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Tools for forming strategies for remediation of forests and park areas in northern Europe after radioactive contamination: background and techniques

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Abstract

This report compiles background information that can be used in planning appropriate countermeasures for forest and park areas in Denmark, Sweden, Finland and Norway, in case a nuclear accident results in large-scale contamination of forests. The information is formulated to inform the forestry sector and radiation protection experts about the practicality of both forest management techniques and mechanical cleanup methods, for use in their planning of specific strategies that can lead to an optimal use of contaminated forests. Decisions will depend on the site and the actual situation after radioactive deposition to forested areas, but the report provides background information from investigations performed before an accident occurs that will make the process more effective. The report also discusses the radiological consequences of producing energy from biomass contaminated by a major nuclear accident, both in the context of normal biofuel energy production and as a means of reducing potentially severe environmental problems in the forest by firing power plants with highly contaminated forest biomass.

Keywords

Forests; Radioactive contamination; Remediation; Northern Europe; Countermeasures; Forest management; Mechanised forestry; Radiation protection; Biofuels

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Preface

This work is part of the BOK-1.4 project (Countermeasures in Agriculture and Forestry), carried out under the framework of the Nordic Nuclear Safety Research Programme (NKS) during 2000-2001. The authors share responsibility for the content of the report as follows:

Lynn Hubbard (project leader, NKS/BOK-1.4b): Editor, presentation of Swedish forestry views, data and facts, Swedish experience on biofuels and guidance for disposal and circulation of biofuel ash.

Aino Rantavaara: Forest management issues, remediation with silvicultural measures, review on forest radioecology and countermeasures, and information about forestry in Finland.

Kasper Andersson and Jörn Roed: Danish experience on mechanised forestry, cleanup of forest environment, facts about Danish forestry, principles of radiation protection, experience from work in Belarus and Ukraine in using contaminated biomass as fuel for energy production.

We appreciate receiving the text on Norwegian forest legislation and administration, written by Berit Lindstad, and thank Gordon Christensen for coordinating the effort.

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1. Summary

This report compiles background information that can be used in planning appropriate countermeasures for forest and park areas in Denmark, Sweden, Finland and Norway, in case a nuclear accident results in large-scale contamination of forests. The information is formulated to inform the forestry sector and radiation protection experts about the practicality of both forest management techniques and mechanical cleanup methods, for use in their planning of specific strategies that can lead to an optimal use of contaminated forests. Decisions will depend on the site and the actual situation after radioactive deposition to forested areas, but preparing background information from investigations performed before an accident occurs will make the process more effective.

Forests cover large areas of land in Denmark, Finland, Norway and Sweden. The majority of the forested land in these countries lies in the boreal coniferous zone, with coniferous species dominating. Boreal mountainous forests are found in Norway, and Denmark belongs to the temperate zone. The length of winter varies in the Nordic countries, with snow cover lasting an average of 4 to 6 months, and even longer in the northernmost parts. Forests are vulnerable to both the northern climate and to environmental conditions. Therefore, it is particularly important to understand the influence remedial measures will have on different types of forests.

The Nordic countries currently have no documented strategic plans for mitigating radioactive contamination in forests and parks. In Finland, Norway and Sweden regional and local organisations are responsible for sustainable forest management.

Remediation techniques for radioactively contaminated forest and park areas can be categorised as mechanical methods for cleanup and forest management techniques. This project report describes technical aspects of mechanical cleanup of forest and park areas, e.g., methods, technical constraints, treatment and disposal of waste, etc., that need to be considered in developing a remediation strategy. The discussion of forest management focuses on advice for applying or altering otherwise normal forest management techniques.

Mechanical removal of some fractions of the contaminated biomass or soil can be considered for a limited land area after heavy fallout. Mechanical techniques include felling, chipping and grinding of forest biomass or litter. Mechanical cleanup can lead to the removal of a large fraction of the contamination, although protection of the workers must be considered and the waste must be deposited properly. Change of land use may be necessary after a radical mechanical removal of forest soil. Practices that are possible in a limited land area are not realistic in large forests.

Techniques for chipping and transport are described for the possible purpose of using the contaminated forest biomass as fuel in power plants. The radiological safety during the whole process of wood energy production is discussed in the report. The special radiological circumstances that occur following a heavy contamination can favour the decision to burn heavily contaminated wood in power plants specially designed to contain the radioactive emissions to an acceptable level.

Normal and modified forest management practices are approaches that can be used in planning a strategy for contaminated forests. These practices must be tailored locally to consider the site qualifications and the contamination situation of the forest biomass and soil. Appropriate uses of contaminated wood and advice on restrictions on consumption of contaminated forest foods are the simplest forms of reducing human radiation exposure in a wide variety of situations.

In the last decade, emphasis has been focused on defining sustainable forestry. Regeneration methods have been discussed, investigated and developed towards ecologically safe practices. Treatments that damage the forest ecosystem are increasingly not allowed. The stabilising function forests have against soil erosion and groundwater contamination has been emphasised in the reviews of countermeasures in the 1990's. Afforestation has often been suggested for contaminated agricultural land after the Chernobyl accident.

Operations in forests differ from those applied in urban parks. Park areas are not maintained for production of timber; they are mostly grown for landscape and recreation, and sometimes for picking berries and mushrooms. Protected forests, such as national parks and nature conservation areas, demand very delicate management methods due to their role as areas of minor human influence. The content and scale of operations is different in timber producing forests versus urban forests where local citizens visit.

Currently, a comparatively large fraction of the energy supply in the more intensively forested Nordic countries, such as Sweden and Finland, is provided by combustion of biofuel in power plants. The technology required to produce energy from biomass has been proven in the Nordic countries, but the mere fact that power can be produced in a way that is under normal conditions safe does not necessarily imply that a safe power production can be sustained based on combustion of biomass contaminated by a major nuclear accident.

It is a well-known phenomenon that combustion can lead to waste products enriched in radionuclides. In those forested areas of the Nordic countries that received the most fallout from Chernobyl, significant amounts of ^{137}Cs remain in different parts of the forest ecosystem. The highest concentration in the prevalent pine trees is in the needles, with decreasing concentrations respectively in the branches, bark and wood. The use of the needles, branches, and bark for biofuels is an increasingly common practice, with the wood left for lumber. Thus, the parts of the trees most concentrated in ^{137}Cs are often used for biofuel. Time-series measurements of the concentration of ^{137}Cs in the trees in Chernobyl-affected forests have shown that the ^{137}C-concentration was still increasing 15 years after the accident.

The most significant exposure pathways to the general population from caesium-137 releases from biofuel plants, including both external and internal doses, are found to be 1) depositing of the ashes, 2) recycling of the ashes to the forests for nutritional purposes, 3) releases of condense-water, and 4) exhaust from the smokestack (flue gas). Assuming an activity concentration of 5 kBq/kg ^{137}Cs in the ashes, which is the recommended limit for the ^{137}Cs concentration in ashes for recycling in Sweden, the largest dose is estimated to occur during occupation with ash deposition, and is estimated to be on the order of 0.1 - 0.5 mSv/yr.

It is estimated that approximately 6-7 percent of the current forested area in Sweden can produce ashes with levels over 5 kBq/kg. With today's production, that area would give 3000-7000 tons ashes/yr. This can increase in the future with increased use of biofuels.

After a major nuclear accident, it may be desirable to reduce the potentially severe environmental problems in the forest by firing power plants with the contaminated forest biomass. In that situation, power plant workers can potentially be exposed to an external dose rate of significance if the workers stand long enough near ash containers, conveyors or other ash-handling locations. Calculations of dose rates to plant workers in a power plant fired with wood from an area with a ground contamination level of 1 MBq m^{-2} of ^{137}Cs could receive an annual dose contribution of 1 – 2 mSv/yr. If contaminated forest biomass is burned in power plants, the ashes must be disposed of according to regulations for radioactive waste, which depends on the final content of ^{137}Cs in the ashes.

2. Introduction

A sense of perspective is needed in planning remediation measures for forests contaminated with radioactive deposition. A variety of conditions must be considered before a strategy can be formulated, such as the magnitude of the contamination, the size and use of the contaminated area, the economical costs and dose-saving qualities expected, and the long-term effects of a given action or non-action.

This document is intended to provide background information that can be used in forming appropriate and balanced strategies for remediation of forest and park areas in the Nordic countries of Denmark, Sweden, Finland and Norway, in case a nuclear accident results in major airborne releases and large-scale contamination of forests. The information is intended to inform both the forestry sector and radiation protection experts about the practicability of some forest management and cleanup methods.

This report discusses the following topics.

- Earlier studies of relevance to remediation of contaminated forests
- Administrative structure and status of plans for remediation of contaminated forest and park areas in Denmark, Finland, Sweden and Norway
- Forest management techniques that should be considered in an emergency preparedness plan
- Mechanical techniques for cleanup methods that could potentially be implemented in an emergency preparedness plan
- Short and long-term consequences regarding the industrial uses of wood from contaminated forests
- Radiological risks of forest fires and doses to forest workers

2.1 Contamination of forests after radioactive deposition

Long-range atmospheric transfer of accidentally released radioactive material deposits on large areas and becomes diluted. Even in such areas, forests can be contaminated for long periods and countermeasures may be needed to improve the quality of forest resources.

The Chernobyl accident showed that tree canopies could intercept very high fractions of deposited radioactive contaminants that can contribute significantly to external doses in the early phase of a fallout situation. Research since the Chernobyl accident has shown that the radionuclide ^{137}Cs remains and re-circulates in the forest ecosystem for many years, with its disappearance from the ecosystem dominated by its physical half-life. Incorporation of ^{137}Cs into the forest flora and fauna takes many years. Therefore, the use of the forests for recreation, industry and as a food source can lead to both external and internal radiation doses.

In the long term, the ingestion pathway dominates human internal radiation doses received from forests contaminated with ^{137}Cs in areas where wild mushrooms, berries, or game meat contributes to the diet. Compared to external doses received during a stay in the forest for hunting or gathering wild food, the ingestion dose can be higher by several factors of ten.

2.2 Forests in Northern Europe

Forests cover large areas of land in the four Nordic countries Denmark, Finland, Norway and Sweden, see Table 1. The majority of the forests discussed here are in the boreal coniferous zone, with coniferous species dominating. Boreal mountainous forests are found in Norway, and Denmark belongs to the temperate zone. Forest coverage maps, ecological zone maps and other forestry information are available for all Nordic countries (as well as the rest of the world) at the useful web site www.FAO.org (Food and Agriculture Organization of the United Nations, 2000).

