PART 4

FORESTS

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20. Contamination in Forests

Forests have the capacity to trap and retain radionuclides for a substantial period of time. The dynamic behaviour of nutrients, pollutants and radionuclides in forests is complex. The rotation period of a forest stand in the Nordic countries is about 100 years, whilst the time for decomposition of organic material in a forest environment can be several hundred years. This means that any countermeasure applied in the forest environment must have an effect for several decades, or be reapplied continuously for long periods of time.

The forest environment as a potential source of radiation to man has been emphasised in several reports. The nuclear weapons tests in the 1950s and 1960s initiated several studies on the transfer of radionuclides from lichen to reindeer and with that the impact on man (Ramzaiev et al., 1969; Mattsson, 1972). Higher external radiation doses to forest workers compared with agricultural workers have been observed in contaminated areas in the former USSR (Melin et al., 1991). There were also observations in the former USSR of damage to coniferous forests exposed to high radiation doses after the accident in Chernobyl (Kozubov et al., 1990; Arkhipov et al., 1995). In evaluating the consequences of radioactive contamination in a forest, it should not be forgotten that forests have a substantial economic value. Even if the radiation dose to man from forest products were infinitesimally small, a decrease in the trade of contaminated forest products cannot be excluded.

To mitigate the detrimental effect of a contaminated forest environment on man, and to minimise the economic loss in trade of contaminated forest products, it is necessary to understand the mechanisms of transfer of radionuclides through the forest environment. It must also be stressed that any countermeasure applied in the forest environment must be evaluated with respect to long, as well as short term, negative effects, before any decision about remedial action is taken.

In some forest-based industries (such as paper manufacturing), industry-specific processes will concentrate radionuclides by up to 200 times. These enrichment processes might cause radiological problems at certain points in the forest-based industries when using highly contaminated forest products (Holm et al., 1992).

20.1 Important radionuclides

Radionuclides that in the past have been considered in the forest environment are radiocaesium and radiostrontium. The root uptake of transuranic elements has been studied in forest stands growing on radioactive waste repositories, but the radiological consequences were not significant (Murphy, 1995).

In this part of the document, only options for reducing external dose will be considered. Foodstuffs from the forest, like berries and mushrooms, may be important sources of radiocaesium intake to man. Countermeasures to reduce radionuclide intake include restrictions on food gathering, dietary advises and food preparation.

Of the radionuclides studied in forests in the past, radiocaesium has been the main contributor to dose to man. In this document, only radiocaesium will be discussed since data on the impact of other radionuclides on man are too scarce for a proper evaluation.

The external exposure of man to radionuclides will diminish with time, partly because of radioactive decay. In addition, the translocation and circulation of radionuclides between soil, forest-floor vegetation and trees will contribute to the change in dose commitment to people living in a forest environment or working with forest products.

20.2 Deposition and retention of radionuclides

The distribution of intercepted radionuclides between different compartments in the forest environment depends largely on the density of the forest canopy. For instance, the canopy of a dense spruce stand has been shown to be able to intercept about 60-90% of the fallout (Melin et al., 1995; Tikhimirov, 1995). The corresponding figure for a leafless deciduous forest was much lower (Table 4.1.).

***Table 4.1** Relative interception (area) of dry deposited ^{137}Cs in different types of forest after the Chernobyl accident (time of sampling May 1986) (Melin et al., 1995).*

Stand	**Age of stand (year)**	**Stem density (stems ha^{-1})**	**Relative interception (m^{-2})**
Spruce	84	1336	1
Pine	139	1622	08
Beech (leafless)	87	687	04
Birch (leafless	68	573	04
Alder (leafless)	116	605	01

The high capacity of a coniferous forest to intercept fallout is independent of the season. However, the interception of radionuclides in a deciduous forest will depend on the stage of foliation, which in turn is governed by the season.

The interception of dry deposited radionuclides in forests will be higher than in grassed areas by about 25-35% (Tikhomirov, 1992). After wet deposition there was no difference between the two areas. A higher interception (2-5 times) at the edges of the forest compared to the inner part can be expected (Tikhomirov, 1995).

20.3 Long-term pathways of radionuclides in forests

During the first year after the initial interception there will be a rather fast transfer of radionuclides from the forest crown to the forest floor. This transfer is mainly caused by wash-off and by leaf fall. However, soil-to-plant transfer cannot be ignored during this period. In Table 4.2, available data on natural field losses from the aerial parts of the forest stand are summarised. It should be born in mind that the level of contamination in a tree is due to a combination of both interception and root uptake. The distribution of a radionuclide within the tree will vary according to the season.

