	41-61	37,5	21,9
B_2	61-81	24,6	10,7
	81-101	3,6	1,2
	101-121	8,7	0,5
C	121-151	11,4	3,4
	151-171	5,8	1,8
	171-201	6,5	2,0
A,B,C	1-201	545	180

TABLE D-2. ROOTS DISTRIBUTION FOR 33 YEARS OLD PINE

Horizon	Layer, cm	Roots dry weight, g/tree	
		large roots (d>1mm)	Small roots (d<1 mm)
A	2-12	290,7	92,2
A-B	12-22	607,3	37,8
	22-32	406,9	29,6
	32-42	298,9	21,6
B	42-62	236,9	20,7
	62-82	146,9	20,9
	82-102	92,9	5,8
	102-122	55,1	4,2
	122-152	87,4	6,6
	152-172	72,7	1,6
C	172-202	117,8	3,8
	202-222	34,0	1,9
	222-252	50,9	2,8
A,B,C	1-252	2498	250

D-4. UNDERSTOREY CHARACTERISTICS

The total biomass of understorey is about 1.0 kg/m^2 (10 t/ha) d.w. The prevailing species of dwarf-shrub is bilberry (*Vaccinium myrtillus;* 0.12–0.14 kg m^{-2}). The main species of mushrooms are *Boletus edulis* and *Xerocomus badius.*

TABLE D-3. BIOMASS OF BERRIES AND MUSHROOMS

Species	Biomass (kg/ha)			
	Aboveground phytomass, (d.w.)	Berries (f.w.)	Berries (d.w.)	Mushrooms, fruitbodies (d.w.)
Berry species				
Vaccinium myrtillus	1200	320	31,8	
Mushrooms				
Xerocomus badius	-	-	-	2.0
Boletus edulis	-	-	-	0.1

D-5. ENDPOINTS

Participants are required to make predictions of ^{137}Cs activity concentrations in the following forest materials:

- Total tree, Bq/kg;
- Total wood (i.e. trunk plus branches), Bq/kg;
- Needles, Bq/kg (annual average);
- Total bark, Bq/kg;
- Cap Bq/kg (for 1m depth at 10 cm intervals from the surface, if possible);
- vegetation, Bq/kg (mushrooms and berries).

Activity concentrations should have been expressed as Bq/kg **fresh weight** (except for the cap, which should have been specified in Bq/kg dry weight).

For each endpoint, results were reported at 1 year intervals for years 0-20 after closure, thereafter at 10 year intervals for years 30–200.

As a minimum, final activity concentrations 200 years after closure should have been given.

Calculations should have been based on best estimates of parameter input values. If possible, results should have been reported as:

- 95% confidence intervals; or
- best estimates.

D-6. REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Derivation of Quantitative Acceptance Criteria for Disposal of Radioactive Waste to Near Surface Facilities: Development and Implementation of an Approach, IAEA Draft Safety Report, Working Document, Version 3.0, March 1999, IAEA, Vienna (1999).

[2] KALININ, M.I., Formation of tree root system, Moscow, p152 (1983).

[3] RAKHTEENKO, I.N., Root systems of trees and bushes, Moscow-Leningrad, p108 (1952).

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