The length of winter varies in the Nordic countries, with snow cover lasting an average of 4 to 6 months, and even longer in the northernmost parts. Forests are vulnerable to both the northern climate and to environmental conditions. Therefore, it is particularly important to understand the influence remedial measures will have on different types of forests.

Forests are an important resource for commodities and multiple uses of forests are emphasised in planning. Laws protect the biodiversity of forests, and landscape management is an important attribute in guidelines for good forest management. Forests have been traditionally protected in the North, and governments support development of recreational use of forests. Forest food products are also important, although there are national differences (Hytönen 1995).

Forests are important for timber production in Sweden, Finland and Norway. Planned timber production is also found in Denmark, although the planning of production is more on a voluntary basis than in the other Nordic countries. Iceland supports afforestation, with small plantations, but they are only significant for the gradual increase of forested areas.

Table 1. Forest cover in Northern European countries (Global Forest Resources Assessment 2000, www.FAO.org.)

Country	Forest land, 1000 ha	Percentage of land area
Denmark	455	10.7
Finland	21 935	72.0
Iceland	31	0.3
Norway	8 868	28.9
Sweden	27 134	65.9

2.3 Some principles of radiation protection and intervention

The description of methods given in this report for mechanical cleanup of forest and park areas is focused on the technical aspects (e.g., method description, technical constraints, treatment and disposal of waste, etc.) that always need to be considered in developing a remediation strategy. The discussion of forest management focuses on advice for applying or altering otherwise normal forest management techniques. However, it should be stressed that a number of potentially equally important aspects should be taken into account in the development of any countermeasure strategy.

In ICRP (International Commission for Radiation Protection) publication 82 (1999) it is clearly stated that the advantages of intervention not only include averted doses, but also the reassurance and decrease in anxiety gained by the population. Similarly, the disadvantages introduced by an intervention may include not only the direct economical costs, but also the harm and social disruption generated. This means that the optimal solution is not necessarily the one that gives the greatest averted dose.

Social factors are typically not of a generic nature, but are particularly important to consider in relation to a specific situation. Anxiety and social disruption will certainly appear in populations normally living or working in or near areas contaminated by large-scale accidents, and considering this in all information and implementation of countermeasures is essential. It is generally important that the local population is allowed to participate in decisions affecting their well being. In this context, not only the total cost and benefits of carrying out a remediation strategy must be considered, but also the distribution of costs and benefits in the population. It should also be considered whether risks imposed on workers in remediation processes are reasonable, and justified by the good achieved for society and industrial life.

The perception of risk may vary both geographically and between different groups of the population. In a recent study (Salt et al., 1999), the public risk perception in relation to consumption of mushrooms was investigated. One consideration was that knowledge, or education, appeared to generally reduce the anxiety. The risk perception pattern was also found to differ between populations in different Northern European countries, where issues of public information had traditionally been treated in different ways.

3. Earlier studies of relevance to remediation of contaminated forests

The information reviewed in this chapter was chosen to show different methodologies for countermeasure evaluation, the importance of reliable on-site data, and the variety of attributes to be considered in discussions on remediation.

3.1 NKS projects

In at least two earlier Nordic Nuclear Safety Research (NKS) programmes, the radioecology of seminatural ecosystems in northern Europe was studied. Radioactivity data were both compiled and produced during the project RAD (Dahlgaard et al., 1994). The EKO-2 project (Bergan 1995, 1997) also addressed the radiation doses received via wild foods, particularly mushrooms and roe deer. Discussions on countermeasures for contaminated forests were activated by NKS during the BER project, but the conclusions were very brief (Melin 1997). The importance of wild foods to human dietary intake was recognised in the AKTU project, when losses of radiocaesium during household cooking of mushrooms and wild berries were studied (Tveten 1990). In a later BER project, changes in consumption patterns and attitudes of Finns after the Chernobyl accident in 1986 were surveyed by Blomqvist et al. (1991). The survey also covered food types of wild origin.

Extensive studies on seminatural ecosystems were performed and compiled during the RAD projects, where contamination of food chains related with semi-domestic reindeer and wild foods of both plant and animal origin were studied (Gaare, Staaland 1994; Johanson 1994; Olsen 1994). In addition, the dynamics of radiocaesium in boreal forests was reviewed (Bergman 1994).

To improve the accuracy and relevance of estimating the ingestion dose, the Nordic countries surveyed the consumption rates of wild mushrooms in the EKO-2 project, reported at the Nordic Radioecology seminar in 1996 (Markkula and Rantavaara 1997, Johanson 1997, Strandberg 1996).

Cleanup was studied in an NKA (Nordic Liaison Committee for Atomic Energy) project in urban and rural areas under winter conditions in the late 1980's (Tveten 1990). The next phase included cleanup studies in forests in the project KAN, which resulted in estimates for quantities of generated wastes, and costs from removal of contaminated forest vegetation and surface soil (Lehto 1994). Forest areas typical of Scandinavia and Finland were chosen for a contamination scenario.

Decontamination of agricultural land and urban surfaces by mechanical cleanup methods was also included in the studies under EKO projects (Andersson 1996, Ulfsand 1997). Effectiveness of cleanup in residential areas and parks by cutting of lawns immediately after a dry deposition event was assessed in the project EKO-5 (Moring and Markkula 1997).

3.2 Projects from the 4th Framework programme of the EC

3.2.1 Forest radioecology and modelling

Studies on the radionuclide dynamics, modelling and countermeasures of seminatural ecosystems, and their application to forests were the main content in several projects of the 4th Framework programme of the EC.

SEMINAT. The project SEMINAT (Long-term Dynamics of Radionuclides in Semi-Natural Environments) investigated the fluxes of radionuclides and derived model parameters (Belli 2000). A database for calibration and validation of compartment models was improved through field experiments carried out in several countries and with laboratory experiments. Much emphasis was put on the understanding of environmental transfer of radionuclides, particularly radiocaesium.

LANDSCAPE. The project LANDSCAPE investigated the human radiation dose pathways associated with forests, existing models were updated and validated, and the selection of moose feed was studied in field conditions. Models and a GIS application were also used to demonstrate regional biofuel and wood ash activity levels in Sweden. Experiments on forest fertilisation, its effect on contamination of forest vegetation and its usefulness as a countermeasure were carried out. Reduction of activity by a factor of five in the entire vegetation biomass was achieved on a mineral soil site. The effect was even greater for stem-wood. Key factors were sufficient doses of fertilisers and proper timing of the treatment (Moberg et al., 1999).

EPORA. The project EPORA studied synergies of heavy metals and radionuclides in their transfer in understory vegetation in both contaminated forests and relatively undisturbed sites (Suomela et al., 2000). The inputs of additional pollutants to soil reduced the soil-to-plant transfer of ^{137}Cs and ^{90}Sr for some understorey species.

Concomitant to these changes, nutrient cations of K, Ca and Mg decreased in the organic horizon. The changes in uptake of Pu, Cs and Sr isotopes by different species along the pollution gradient studied gave interesting new findings for forest ecosystems.

RODOS. A food chain and dose model for forests is an integral part of RODOS, the European decision support system for nuclear emergency management. A forest model was developed under the umbrella of the RODOS project (Rantavaara et al., 1999), which simulates the fate of radionuclides in the forest ecosystem. It gives the contamination of forest products as a function of time and shows their spatial distribution on geographical maps. Both external and internal radiation doses received by different population groups can be assessed. Development of the forest model to include countermeasure assessments is continuing under the project RODOS Migration in the 5th Framework Programme of the EC.

3.2.2 Countermeasures, remediation and restoration

FORECO. A realistic and ecologically oriented evaluation report of countermeasures suggested for contaminated forests was a result of the project FORECO (Rafferty, Synnot 1998). A review of radiological measures with potential value for contaminated forests considers both reported and potential secondary effects. All human dose pathways related with forests are covered by the variety of countermeasures discussed.

Emphasis was placed on vegetation and soil related measures. Leaves can be removed from trees with a chemical defoliant, using the method of non-lethal defoliation, in order to remove radioactive material intercepted by leaves. Soil additives range from different clay minerals to a chemical compound AFFC (ammonium-ferrous-ferric-cyanide). Liming and fertilisation are also discussed. The evidence on effectiveness of these methods in agriculture may indicate their usefulness in forests, but some reservations are obvious, such as the known influence of fertilisation on the composition of understory species in forests. Soil decontamination methods based on removal of surface layers have been developed for and tested in agriculture for rehabilitation of severely contaminated sites. The function of forest as a stabiliser of soil was emphasised.

The secondary effects were sometimes derived from expertise on seminatural upland pastures or agriculture. After clear felling as a method of decontamination, environmental and waste problems would have to be solved. Relevant to the current thinking on sustainable forestry is the critical attitude towards methods using artificial agents, or changing radically the structure of the forest ecosystem. Resistance from local populations were also among the secondary effects.

The conclusion on far-reaching secondary effects of, e.g., interfering with or disturbing the soil in a seminatural environment, is certainly important in the northern climatic conditions. From a Nordic point of view, it is also useful to remember that snow cover might reduce resuspended radioactive dust during forest work, when compared with conditions without snow.

CESER. The CESER project studied environmental and socio-economic responses of countermeasures (Salt et al., 1999). Although mainly related with agriculture, the project also included parts that are of interest for forest remediation. For example, the landscape structure analysis of biodiversity changes and the results of economic assessments of countermeasures are relevant. The survey on consumer attitudes and behaviour included changes in consumption levels, and some wild foods (berries, mushrooms, game) and reindeer were among the food types studied.

TEMAS. The project TEMAS dealt with techniques and strategies for environmental restoration and their ecological consequences, and considered forest industry but did not discuss techniques of countermeasures applied to forests (Gutiérrez et al., 1999). The assessment model developed for remediation of forests for the IAEA (International Atomic Energy Agency) was briefly discussed (Frissel et al., 1996). The TEMAS project assumed the probability of developing feasible countermeasures for growing stands was small. The reason must have been lack of evidence for any effective management method, which could reduce the radionuclide content of forest vegetation. Such methods were tested by two systematic field experiments in the LANDSCAPE project, which gave evidence for the usefulness of forest fertilisation as a countermeasure (Moberg et al., 1999).