In a later phase, the soil-to-plant transfer, together with the translocation of radionuclides in the plants, will be the dominant processes for radionuclide transfer in the forest system. A steady-state is established in the forest soil/plant community within ten years after deposition (Alexakhin, 1995, Tikhomirov, 1995).

Table 4.2 *Initial transfer of Chernobyl radionuclides from a mixed birch/oak/pine forest stand to the forest floor (after Mamikhin et al., 1992)*

Year after deposition	**Distribution (%) tree stand/soil**	
	Aerial parts of tree	**Forest floor, soil**
	border of the 30 km zone, Chernobyl condensed particles	
0 (initial)	60-90	10-40
0 (August)	17	83
1	8	92
2	6	94
3	6	94
4	5	95
	7 km from the Chernobyl NPP, fuel particles	
0 (initial)	60-90	10-40
1	0.3	99.7
2	0.2	99.8
3	0.6	99.4
4	2	98

The assimilation of radiocaesium and radiostrontium into the trees by leaves and roots is rather limited. It has been shown that 30 years after deposition (in the 1950s and 1960s) only 10% of recovered radiocaesium was found in the trees; 5% in the crown and 5% in the trunk. The corresponding figures for radiostrontium were 10% for total recovery and 8% in the trunk (Melin et al., 1995).

The incorporation of radionuclides into the trunk of the tree will increase with time from deposition until harvest. Apart from the assimilation of radionuclides into the trees, direct deposition on the trunk, branches and needles must be considered. The activity concentrations of radiocaesium and radiostrontium in the tree trunks with respect to the deposition rates are summarised in Tables 4.3 and 4.4 for a deposition of 1 kBq m^{-2}. For radiocaesium, the expected activity concentration in wood is in the range 0.1 - 3.9 Bq kg^{-1} and 0.1 to 4.2 Bq kg^{-1} for ^{90}Sr. For bark, the corresponding valves are 0.2 - 18.0 and 3 - 50 respectively.

Table 4.3 *Relationship between deposition of ^{137}Cs and activity concentrations found in wood and bark*

Species	Age of tree (years)	Deposition to ground (kBq m^{-2})	Time elapsed since deposition (years)	Ratio: Bq kg^{-1}/kBq m^{-2}		Location	Reference
				(a) Wood	(b) Bark		
Birch	30	15	34	0.1	0.2	Kyshtym	Karavaeva (1995)
Birch	45	7	34	0.1	1.3	Kyshtym	Karavaeva (1995)
Birch	70	14	34	0.0	0.5	Kyshtym	Karavaeva (1995)
Oak			1	0.7		Chernobyl	Tikhomirov (1995)
Oak			5	0.8		Chernobyl	Tikhomirov (1995)
Pine			1	0.8		Chernobyl	Tikhomirov (1995)
Pine	17	126	2	0.5	14.0	Chernobyl	Vetrov (1995)
Pine	30	311	2	0.1	8.0	Chernobyl	Vetrov (1995)
Pine	85	3700	2	0.6	11.0	Chernobyl	Vetrov (1995)
Pine	85	2900	3	1.0	11.0	Chernobyl	Vetrov (1995)
Pine	85	3700	3	1.4	12.0	Chernobyl	Vetrov (1995)
Pine	17	126	4	2.5	14.0	Chernobyl	Vetrov (1995)
Pine	85	2900	4	0.7	10.0	Chernobyl	Vetrov (1995)
Pine	85	3700	4	1.0	10.0	Chernobyl	Vetrov (1995)
Pine			5	0.4		Chernobyl	Tikhomirov (1995)
Pine	17	126	5	3.9	18.0	Chernobyl	Vetrov (1995)
Pine	30	311	5	0.3	7.3	Chernobyl	Karavaeva (1995)
Pine	85	3700	5	1.5	11.0	Chernobyl	Vetrov (1995)
Pine	85	2900	5	1.9	8.0	Chernobyl	Vetrov(1995)
Pine	50	2	20	1.4	7.1	Sweden	Melin(1992)
Pine	30	15	34	0.1	0.4	Kyshtym	Karavaeva (1995)
Pine	45	7	34	0.1	1.6	Kyshtym	Karavaeva (1995)
Spruce			1	1.5		Chernobyl	Tikhomirov (1995)
Spruce			5	2.5		Chernobyl	Tikhomirov (1995)
RANGE				0.1-3.9	0.2-18.0		

Table 4.4 *Relationship between deposition of ^{90}Sr and activity concentrations found in wood and bark*