RESTORE. The objective of the project RESTORE (Restoration Strategies for Radioactive Contaminated Ecosystems) was to provide practical recommendations for methods of reducing radiation exposure within contaminated areas in the Commonwealth of Independent States (C.I.S.) (Voigt and Semioschkina 1999). Radionuclide fluxes were assessed for different environments, including forests, and for the harvesting of wild foods. Other local pathways than those derived directly from forests, of key importance to dietary intake, were fresh water fish and produce from private dairy farming. Use of flooded areas for cultivation of food crops was mapped and recommendations were given on how to reduce foodstuff contamination with potassium fertilisers. Self-help advice to people in affected areas for reduction of radiation doses from wild berries and mushrooms was a cost effective countermeasure proposed by the project group. Reassessing some current countermeasure strategies was suggested for better usage of limited resources.

RECOVER. The project RECOVER (Relevancy of Short Rotation Coppice Vegetation for the Remediation of Contaminated Areas) was set up for adding to a rather scarce radiological data base that would allow evaluation of the cost efficiency of different short rotation vegetation options in agriculture. (Vandenhove et al., 1999). The field experiments with willow and annual plants, the cost estimation models and comparisons of economic profitability by site and plant types relate to bioenergy production options in Northern Europe. The ecological aspects were also discussed. The use of short rotation coppice could be used to prevent harvesting of highly contaminated vegetation products and mushrooms in forests.

RESTRAT. In the project RESTRAT (Restoration Strategies for Radioactively Contaminated Sites and their Close Surroundings) a methodology for ranking restoration options was developed (Zeevaert et al., 2001). The major criteria for evaluation of benefits and detriments were: radiological health detriment, economic costs and social factors. Existing contaminated sites were used as examples of the use of methodology. The project also resulted in a manual on restoration techniques most appropriate to remediation of sites that have been contaminated by radionuclides from European nuclear installations (Zeevaert and Bousher 1998). The information is useful to consider for comparisons of the level of contamination, areas of the sites, and the results of optimisation.

3.3 NATO workshop 1998

Content and practicality of forest related countermeasures were reviewed in the Advanced Research Workshop with title *Contaminated Forests – Recent Developments in Risk Identification and Future Perspectives*, organised by NATO in 1998 (Linkov, Schell 1999). Gaps of knowledge concerning countermeasures applicable to contaminated forests and related radiation sources were evaluated. Emphasis was given to the contaminated forests in the C.I.S. in the near future, or 15 – 20 years after the Chernobyl accident in 1986. Four dose pathways were suggested as being of radiological importance. They were external dose from ground sources to forest workers and some forest residents, external doses from tree sources to workers in specialised operations, ingestion doses to the public from tree sources related to the use of wood ash, and food ingestion doses to the public.

The workshop showed the necessity of monitoring food chains contributing such doses to the public that intervention is needed. Monitoring was emphasised in the intervention programmes of the Russian Federation (Panfilov 1999) and Ukraine (Kaletnyk 1999). The Biomass-into-Energy options suggested for Belarus were also presented (Grebenkov et al., 1999).

Discussions of countermeasures resulted in a list of topics for further research, covering validation of dose assessment methods against real data, and validation of schemes for and testing of the effectiveness of education and information programmes. Full dose assessment was proposed for use of wood ash on gardens and forest fertilisation, although the practical knowledge of such pathways is improving (Rantavaara and Moring 1999). Variability of reported transfer parameters for ^{137}Cs in different forest products and the obvious uncertainty derived from it makes decisions difficult to make. Measures to reduce external radiation need further research with regards to removal of contaminated forest floor organic material and ploughing. In addition, the practicality of reducing stock density for radiological reasons needs assessment on its effectiveness. Bioenergy concepts for contaminated vegetation and litter 'require detailed evaluation with regard to economical, ecological and social factors, and the assessment of potential added risk' (Amiro et al., 1999).

3.4 Activities of the IAEA in the area of intervention after radioactive contamination of forests

3.4.1 IAEA intervention exemption level system for forest biomass

ICRP publication 82 (1999) stresses that 'due to the globalisation of markets, intervention exemption levels of radionuclides in commodities cannot be established on a case-by-case basis; rather they need to be standardised'. ICRP further addresses this statement by setting a generic intervention exemption level of 1 mSv as the maximum permissible annual individual dose from what is deemed the radiologically most important type of commodity. In practice, this means that the maximum permissible contamination levels in forest products (e.g., timber, pulp wood and fire wood) should be those that lead to an annual individual dose of 1 mSv. The IAEA have prepared a report, which provides estimates of the conversion factors between forest biomass (wood) contamination levels and annual doses that would be received due to the contamination, assuming conditions that are believed to adequately reflect 'typical' situations (Balonov et al., 2001). These factors are given as guidance for calculation of reference contamination levels, but it should be stressed that intervention exemption levels in use currently vary widely between countries (Guillitte et al., 1993), and may be considerably lower than the recommended 1 mSv.

Table 2 below gives a number of examples of calculated dose conversion coefficients for different types of application of wood products, as suggested by the IAEA (Balonov et al., 2001). The values should be regarded as examples of possible conversion factors, based on a series of assumptions regarding e.g., types and amounts of wood applied, geometries, inhaled ash fractions, uptake by plants, diet, etc. The presented figures are therefore obviously subject to some variation. For more detailed estimates of the individual dose contribution, it would be advisable to apply actual, case-specific data in the exposure models presented in the IAEA methodology document.

Table 2. Conversion factors from ^{137}Cs content (Bq kg^{-1}) in wood to annual individual dose (mSv) from different types of exposure in connection with the use of contaminated wood or wood products (data from Balonov et al., 2001).

Type of exposure	**DCC, mSv / Bq kg^{-1} in wood**
External dose from stored wood at sawmill	1 10^{-4}
Inhalation dose from dust at sawmill	4 10^{-8}
External dose from ash deposit	8 10^{-4}
Inhalation dose at ash deposit	1 10^{-7}
External dose from wooden floor	3 10^{-6}
External dose from wooden bed	3 10^{-5}
External dose from wooden furniture set	3 10^{-5}
External dose from domestic use of wood fuel	1 10^{-6}
Inhalation dose from domestic use of wood fuel	2 10^{-7}
External dose from use of wood ash fertiliser	7 10^{-5}
Ingestion dose from use of wood ash fertiliser	4 10^{-7}
Inhalation dose from use of wood ash fertiliser	8 10^{-9}

3.4.2 IAEA decision aiding model for contaminated forests

The IAEA have recently described their model, FORM, for evaluation of management options for contaminated forest areas (Dvornik et al., 2001). This model can be run in an excel spreadsheet. FORM includes a model part for prediction of radionuclide migration in a forest environment, a part for calculation of dose contributions through various pathways, and a part introducing a limited number of management options, including direct economic cost components. The model is essentially a ^{137}Cs model, though also some data for strontium and plutonium contamination are supplied. The radionuclide migration part is based on assumptions regarding the initial distribution of the contamination in the forest, rate constants and transfer coefficients between the different compartments in a coniferous or deciduous forest (bark, leaves, new wood, old wood, litter, organic soil, mineral soil, etc.). The calculation of dose includes contributions from ingestion of forest products, inhalation in the forest, (including resuspension), inhalation from resuspension in industry, inhalation from forest fires, and external exposure under various circumstances, using a series of relatively uncomplicated formulae. Management options considered include minimum management, delayed cutting, early clear cutting, soil fertilising or improvement and limiting public access.

When the model was applied to the post-Chernobyl radiation situation, the most cost-effective countermeasure was restriction of mushroom consumption. The forest management operations were not cost-effective when assessed using the model database (Shaw et al., 2001).

3.5 Conclusions

The behaviour of affected populations and the effectiveness of restricting ingestion doses with dietary advice should be included in intervention planning and local investigations. The work under CESER (Salt et al., 1999) and RESTORE (Voigt and Semioschkina, 1999) motivate using an advanced methodology in studies on changes in consumption pattern after radioactive contamination of food products. Studies of Jacob et al. (2001) and Shaw et al. (2001) confirm the cost-effectiveness of restrictions of individual food types, especially mushrooms. These studies consider the post-Chernobyl conditions in the most affected areas. Socio-economic values were generally considered, but additional forestry related values, for example the traditional respect of nature inherent in the population of Northern European, was often missing.

Not all of the earlier studies strongly emphasise ecological and environmental factors in remediation of forests, although they were mentioned by Rafferty and Synnot (1998), Amiro (1999), Salt et al. (1999) and Vandenhove (1999).

Some suggestions for reduction of radiation exposure from forests in C.I.S.-countries presented in individual papers did not explicitly refer to environmental protection practices. Burning of soil humus was suggested for promoting the leaching of radionuclides from the surface of forest floor and was prescribed without consideration of soil types. The removal of organic surface soil needs further evaluation (Grebenkov et al., 1999). The opposite effect to remediation of forests may appear through reduction in the nutrient budget of soil, which may cause decrease in growth and increase of radio-caesium and –strontium uptake.

The lack of evidenced effectiveness of some suggested forestry operations is obvious. For instance, reduction of stock density in order to limit workers time for maintaining the forests in the next two or three decades needs further evaluation to weigh the advantages of reduced worker dose against the principles of sustainable forestry.

A development has occurred in distinction of external and internal exposure during forest work in affected areas in the C.I.S. countries. There may still be need for improved external dose estimates and monitoring in forests. In the majority of affected areas, the suggested mechanisation of forest work in order to shorten working times and thereby reduce doses may not be an optimised measure.

The discussion on forest related countermeasures in earlier post-Chernobyl literature often represent views derived from radioecology, radiation protection and methodologies known to representatives of these disciplines. Most scientists would be prepared to include principles of sustainable forestry and related environmental values in their thinking, after clarification of the importance of such an area in modern forestry to them. Relevant multidisciplinary collaboration, adjusting the use of terms and defining the context in planning of countermeasures would certainly reduce the number of impractical measures and strategies proposed. None of the critical comments given above shall reduce the value of extensive databases collected and experience obtained in affected areas, for development of a realistic remedial guidance for forests. However, the process requires participants from radioecology, radiation protection and forest industries and authorities in order to be optimum.

4. Administrative structure for planning restoration of contaminated forest and park areas in Denmark, Finland, Sweden and Norway

Laws related to forestry have existed in the Nordic countries since the 19th century, and similar to the current legislation, they demonstrate the importance of forests to the society. The current legislation reflects the trends in forestry and different forestry sectors in each country. Timber production and forest industry are most important in Sweden and Finland. Environmental impacts of forest management are considered, and biodiversity, protection of waters and the northern extent of the forests are of concern. Landscape management is also considered in forestry work planning and practice today.

In all five countries, the common citizen’s right to access nature unrestricted, regardless of land ownership, is traditional and protected by law. The function of forests as a source of recreation and as a supply of forest food products is old, but it is emphasised in current legislation and guidance for forestry planning more explicitly than earlier. Non-wood forest products are still important as sources of livelihood in northernmost parts of the Fennoscandia. Semi-domestic reindeer herding also has a cultural value related with forestry, and maintaining it is important to northern countries.

In Denmark and Iceland, forestry legislation is partly included in legislation for protection of nature. In these countries, timber production is by far not as important as in Fennoscandia. Iceland supports plantations to increase the forest area. Campaigns for recreational use of forests are important in all countries, and popularity of these activities is supported by governments. Geography in Northern countries differs, and therefore the forms of forest-related free time activities differ. For instance, Norway has facilitated the excursions to mountain forests by reserving areas particularly for this use. In Denmark forest, excursions are popular, but not necessarily picking of berries and mushrooms in this connection.

4.1 Denmark

The Emergency Management Agency under the Ministry of the Interior in Denmark has the responsibility for handling radioactive contamination emergencies in forests and parks. To date, however, no strategies have been developed for the handling of such events. In case of an accident, the Emergency Management Agency would undoubtedly draw on the expertise of the Forestry and Nature Agency

(Forskningscentret for Skov og Landskab) under the Danish Environment and Energy Ministry.

In Denmark the forest cultivation and administration is regulated through Danish law (the Danish Forest Act). The law applies to both public and private forest areas. The administrative responsibility in relation to the law lies with the Forest and Nature Agency. In practice, 24 local forest districts under the Forest and Nature Agency undertake the daily administration.
Denmark has no formalised emergency preparedness concerning radioactive contamination of forests.

4.2 Finland

The emergency preparedness act (1991) gives the responsibility to all sectors of administration, including regional and local levels, to plan and maintain preparedness for large-scale accidents and nuclear emergencies. No public strategic plans for restoration of forests after radioactive contamination have been prepared by the year 2000. However, the forest industries are required to have preparedness plans for performing their normal activities, to the extent possible, after emergencies.

The performance of remediation strategies including remedial measures could in practice be delegated to forest owners through Forestry Centres and Forest Management Associations. According to existing regulations, it is not easy to compensate forest owners for additional work for remedial measures. The principles applied will depend on the situation (Setälä 2000).

<u>Administration of forest management in Finland</u>
The Finnish Forest act (1996) and Forest decree (1996) regulate all forest management operations in Finland. Additional statements are given by the Government or the Ministry of Agriculture and Forestry, the competent ministry in affairs related directly with forests. The law also states that management practices must support sustainable development and maintain the biodiversity of productive forests. It pays special attention to preventing the northernmost forest areas from shifting southwards. The legislation applied to forestland covers also other laws, e.g., acts for use of land, environmental protection, housing construction, etc.

The forest act gives the responsibility for supervising the law regarding forest management operations to 13 Forestry Centres. They accept and suggest modifications to the forest felling and management plans of forest owners or other actors having legal right for felling or management operations. For preparation of strategic proposals there are several potential contributors: Ministry of Agriculture and Forestry, The Forestry Development Centre TAPIO, The Central Union of Agricultural Producers and Forest Owners, and The Regional Unions of Forest Management Associations. Locally Forest Management Associations (in all 200) linked with the Union of Agricultural and Silvicultural producers provide services and carry out felling and management operations in forests to private forest owners for pay fixed by law. The Forest and Park Service manages the state-owned forests (about a quarter of forest area and especially northernmost forests) (Aro 2000).

4.3 Sweden

The county administrative boards (Länsstyrelser) in Sweden are responsible for planning and executing all types of mitigation in case of emergencies involving radioactive contamination. They can request assistance from the local municipalities within each county. The county administrative boards also work closely with the Swedish Radiation Protection Authority (SSI), a government expert authority, which gives guidance and advice in case of an emergency. The National Expert Group for Decontamination is organised within SSI's emergency preparedness program. This group is made up of experts from SSI and other government authorities and universities, and is one of the key advice-giving groups in case of an emergency involving radioactive contamination. There exists no organised strategy for remediation of forests or decontamination of forested land in any of these administrative levels in Sweden today.

Administration of forest management in Sweden

The National Board of Forestry is the Swedish Government's expert authority on forests and forest policy. Their mission is to work for a sustainable utilisation of the Swedish forests according to the guidelines given by the Parliament and the Government. The National Board of Forestry leads and co-ordinates the work of 10 County Forestry Boards.

4.4 Norway

Norway has no specific emergency plan concerning radioactive contamination of forests.

Administration of forest management in Norway

Forest management in Norway is regulated by the Forest Act on Forest Production and Protection from 1965, with later amendments. The Act applies to all forestlands, and all forest owners in Norway. The overall objective for the forest policy is to contribute to sustainable development, through balancing environmental, economic, and socio-cultural aspects of forests and forestry. A White Paper to the Parliament and their approval (in 1998-99) proved a great deal of agreement on forest issues, and stated that the main aims today are to increase the value adding in forest-based enterprises and the contributions from the forest sector to meet environmental challenges. Norway is currently preparing a new Forest Act. A proposal for a new Act is scheduled for debate in the Parliament in 2003.

The Ministry of Agriculture is the responsible authority at the national level. In addition, there are local forest authorities in counties and municipalities.

4.5 Summary

The Nordic countries currently have no documented strategic plans for mitigating radioactive contamination in forests and parks in case a nuclear accident contaminates forested areas. Finland, Norway and Sweden have given the responsibilities for sustainable forest management to regional and the local level organisations. The competent authorities, forestry consultants and forest owners need information on different methods of remediation and dose restriction. Optimised strategies for forestry can be created through discussion and exchange of information, where the decision makers of the forestry sector are given the strategic planning tools to be applied for site-specific radiological remediation.

5. Remediation of forests with silvicultural measures

5.1 Goals of remediation

The principles developed for forest management can also be used in decreasing the radiological effects of contaminated forests. In the last decade, emphasis has been focused on defining sustainable forestry. Regeneration methods have been discussed, investigated and developed towards ecologically safe practices. Treatments that damage the forest ecosystem are increasingly not allowed. The stabilising function forests have against soil erosion and groundwater contamination has been emphasised in the reviews of countermeasures in the 1990's. Afforestation has often been suggested for heavily contaminated agricultural land after the Chernobyl accident.

Important goals of forest remediation incorporate the values inherent in forest resources and their usage:

- Human radiation doses from the utilisation of forests and forest products must be at an acceptable level, including doses received by forest workers.
- Availability of forest resources in the short and long term should be optimal from the point of view of different interest groups and forest owners.
- Environmental, ecological and economic criteria of a remediation process should strive to avoid conflict with those applied in forestry.
- Advanced forest planning procedures and the involvement of interest groups specified in them shall be respected in planning of remediation.

5.2 The potential for emergency preparedness in silvicultural planning

Principles of forest management in Nordic countries have changed radically in the 1990's. Ecological, environmental and landscape values, as well as multiple-use forestry and hearings of interest groups are more pronounced in decision making than earlier.

The idea of hierarchic planning is useful. Starting from a national strategy and long-term goals, regional plans for responding to the market demand of timber, and finally considering local involvement, the stand level planning is made. It will be based on stakeholder participation and expertise. Site conditions and parameters of the stand are important for solving the multi-value and multivariable problems of remediation.

The inclusion of remediation of contaminated forests in planning of forestry guidelines would be an opportunity for development of emergency preparedness for forestry in Nordic countries. The experts on forestry and forest management are capable of developing further and improving the effectiveness of countermeasures based on the conditions of a site. Regional suggestions for timed felling operations should be derived from acute market demand of the available timber, and careful selection of stands, to avoid unnecessary costs and not-well-optimised operations.

In a real radiation situation it is worth realising the value of existing forest work plans. They contain the basic information on site conditions and stand type, including, at least implicitly, the goals of the forest owner for the period covered by a plan. Assessing the need to modify the existing plan would be a useful starting point in areas were contamination would not restrict access to the site.

Thinnings, intermediate cuttings and regeneration fellings offer opportunities for harvesting acceptable timber in contaminated forests. Such measures are connected with regional and stand-level planning of forestry, and are a part of optimal use of forest resources after contamination.

5.3 Radioactivity data for planning of remediation

It is crucial to know the basic facts about the radiation situation before any forestry operations are undertaken. Because of the long time dynamics associated with forest radioecology, there will be time to evaluate the practicability of measures, considering the preliminary predictions for future ecological development of the contamination pattern for different types of stands.

Radionuclide transfer in forests is a combination of several simultaneously occurring processes with different rates, which may vary seasonally and with time after the fallout occurred. In the scale of managed forests, intervention does not need to be urgently implemented before the contaminants enter the forest floor or before leaf fall the first autumn after the contamination. There would be many uncertainties in such measures. The weather conditions might change in different parts of an intervention area, and the benefit from a timed measure could be significantly reduced or lost.

The inventory of environmental ^{137}Cs will be halved in 30 years. After a rotation period of a stand, in 80 -150 years about 16 - 3 per cent of initial ^{137}Cs activity remains. Other radioisotopes than ^{137}Cs, e.g. long-lived ^{90}Sr ($T_{1/2}$ = 28 a) are by far not as significant as ^{137}Cs for human radiation exposure and for contamination of forest products. However, in an early phase after deposition, short-lived fallout isotopes would contribute significantly to the radiation dose in forests.

The whole package of reliable radioecological predictions for all types of sites and stands is hardly available for long-term planning. Quantitative assessments of contamination of different forest compartments until harvest time of trees might often be rather superficial, as the whole chain of management operations will influence the ^{137}Cs distribution of a stand. The volume and quality of radioecological investigations on forests was significantly improved in the 1990's, but still a sufficient understanding of all important transfer mechanisms has not been reached.