Species	Age of tree	Deposition ground (kBq m^{-2})	Time elapsed since deposition (years)	Ratio: Bq kg^{-1} kBq m^{-2}		Location	Reference
				(a) Wood	(b) Bark		
Birch			2		30	Kyshtym	Tikhomirov (1995)
Birch			3		15	Kyshtym	Tikhomirov (1995)
Birch			4		10	Kyshtym	Tikhomirov (1995)
Birch			13		4	Kyshtym	Tikhomirov (1995)
Birch	30	5	34	3.4	27	Kyshtym	Karavaeva (1995)
Birch	45	2	34	4.2	18	Kyshtym	Karavaeva (1995)
Birch	70	34	34	1.8	20	Kyshtym	Karavaeva (1995)
Pine			2	1.0	50	Kyshtym	Tikhomirov (1995)
Pine			3	0.4	40	Kyshtym	Tikhomirov (1995)
Pine			4	0.1	10	Kyshtym	Tikhomirov (1995)
Pine			13	0.5	3	Kyshtym	Tikhomirov (1995)
Pine	50	1	20	3.1	10	Sweden	Melin (1995)
Pine	30	5	34	1.8	9	Kyshtym	Karavaeva (1995)
Pine	45	2	34	1.5	11	Kyshtym	Karavaeva (1995)
Pine	70	34	34			Kyshtym	Karavaeva (1995)
RANGE				0.1-4.2	3-50		

20.4 Long-term changes in external exposure

The distribution of radionuclides will change from the time of deposition until the maturation and harvest of the stand. This will influence the external exposure to man. In addition, the physical half-life will contribute to external dose reduction up to the time of harvest, as illustrated in Figure 4.1 (based on the assumptions given in Table 4.5).