Considering the state of the art in the radioecology of boreal forests, it is essential to understand the primary change in soil-to-plant uptake after an individual remedial measure, and to follow the effects of the measures by test measurements. The normal planning period in forestry, 5 – 20 years, allows gradual intensifying of measures, to be based on control of remedial effect where needed. In large silvicultural operations, the investments made and the expected yield of acceptable timber will justify sufficient follow-up measurements on critical sites.

5.4 Access to forests during a radiation situation

When forest management measures following radioactive contamination are discussed, either free or restricted access to forests has to be assumed. Silvicultural measures can be undertaken at least under observance of doses received, if not without limitations. After a contaminating event, the removal of radioactive material from the surfaces of vegetation by weathering reduces the external radiation dose from the overstorey to less than half of the original within a few weeks. Doses through inhalation of resuspended radioactive particles decline rapidly in the early phase of a fallout situation. External radiation from medium- or long-lived radionuclides accumulated in the ground layer continues being the main component of external doses received in contaminated forests. Radiation from the ground will decline both by radioactive decay of radionuclides, and through downward migration of these substances in soil. Especially in an early phase of a fallout situation, snow cover reduces the risks from resuspended material (Rafferty and Synnot 1998) and offers some shielding against radiation from the ground (Arvela 1988).

External radiation in forests varies with the surface density of soil contamination, the radionuclide composition of the fallout, and the distribution of radionuclides in the forest ecosystem. Human doses received depend on exposure time. Internal doses from forests are received through ingestion of wild forest products, and are greater than external doses in the later stages after fallout. Visiting forests without picking anything for food can still often be allowed, as the external exposure and doses received during recreational visits are much lower than from ingestion of wild food originating in the same forest.

After contamination of forests near to residential areas, the collecting or harvesting of non-wood products and recreational use of these forests should be planned considering the local needs. Non-food products such as lichens and other decorative materials may be locally important for economy (Hytönen 1995). Patterns of local usage of forests illuminate the radiation dose pathways that need to be assessed and sometimes restricted. Evaluation of different dose pathways to specific population groups should be performed early in the planning to determine the needs for restrictions.

5.5 Remedial potential of silvicultural methods

5.5.1 Measures during rotation period of a stand

Site preparation and regeneration. There are soil related measures with significant remedial value. When the nutritional status of soil is improved, the radionuclide uptake by forest vegetation also can be reduced. Soil preparation increases the mobility of nutrients and has the same effect. When regeneration is based on both natural seeding and planting, only patchy or partial disturbance of surface vegetation and soil is needed for soil preparation (Moilanen 2000). For successful regeneration of forests, the moisture and temperature conditions of soil are decisive when soil preparation methods are chosen (Mälkönen 2001). The preparation of a thin surface layer has replaced ploughing in many cases.

In a part of earlier suggestions for countermeasures in forests deep ploughing was also mentioned (Rafferty, Synnot 1998). The advantage of getting a major fraction of the surface contamination of the forest floor turned down below the root zone of trees seems radiologically meaningful. However, ploughing is only exceptionally used as soil preparation method nowadays. It is recommended only for moist sites with a thick humus layer, as some forests in Northern Finland are.

Thinnings of young and advanced stands and intermediate fellings all improve growth of trees remaining on site, and can thereby dilute the radioisotope concentrations in wood. Direct evidence for such a change in trunk contamination may not be available in the literature. It is possible that some effect on the uptake rate of radioisotopes could be derived indirectly from existing data.

Soil amendment with caesium binding agents. There is evidence for an uptake reducing effect of soil additives known from earlier soil amelioration practices (Paasikallio 1999). Zeolithes did not show any significant effect for Cs in the new experiments carried out in the C.I.S. after the Chernobyl accident, as reviewed by Rafferty and Synnot (1998).

Fertilisation, especially if applied with sufficient dosage in the coming years after contamination, and the timing coincides with the final increment increase, can give a significant reduction in contamination of the timber (Moberg et al., 1999). There are different options of dosage and timing. Kaunisto et al. (2002) have reported a long-lasting influence, although declining with time. Use of wood ash for forest fertilisation was reported to reduce radiocaesium uptake by dwarfs, when berries of lingonberry were studied by Levula et al. (2000).

In a field experiment with rye grass, the addition of biotite reduced uptake of Cs on peatland (Paasikallio 1999). Biotite, a slowly soluble agent with considerable concentration of potassium was shown to have a long lasting effect, a feature that is required in forest fertilisation. Great quantities of biotite were needed; in one field experiment 30 t ha^{-1} was applied. Natural zeolite combined with biotite might result in both early and long lasting reduction on Cs uptake (Paasikallio1999). Resources and availability of biotite in Northern Europe would suggest testing its influence on forest vegetation in field conditions.

Prescribed burning is appreciated as a site preparation method today. The experiments with understorey dwarfs by Levula et al. (2000) included also prescribed burning, which reduced caesium uptake during a follow-up time of 5 years. Caesium accumulated in litter and humus may be evaporated in the high temperature of burning, at lest partially. Resuspension of particle bound radiocaesium would cause redistirbution of radiocaesium near the site during the operation.

5.5.2 Criteria for remedial measures

Normal forest work performed before the contaminating event should be possible to continue in the forest areas that receive only low-level contamination. The following criteria are suggested for evaluation of remedial methods for more heavily contaminated productive forests.

Effectiveness. The activity concentrations of contaminants in forest products, not all of equal radiological significance, can be reduced with several soil preparation methods, mentioned above. It is logical to let the reduction factor indicate the effectiveness. Reduction of uptake from forest soil will also reduce doses received by users of products of forest industry, but for calculation of averted doses, the type of products should be known.

Acceptability criterion and wide discussions about it have resulted in at least part of the changes in forestry towards sustainable development in the 1990's. Certified environmental systems applied in forestry are also convincing (Wallenius 2000). There is no reason to let remediation measures conflict with management principles that are acceptable from the ethical, environmental protection and landscape management points of view. Ethical issues are under discussion that may result in new aspects of e.g. social acceptability and biodiversity.

Monetary costs. The distinction between normal management and remedial measures discussed above is needed in estimating costs of remediation. Only partial loss of profit will follow if felling is delayed or carried out earlier than planned. Costs are derived from reduced yield in both cases. When radionuclide uptake is reduced with additional fertilisation, annual increment on the site will increase, and thereby the cost may in some cases be compensated. For reliable comparison of costs on how additional remedial costs should and can be estimated, more discussion with experts of forest economy is needed.

Environmental impacts like soil erosion, negative changes in site hydrology, and nutrient losses are often connected with clear felling. Use of clear felling in regeneration has been significantly reduced since the 1960's, and remediation would not have additional benefit from it either. The implicit optimising included in current guidelines for forestry, if followed, will also minimise the environmental impact of remediation (Raitio et al., 2001).

Capacity. Remediation with silvicultural and related measures means availability of competent forest workers and machinery. The schedule of operations in a large region can often be flexible enough for receiving imported resources from less contaminated areas. Technical descriptions of forest machinery have been published by, e.g., the Forest Improvement Foundation (1980). Productivity, costs, mobility and performance of forest machines are investigated in projects like the one described in Johansson (2001).

Radiation protection of workers. The construction and efficiency of machines have an influence on radiation exposure to forest workers. Both shielding and time needed for work affect the doses received by workers. In some cases, improving the shielding of cabins can be beneficial.

Harvesting of timber is mechanised by as much as 95% in big companies and 93% in forest associations in Finland. Harvesters and forwarders have an air-conditioned cabin, where excess of pressure prevails. Part of reforestation work (soil management and sowing) and planting of forests (<10%) are mechanised. The tractors are equipped with an air-conditioned cabin.

Thinning and clearing of seedlings and saplings is mostly carried out manually with motor-driven saws, specially designed for the purpose. Collection of harvest and thinning residues, chipping and logistics are under intensive development due to increasing use of and need for biofuel. Chipping can in principle happen at the collection station not too far from the cutting site, or at the bioenergy plant. The scale of chippers ranges from private machines for the needs of one farm to chippers for regional heating or electricity production plants.

Technical feasibility is largely an issue of current management methods. The management guidelines, if applied, will keep the remedial methods feasible.

Wastes. If remediation measures concentrate on silvicultural methods such as timed felling of trees and soil improvements, no biological waste will be generated. After tree cutting and transport of trunks, the harvesting losses of trees are worth leaving in forest until decisions on their eventual use as biofuel are made. They are sources of nutrients independent of their contamination, and removing them for reduction of forest contamination is not often effective from radiological point of view. The fraction of radioactive material incorporated in needles and branches is small compared to the activity budget of the site. The reasons for avoiding waste generation in connection to forest remediation are the high costs of waste treatment, transport and disposal (Lehto 1994, Linkov et al., 1997).

5.6 Conclusions

- Good remediation guidance considers the hierarchic planning procedure established for forest management, the actual site conditions and the local radioactive contamination.

- Remedial actions in forests after a contaminating event involving radioactivity should be implemented only after a realistic view of the contamination has been achieved. The measures to be undertaken in forests are based on planning, use of practicable methods, and understanding the consequences. Urgent application of technical measures without consideration of the actual situation would cause unexpected secondary costs.

- The potential for remediation and the practicality of silvicultural measures is based on
  - scientific evidence on their effectiveness in reducing contamination of trees and undergrowth in boreal forests
  - their closeness to normal forestry practices, which keeps them feasible and acceptable
  - low additional costs for the remedial dimension of a normally applied silvicultural measure
  - observance of site and stand condition and follow-up of radiological results
  - motivation of interest groups and forest owners by calling for their involvment in the remediation of forests.

6. Mechanical techniques for remediation of forests

The removal of forest vegetation and/or soil as a remedial measure in contaminated forests would damage the diversity and stabilising characteristics of the forests flora and fauna. Before such a suggestion could be considered as a remedial measure in a contaminated forest area, silvicultural measures should be evaluated first.

6.1 Felling techniques

This chapter describes some techniques that are available for felling, chipping and grinding of forest biomass or litter. Description of machinery used in forestry is addressed to those readers who are not familiar with current practices. There is no implicit optimisation in the selection of methods discussed. Where possible, dose reduction efficiency of a technique is given. Site-specific information is necessary before making decisions on measures to be applied in a real contamination situation.

6.1.1 Machinery for felling

The machinery currently applied for the felling of trees in Denmark, and in Fennoscandia in general, is partly chainsaws and partly large felling machines. In clear-cut areas, only about 5 % of the coniferous forests are harvested manually with chainsaws; the rest are machine-harvested. For these types of forest, it is generally so that only gnarled trees and trees with very coarse branches are harvested manually. In relation to deciduous forests, the picture is very different. Here, only 5-10 % are harvested with machines.

Rather sophisticated tree-felling machines are in use and therefore available for purposes of remediation over Europe, including the Nordic countries. Valmet in Sweden makes one of the comparatively more widely sold felling-machines. This machine was tested in a French forest area in connection with the CEC supported ECP/4 project (Hubert et al., 1996). The machine is designed for felling of coniferous trees with diameters between 30 and 50 cm. It is mobile and mounted with an arm equipped with a cutting head. This head cuts the tree with a circular chain saw. The arm can then move the tree to another place (within a radius of 10 m), where the same cutting head, in combination with two wheels 'feeding' the tree (at a max. speed of 4 m s^{-1}), can be used to remove branches and bark. It is estimated that such a machine can perform the work of about 12 manual felling workers with chainsaws.

Among the felling-machines used in Denmark are the Valmet-701 and the Silvatec-454 (Bøllehuus, 2000). The Valmet-701 is a relatively small machine primarily designed for thinning in forest areas where trees are not too big and coarse (Bøllehuus, 1990). Its width is only 1.8 - 2.0 m, depending on the type of wheels applied. This makes it easy to manoeuvre in thinning areas. It is equipped with a crane-arm with a maximum range of 5.4 m and a momentum of 26 Nm at 3 m arm length. The crane is mounted on a platform that can be tilted 30° forward and 15° backward. The cost of the Valmet-701 is about 200,000 Euro. This corresponds to an average hourly cost of operation of about 75 Euro (Bøllehuus, 1990).

The Silvatec-454, which has been jointly developed by Silvatec Forestry Machines Aps and the Danish Forestry and Nature Agency, is a more powerful and robust machine with a higher stability. It can therefore be used for all types coniferous forests. The maximum length of the crane arm mounted on this machine is 8.3 m. The cost of the Silvatec-454 is about 210,000 Euro. This corresponds to an average hourly cost of operation of about 80 Euro (Bøllehuus, 1990). The principle of functioning applied in the cutting-heads of the two latter machines is similar to that described above for the machine tested in France.

Some felling machine aggregates (manufactured by e.g., Valmet in Sweden and Moipu in Finland) can also be used as log transport shuttles to the trucks for road transport (Theilby and Bøllehuus, 1999). Even small remote-controlled felling-machines exist, which can also place harvested material in a carrier attachment (max. volume 3 m^3) and shuttle transport it to an area outside the forest. Such machines can currently maximally harvest about 5-6 m^3 per hour (Theilby and Bøllehuus, 1999).

An alternative to the specially designed felling machines, which can be applied also in emergency situations, is excavators equipped with felling-aggregates. This is, however, not in very wide use in all the Nordic countries. The total number of excavators with felling-aggregates was in 1994 5 in Norway, 30 in Finland, and 50 in Sweden (Bøllehuus, 1996). In Denmark, use has only occasionally been made of such machinery. An advantage is the reliability and comparatively low cost of the excavators, which are, however, not nearly as mobile for transport as the other felling-machines. The excavators should have a weight of at least 14 tonnes and an engine power of at least 90 kW (Bøllehuus, 1996). The cost of the aggregate is estimated to 80,000 Euro, in addition to which comes the cost of the excavator (approximately 150-200,000 Euro). Excavators can, however, particularly during the winter season, often be hired at relatively low costs. The efficiency of the excavator-harvester is not significantly different from that of the special felling-machine, but the excavator's large crane may be useful in areas with tall trees (Bøllehuus, 1996).

Specific recommendations can be given as to how the felling should strategically be carried out (Junker et al., 1998).

6.1.2 Some views for planning a felling strategy for a contaminated site

When the general condition of the stand allows it, one option is to thin out the forest rather than to carry out a complete felling. The purpose of thinning would be to make it possible to leave the forest unattended for very long periods of time, possibly many decades, depending on the contamination level and radiological half-lives of the contaminant isotopes. When the contamination level in the wood has declined to a level that permits a less restricted use of the wood, the remaining part of a commercial forest could be harvested. An immediate removal of the organic layer, which would at least over the first approximately 20 years be expected to contain a major part of the contamination, would prevent much of the uptake to the wood that would otherwise occur. Particularly in deciduous forests, it would be a possibility to remove the organic layer just after the first leaf-fall.

A practical concern in connection with forest thinnings is that trees should be felled in a 'herringbone' pattern to facilitate further work with the wood. This means that the maximum angle of the tree to the path from which it is to be picked up should be 30 °.

The alternative option would be to clear-cut forest stands, using a chessboard pattern so that the various habitats can repopulate clear-cut areas over a period of time. This should help prevent desertification, as the organic forest layers are removed only in the selected 'chessboard pattern' areas. In general, the impact of the operation on the forest bio-diversity should be minimised.

The felled trees, whole or delimbed, can be left to dry over the summer period. In clear cutting using a chessboard pattern, it will not be possible to achieve complete removal of the organic forest floor layer, therefore this technique would be less efficient in terms of forest decontamination. On the other hand, its implications for the future forestry as a whole would often be less drastic. Removal of duff will make future growing conditions inferior. However, the deterioration will not be fatal or seriously detrimental for the establishment of young plants. Instead, the impact will be on stand increment, which, in the long run, will be reduced compared to a situation where the upper soil layer has been left intact. It is estimated (Junker et al., 1998), that a felling team of two workers with a chainsaw can in one day produce a volume of wood corresponding to 15-30 m^3 of chips by thinning, and 20-30 m^3 of chips by clear cutting.

Modelling of the fate of radiocaesium in coniferous forests, mainly based on experience from the Chernobyl accident (Linkov et al., 1997), indicates that without action the contamination in the trees will rather rapidly (within the first year) decline to a vanishing small fraction of the total contaminant inventory in the forest. However, the level will build up to a maximum of about 5 - 15 % of the total inventory after some 15-20 years, if the forest floor is not treated. After this point, the radiological half-life of caesium will largely govern the wood contamination level. The effect of felling trees in relation to the reduction of the contaminant inventory and radiation field in the forest will thus depend on the time at which the operation is carried out.

6.2 Machinery and costs for loading, chipping and transporting felled vegetation

Techniques for chipping and transport are described here for the possible purpose of using the contaminated forest biomass as fuel in power plants. The radiological safety in the whole of wood energy production is discussed in chapter 6. The special radiological circumstances that occur following a heavy contamination can favour the decision to burn heavily contaminated wood in power plants specially designed to contain the radioactive emissions to an acceptable level.

Both mobile and stationary chippers exist. If not readily available, the estimated investment costs for a chipper would range from about 15,000 EURO up to 10 times that. The need depends on the strategy for the process, and there are several options (Junker et al., 1998).

For thinnings, one recommendation would be to forward crosscut tree sections (possibly after summer drying) outside the forest, where they are chipped and directly transported by container truck to a final destination (e.g., a biomass operated power plant). Another option would be to carry out the chipping in the stand and have a tractor-driven shuttle transport to the road, from where it can be loaded into containers on a truck.

Shuttle-vehicles are getting used more and more in Danish forestry. Such shuttle-tractors are equipped with computer-controlled hydrostatic transmission and electric-hydraulic control of practically all functions. Among the vehicles currently in use in Danish forests are the Silvatec 856F, the Timberjack 810B, the Valmet 820 and the Valmet 840 (Bøllehuus, 1997). Similar vehicles are used in Sweden and Finland.

Mobile delimbing with felling-machines (investment cost approximately 200,000 EURO, as described above) may be used to facilitate stacking of unchipped material for transport. Mobile cranes could be necessary in the processes. The latter may be integrated parts of mobile chipper machinery or felling-machines. Mobile chippers, depending on size, can typically produce some 50-200 m^3 of chips in a day. The procedure is generally expected to be faster by crane-fed operation than by hand-fed. In contrast, it is estimated that a chipping plant can produce 500-1000 m^3 of chips in a day.

Mobile chippers are, for example manufactured in Sweden by L. Lindh Maskin AB, Bottnaryd (Theilby and Bøllehuus, 1999).

6.2.1 Possible use of the felled vegetation for bioenergy

The following strategy may be followed for clear-cutting if the contamination level permits the use of a part of the wood in industry rather than power production.

The felled trees are de-limbed and sectioned and the industrial round wood is transported to the industry, whereas the part that must be applied in energy production is left to dry over the summer, and subsequently chipped in the area and transported in tractor shuttles to the road transport trucks. Alternatively, chipping may take place outside the stand.

An alternative option, to be considered if the wood is so contaminated that no significant part of it can be used in industry, would be to section the felled trees, summer dry them and transport the whole sections to a biomass fuelled power plant, where the chipping could take place.

6.3 Use of grinding machines for understorey vegetation

Although understorey vegetation is generally expected to contain a very little fraction of the total contaminant inventory of a contaminated forest area (Linkov et al., 1997), it must first be removed to enable removal of the organic forest floor layer usually containing a major part of the contaminant inventory. In addition, this type of vegetation often has shallow root systems and thus takes up more contaminants than do for instance the trees. Of particular importance in this context are also contaminated lichens and mosses, which may through consumption give rise to significantly increased meat contamination levels in some forest animals.

A 'grinding mower' for removal of understorey vegetation including smaller shrubs has been tested in the contaminated forests of Belarus (Roed et al., 1995). The grinding mower, which is manufactured by Wiedenmann in Germany, is a 1.2 m wide drum grinder with knives. It is attached to a tractor. The test revealed that the machine was too wide to follow the unevenness of the landscape, and the understorey vegetation removal was consequently not complete. In addition, the machine created much dust. However, a dose reduction factor of 1.2 was reported in the test, and this must be regarded as a high value compared with what can mostly be expected. On the basis of the test, it is estimated that a machine can treat some 1500-2000 m^2 in an hour. The cost of the machine is some 10,000 Euro, in addition to which comes the expense for a tractor, and 30 l of diesel per hour. Norevert in Sweden makes similar machinery. Only some of these machines are equipped with a waste storage container. This type of equipment is to some extent available from contractors.