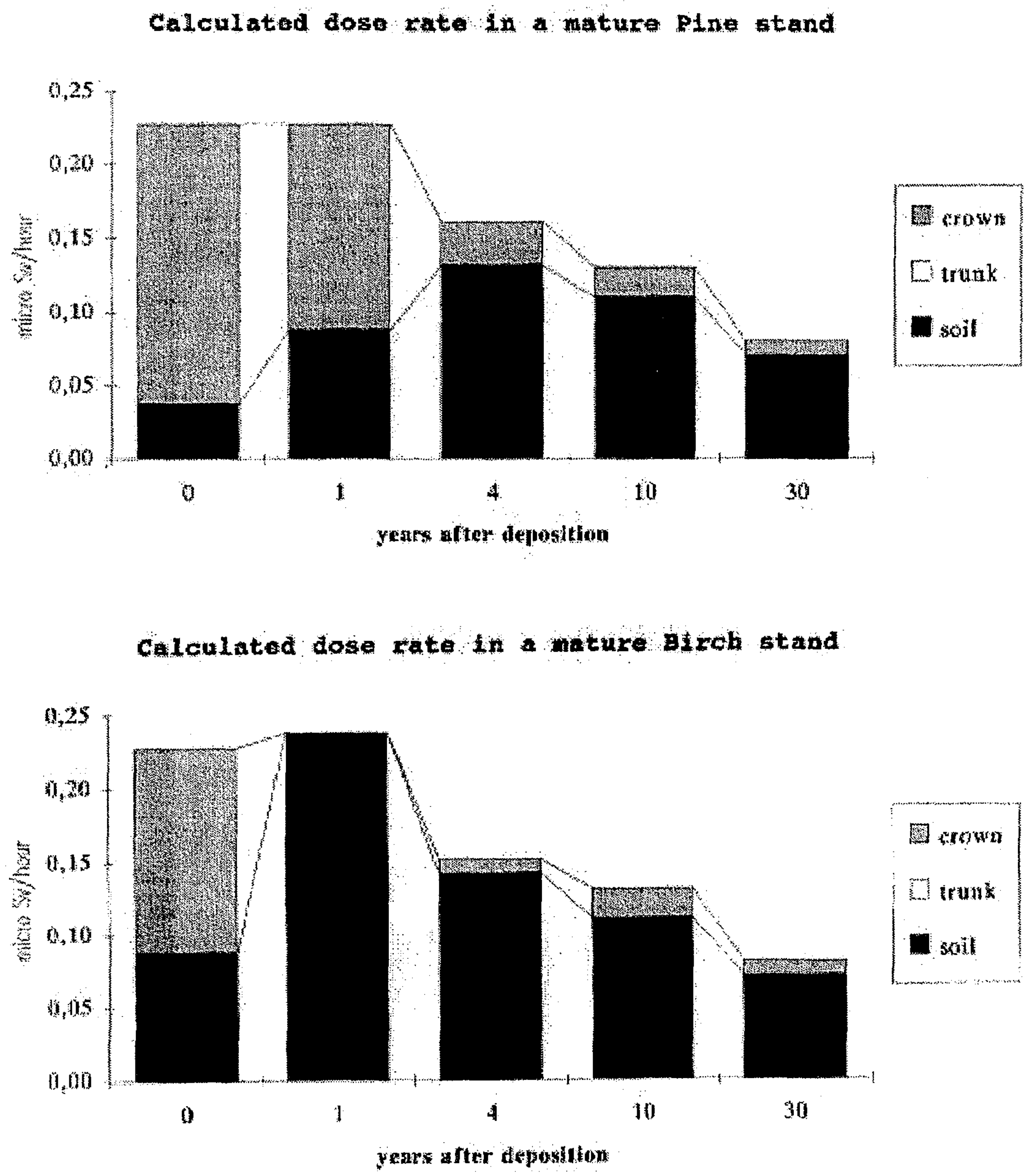

Figure 4.1 Calculated external dose rate in mature stands of pine and birch from deposited ^{137}Cs. Deposition rate 100 kBq m^{-2}.

Table 4.5 The external dose rate calculated in Figure 4.1 are based on the assumptions given here.

Stand density		**Years after deposition, deposition occured when the trees were fully leafed**							
		0		**1**		**4**		**10**	
		Cs-137 distribution, Bq m^{-2}	**Calculation of dose, source distribution[1]**	**Cs-137 distribution, Bq m^{-2}**	**Calculation of dose, source distribution[1]**	**Cs-137 distribution, Bq m^{-2}**	**Calculation of dose, source distribution[1]**	**Cs-137 distribution, Bq m^{-2}**	**Calculation of dose, source distribution[1]**
Pine, 1000 stems ha^{-1}	Crown	80	Plane surface[2]	60	Plane surface[2]	10	Plane surface[2]	10	Plane surface[2]
	Trunk	5	Point source	5	Point source	10	Point source	10	Point source
	Soil	15	Plane surface[3]	35	Plane surface[3]	80	Exponential depth[4]	80	Exponential depth[4]
Birch, 250 stems ha^{-1}	Crown	60	Plane surface[2]	0	Plane surface[2]	4	Plane surface[2]	10	Plane surface[2]
	Trunk	5	Point source	5	Point source	10	Point source	10	Point source
	Soil	35	Plane surface[3]	95	Plane surface[3]	86	Exponential depth[4]	80	Exponential depth[4]

[1] Finck (1992)

[2] Attenuation 0.9, 0.6 (primary photons) x 1.5 (build up factor)

[3] Linear relaxation depth 1 mm, soil density 1600 kg m^{-3}

[4] Linear relaxation depth 1 cm, soil density 1600 kg m^{-3}

21. Countermeasures in forests

When considering countermeasures in the forest environment, one should also bear in mind that they might also disturb the forest ecosystem and is likely to adversely affect productivity.

In this report only the influence of forest management procedures on the accumulation of radionuclides in different parts of the forest environment will be considered, together with radiation safety aspects for forest workers.

21.1 Clear-felling

Clear felling of a forested area within the first years after deposition can considerably contribute to a reduction in dose rate. For the examples given in Fig 4.1 a clear felling of the birch and pine stand could decrease the dose rate by 70 and 85% respectively over a period of 30 years if all the harvested material is removed. It has to be stressed that if clear felling is considered as a countermeasure it has to be carried out within the first year after deposition. If the forested area has to be decontaminated at a later stage other actions have to be taken such as removal of the litter layer, deep ploughing, covering with clean soil etc.

Clear felling and banning the harvested material will lead to a substantial loss in economical value of the forest. The economical loss is estimated to be within a range of 3000-12000 ECU ha^{-1} depending of stand age and productivity. In addition the felled material must be taken care of (see part 6).

The cost-effectiveness of clear-felling as countermeasure is dependent of the number of individuals concerned and the exposure time.

It must be stressed that clear-felling will increase the mineralisation of soil organic matter. Radionuclides bound in the soil organic matter may thus be released and eventually reach the ground water. There is also a risk of an increase in surface run-off following clear felling that might contaminate nearby surface water.

21.1.1 Ploughing and tilling of a clear-felled area

Ploughing and tilling the clear-filled area will further increase the rate of mineralisation of the soil organic matter. However, ploughing and tilling will usually decrease the radiation levels.

21.2 Processing of trees

Removing certain parts from the tree before processing to produce timber, board, paper etc., will reduce contamination levels in the products. For instance, taking off the bark can remove up to 50% of the contamination (Tables 4.3 and 4.4).

22. References

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