Another important process that must be carried out before the organic forest floor can be removed is the extraction of stumps. Here the recommended strategy (Junker et al., 1998) would be to first use a special grapple mounted on an excavator to extract the stumps, and then leave the stumps in a pile to dry for a couple of years. Thereafter, if the radioactivity levels are low enough, they could be transported to a power plant, crushed and burnt, or deposited in a waste repository.

6.4 Techniques for litter/organic topsoil removal by scraper/mechanical brush

The organic top layer in the forest floor will, as mentioned above, be expected to contain a very large fraction of the total contaminant inventory in the forest. The FORESTPATH caesium model (Linkov et al., 1997) indicates that within the first year, about 90 % of the caesium contamination in a certain coniferous forest may be held in this layer. After some 10-20 years, a considerable part of this will have reached the underlying, more mineral-rich soil at sites were soil easily penetrates nutrients.

On the basis of investigations made by Risø on the radiocaesium distribution in soil in the contaminated Belarussian forests, it was estimated that some 80 % still lay in a combustible top layer 12 years after the Chernobyl accident. In comparison, investigations by Grebenkov et al. (1996) indicate that more than 90 % of the radionuclides in most forested regions were at that point located in the combustible part of the duff. This agrees reasonably well with the ecological half-lives reported by Rühm et al. (1996) for the transfer of radiocaesium between the different soil layers in a coniferous Bavarian forest. It should be stressed that ecological half-lives are highly site-specific, since radiocaesium dynamics may be influenced by for instance pH, layer thickness, clay mineral content, climatic conditions, and type of forest (deciduous or coniferous) (Rühm et al., 1998).

In relation to this information, it can be mentioned that Belli et al. (1996) measured the vertical Chernobyl-derived caesium distribution in forest soils in a number of places in the affected areas of the CIS. At this point, the percentage of the contaminants in the organic layers (Ol, Of and Oh) ranged from 60 to 80 %, which is in reasonably good agreement with the other measurements reported above. The variability between different investigated forests may be due to physical-chemical differences of the fallout at the time of deposition. In the areas closest to the Chernobyl power plant, the greatest concentrations in organic top layers were recorded. The reason for this was probably that the deposited radionuclides were here to a greater extent associated with large insoluble fuel fragments and condensed particles of rather large dimensions.

With this background, it is clear that the effect of harvesting the top few centimetres (according to the distribution at the particular time) of the organic layer from the forest floor will vary with time, and the process should be carried out as soon as possible following the first leaf-fall. The effect would be expected to be substantial, if a large fraction of the organic layer is removed. This again depends on the chosen strategy (e.g., whether thinning or clear-cutting of the trees is preferred). Removal of the organic top layer of the forest floor would not only reduce the external dose rate in the forest, but also reduce the contamination level in subsequently growing forest fruit (mushrooms, berries, etc.), which may appear in the area after a new humus layer has been developed.

A tractor-powered machine is currently being developed at FSL in Denmark, which can harvest the organic forest floor layer without first requiring a total removal of stumps and other vegetation. The machine is a further development of a Dutch prototype.

In connection with the ECP/4 project, technology for organic forest floor layer removal was tested and described (Roed et al., 1995). This essentially consists of a mechanical rotating brush powered by a hydraulic engine, and requires the use of a tractor. The device was during the test mounted with a 0.4 m^3 storage bin for collection of the harvested organic material. This bin can easily be unloaded to a trailer. The depth of the rotating brush is controlled by means of a set of wheels. This equipment is produced in Belarus, and its cost was in 1995 estimated to 5000 Euro. In addition to this comes the cost of the tractor, to which it is attached, and about 30 l of diesel per hour. It is operated at a speed of 540 m^2 h^{-1}.

The removal of the organic top layer could also be achieved with a caterpillar skidder, which would have an investment cost of close to 100,000 Euro. The removed material could then be loaded onto tractor-powered shuttles for transport to the roadside. Here, trucks can transport the organic material either to a waste repository or to a bioenergy power plant, depending on the availability of power plants designed to contain the emissions of radioactive contaminants to acceptable levels. The advantage, provided the mineral fraction is very small, would be that it could be applied in energy generation. At the same time, the combustion process would greatly reduce the very large volume of waste before final storage.

Scraping should not be carried out in areas that are prone to erosion.

6.5 Turf harvesting and other techniques for urban parks

The use of turf harvesters in removal of contaminated topsoil has been suggested in connection with the ECP/4 project (Hubert et al., 1996). The turf harvester skims off a thin (approximately 5 cm) contaminated top layer from an area of soil/grass. Turf harvesters are available in grass nurseries, but there may not be sufficient numbers of harvesters readily available in Nordic countries. Their application is restricted to specific areas. To achieve removal of the surface layer in slabs or rolls, a requirement is that the area has a mature grass mat cover. In forested areas, the turf harvester would be considered impossible to use, since its design is not robust enough to handle the matured root systems that would inevitably be present in any forest, even after extraction of stumps.

The turf harvester could however be useful in areas of mature meadow. Here the restrictions on its use are connected with several problems. The area must be smooth to give a homogeneous removal of the topsoil layer. Further, and very importantly, there must not be any rocks in the area, as these could destroy the turf harvester. If the layer to be skimmed off is adjusted carefully in relation to the vertical distribution of the contamination, the effect could be a dose reduction by a factor of up to 20. The turf harvester is operated by 2-3 workers at a speed of approximately 0.14 man-days ha^{-1} (Roed et al., 1995). The investment cost would be some 8000 Euro for the turf harvester. In addition to this comes the cost of a tractor to drive it, and some 15 l ha^{-1} of petrol. It is estimated that the method generates approximately 20-30 kg m^{-2} of solid waste, which must be transported away at a cost of approximately 1500 EURO per ha (assuming that the final repository is less than 20 km away).

In park areas, more robust technology would normally be called for, e.g., caterpillar skidders that are briefly described above in section 5.4. In connection with the application of any scraping or skimming procedures in areas that do not have very mature grass coverage, it would often be advantageous to combine the procedure with the application of, for example, polymer gels or lignin to give the top layer sufficient strength to facilitate removal in rolls or slabs (Andersson & Roed, 1994). Particularly lignin, which is sold under commercial names such as Lignosol BD, would be attractive to apply, as it is a natural waste product of wood processing in the paper industry. The thickness of the gel would govern its downward penetration into the soil and thus the thickness of the layer that would be intact after stripping or skimming. It must however be stressed that under wet conditions it may not be possible for the water-based film to dry sufficiently to permit stripping of a continuous intact layer. These agents, which could be applied with a water spray truck, would also be beneficial in retaining the contamination, as they would embed the contaminated soil and thus protect against loss of contaminated soil particles through crumbling. The method would make it possible to remove soil layers of only a few millimetres in thickness. The cost of application of these coatings is estimated to be some 5-10,000 Euro per ha, including costs of the coating, mechanical removal, labour and transport to a waste repository within 20 km distance (Andersson & Roed, 1994).

6.6 Decontmination by removal of snow

In the 1980's, a project of the NKA (Nordic Liaison Committee for Atomic Energy) tested decontamination of roads and covered land surfaces by removal of snow. When the experiment was carried out with equipment convenient for complete removal of snow layer on either ice or asphalt, nearly 100 percent of the contamination was removed (Tveten 1990).

Applicability of snow removal to forests would work only in special conditions, which allow collection of snow without damaging vegetation. However, decontamination is possible if dry deposition is on snow cover, or contaminants have been deposited with snow. Convenient ice, snow and weather conditions are a condition of a successful application of the method. As long as the deposited radioactive material is on the snow or inside a stable snow layer before the first partial melting of the snow or rain after the deposition, rather efficient removal of contamination is possible.

In Northern Europe snow cover is found 4 to 6 months a year. The method is worth considering in open forests, where frequent visits of the public would justify decontamination. Decontamination with snow is much less destructive to the environment than corresponding mechanical methods in summer conditions. The collected snow should be taken to a discharge site that the local sewage experts would recommend, if not to sewage plant.

6.7 Ploughing of parks and of forest sub-soil

Deep ploughing is a recommended option for contaminated clear-cut forest areas, where it is possible to introduce large machines (Junker et al., 1998). The method is mainly carried out in current Danish forestry in connection with new plantations. A requirement will often be a prior removal of stumps as well as all vertical vegetation. Ploughs have been developed, which can be applied without first removing stumps, but these are not in wide use (Bøllehuus, 2000). An alternative is the application of special machines that can crush roots down to a depth of about 20 cm in the soil.

By deep ploughing, the radioactive contamination is, in favourable conditions, buried deep in the soil profile, and placed below the root-uptake zone of much subsequently growing understorey vegetation (e.g., mushrooms and berry bushes). Here ordinary ploughing may not be sufficient. Deep ploughing can also be applied in large open areas such as parks. However, by deep ploughing, not only the contamination, but also the complete growth layer of the soil area is buried deep in the vertical profile. The result may thus be a significant decrease in soil fertility.

In this context, skim-and-burial ploughing (Roed et al., 1996) may be an attractive alternative. This type of ploughing skims off a shallow layer of the contaminated topsoil and buries it at a depth of about 45 cm without inverting the 5-45 cm horizon. The result is that the radiation level at the soil surface is greatly reduced, the contamination becomes much less available for plant uptake, and in most cases there is little or no effect on soil fertility. Large ploughs are used for deep ploughing, which are normally available in large numbers. Special skim-and-burial ploughs are produced, but only in very small numbers. If the need arose, a large production could be established.

6.8 Costs for decontaminating operations in forest and waste transport

Waste problems in cleanup operations in contaminated forests were studied in a Nordic co-operative project NKS/KAN-2 in the early 1990's (Lehto 1994). The forests studied were assumed typical of Finland, Norway and Sweden. They represented coniferous (spruce and pine) and deciduous (birch) forests. A hypothetic accidental release caused areal contamination with long-lived radionuclides ^{90}Sr, ^{137}Cs and ^{239}Pu. There were several options for cleanup, based primarily on felling of trees, removal of understory vegetation and surface layer of litter and soil.

Examples of quantities of waste composed of forest vegetation and soil were given for areas with varying size, belonging to different contamination categories. Costs for the working time in forests, and for transport from the forest to a waste disposal site were estimated. Transport costs were given for two options: local disposal with short-distance transport, and disposal outside the affected area demanding long-distance transport.

The amounts of biological waste from clear-felling and removal of understory vegetation per hectare varied by forest type from less than 20 to about 70 tons. Barked trunks were not assumed to be waste. Total costs of the operations in the forest (vegetation and surface soil removal), crosscutting of trees, and transport of all waste to a waste disposal site ranged from 4500 to 6300 EURO per hectare forest (costs in the early 1990's).

The data on quantities of forest biomass and different types of costs compiled in the KAN-2 project were applied for a forest area in Belarus, contaminated with ^{137}Cs (185 kBq m^{-2}) by the Chernobyl accident in 1986. The risk assessment study revealed the high costs of this type of cleanup (Linkov et al., 1997). The cost for averted doses and reduced cancer incidence was far too high, confirming the lack of practicability of the decontamination method for the case studied. It is important to realise that no monetary costs were estimated for environmental and social impact, for losses of yield of timber, or for regeneration of forest with additional costs due to removal of a considerable fraction of nutrient containing surface soil.

7. Bioenergy production

Currently, a comparatively large fraction of the energy supply in the more intensively forested Nordic countries, such as Sweden and Finland, is provided by combustion of biofuel in power plants. In Sweden, for example, this covered about 90 TWh in 1996, corresponding to some 20 % of the energy supply (Hubbard & Möre, 1998; Hedvall & Erlandsson, 1997). In Finland, wood combustion accounts for approximately 19 % of the energy consumption (15 % large scale and 4 % small-scale wood firing). Further, in Finland, the firing with peat alone annually produced 5 % of the energy consumed in 1999 (Statistics Finland 2001). Therefore, a number of power plants that can be fired with biomass currently exist in these countries. Although the annual wood production in Denmark is according to Eurostat (1999) only about 4 % of that in Finland (it is approximately 20 % in Norway), power plants have also been created in Denmark to produce energy from biomass, following a government decision in 1986. These power plants are normally co-fired with waste, straw, and gas. The total annual Danish energy production from biomass constitutes some 4 TWh (Statistisk Årbog, 2000).

The technology required to produce energy from biomass has thus been proven in the Nordic countries, but the mere fact that power can be produced in a way that is under normal conditions safe does not necessarily imply that a safe power production can be sustained based on combustion of biomass contaminated by a major nuclear accident.

7.1 Radiological consequences from the use of forest biofuels

It is a well-known phenomenon that combustion can lead to waste products enriched in radionuclides. In those forested areas of the Nordic countries that received the most fallout from Chernobyl, significant amounts of ^{137}Cs remain in different parts of the forest ecosystem. Root uptake of ^{137}Cs has distributed the contamination to different parts of the tree. The highest concentration in the prevalent pine trees is in the needles, with decreasing concentrations respectively in the branches, bark and wood. The use of the needles, branches, and bark for biofuels is an increasingly common practice, with the wood left for lumber. Thus, the parts of the trees most concentrated in ^{137}Cs are often used for biofuel. The concentration of ^{137}Cs in the trees in the Chernobyl-affected forests has been measured to be still increasing 15 years after the accident, and various model calculations also predict a 10 – 20 year time period when the ^{137}Cs continues to increase in the trees due to root uptake (Moberg et al., 1999).

Estimates of the radiation doses from different types of releases from biofuel plants are presented in Hubbard and Möre, 1998. The estimates use currently available data concerning the transfer of ^{137}Cs from the soil to the forest flora and fauna. The most significant exposure pathways considered, including both external and internal doses, occur during: 1) depositing of the ashes, 2) recycling of the ashes to the forests for nutritional purposes, 3) releases of condense-water, and 4) exhaust from the smokestack (flue gas). The calculations use an activity concentration of 5 kBq/kg ^{137}Cs in the ashes, which is the recommended limit for the ^{137}Cs concentration in ashes for recycling in Sweden.

The largest estimated dose occurs during occupation with ash deposition, and is on the order of 0.1 - 0.5 mSv/yr. Next comes the dose to a critical group composed of hunters and gatherers in a forest that has been fertilised with recycled ashes, with 0.02 mSv/yr (Table 3). People with the diet and free-time behaviour of the average Swedish population in the same forest conditions receives 0.003 mSv/yr. Releases from smokestacks when normal cleaning practices are used and releases of condense-water give insignificant doses. The table shows the dose estimates at different activity concentrations of ^{137}Cs in the ashes. The SSI-report also summarises the uncertainties and unknowns in the estimations of the doses.

It is estimated that approximately 6-7 percent of the forested area in Sweden can produce ashes with levels over 5 kBq/kg. With today's production, that area would give 3000-7000 tons ashes/yr. This can increase in the future with increased use of biofuels.

Table 3. Radiation dose to a critical group with different ^{137}Cs concentrations in the biofuel and resulting ashes

		Dose [mSv/yr]				
Biofuel ^{137}Cs concentration [Bq/kg]	Ash ^{137}Cs concentration [Bq/kg]	Ash Fertilis-ing	Condense-water	Flue gas	Deposited ashes	Estimated forest area that can produce biofuels of given concentration
10	500	0,002	10^{-10}-10^{-4}	10^{-6}-10^{-4}	0,01-0,05	> 50 %
100	5000	0,02	10^{-9}-0,001	10^{-5}-0,001	0,1-0,5	6- 7 %
1000	50000	0,2	10^{-8}-0,01	10^{-4}-0,01	1- 5	<< 1 %

7.2 Occurrence of ^{137}Cs in forest biofuels: A Swedish Example

The Swedish Radiation Protection Authority (SSI) investigated the radiological consequences following energy production using biofuels from forests with the goal of formulating a policy concerning radiation protection. The investigation concentrated on the consequences from the enrichment of ^{137}Cs in the waste products and the subsequent handling of the waste products. The initial task was to fill the gaps in the existing knowledge. That need was countered by a more immediate need for a policy concerning the radiological consequences from a growing energy production based on forest biofuels in Sweden.

The use of biofuels for energy and warm water production has increased significantly in the past decade. Approximately twenty percent of the gross energy production in Sweden in 1996 came from biofuel-powered plants; the majority (85%) of that amount came from forest biofuels. Two related factors have influenced the increase in the use of biofuels for energy production. One is the countrywide decision by vote in 1980 to eliminate nuclear power in Sweden. The other is that forest biofuels are renewable in Sweden, with 27 x 10^6 hectares of forest. That is enough land surface to successfully manage farming of the forests. Thus, forest biofuels in Sweden are both renewable and their use comprises a natural recycling of the forest biomass, as it is taken from the forest, incinerated at the plant, and recycled back to the forest through the spreading of ashes for nutrition. This is an appealing energy source to a country that is working towards sustainable growth in a durable environment.

7.3 A Policy for forest biofuels from the Swedish Radiation Protection Authority

In February 1999, SSI formulated a policy of recommendations applicable during the production of energy and the disposal of the resulting waste products from the burning of forest biofuels. The policy is based on the knowledge and material that SSI had recourse to at that time. The knowledge base regarding radiological consequences is not complete; a better understanding of the consequences awaits further research. For example, scientific studies on whether the uptake of ^{137}Cs in forest fauna is enhanced or reduced after fertilising with biofuel ashes is needed for a complete understanding of the consequences. The policy can be revised if it becomes justified as the knowledge base increases.

The policy states:

1. Ash fertilising is not recommended on lichens and mosses within grazing lands for reindeer.
2. Ash recycling to the forested lands that are not defined in point one is recommended to proceed according to The Swedish National Board of Forestry's recommendations for compensation fertilising, if the ashes contain less than 5 kBq/kg. Ash recycling should not result in an additional contribution of ^{137}Cs to the ground that is greater than 1.5 kBq/m^2.
3. Ashes that contain 5 kBq/kg ^{137}Cs or more must be stored in a deposit that is specially designed for the purpose. SSI has specified the demands for the deposit (see section 8.6).
4. Management of the ashes and labour with the deposited ashes is a planned practice with ionising radiation, and is regulated according to the Swedish Radiation Protection Act (SFS 1988:220).

5. SSI recommends that the dose rate resulting from the use of ashes with concentration less than 5 kBq/kg ^{137}Cs in road or filling material does not exceed 0.0005 mSv/h, measured 1 m over the prepared surface.
6. Aspects relevant to radiation protection must be considered in an environmental impact assessment, completed as part of an application to build a biofuel plant.

7.4 Background for the policy

The policy was formulated after consideration of the principles fundamental to radiation protection and a standpoint on consciously contaminating the environment with radioactivity by the practice of fertilising with the ashes. Ethical questions in connection to recycling contaminated ashes back to the environment as fertiliser were also discussed. SSI attempted to illuminate the consequences that could result from the policy formulation. A public hearing was arranged in early February 1999, where representatives from local and central authorities, businesses including forest industries, universities and the public were invited. Finally, the following points are examples of what was considered in SSI's formulation of the policy.

- The same limits of additional radiation dose to the public shall be used for different ways of producing energy.
- Labourers that handle the ashes shall be protected against exposure to ionising radiation.
- An additional dose of less than 0.01 mSv is considered acceptable. This is the dose limit used, for example, in determining the acceptability for the final management of spent nuclear fuel and nuclear waste.
- It is well documented that reindeer lichens and mosses are extremely sensitive to the uptake of ^{137}Cs that comes from fallout. Relatively little is documented, however, about the uptake of ^{137}Cs that is spread by fertilising with ash. Using the transfer factors established from ^{137}Cs from fallout, even the lowest measured levels of ^{137}Cs in ashes (i.e., that which came from the nuclear weapons tests), can give an additional dose of 0.01 mSv or more to the population of Laplanders whose diet contains significant amounts of reindeer meat. Thus, special restrictions are recommended for the grazing lands of reindeer.

An additional comparison is useful. The nuclear weapons tests left a rather uniformly spread ^{137}Cs-coverage on the ground of roughly 2.0 kBq/m^2. As a comparison, the limit of 5 kBq/kg of ^{137}Cs in the ashes spread on the forest floor at a maximum of 3 ton per hectare[1] results in a ^{137}Cs coverage of 1.5 kBq/m^2.

The combustion of forest biofuels is an efficient means of collecting a part of the ^{137}Cs deposited in Sweden from the Chernobyl accident and the nuclear weapons tests. Ash recycling through fertilisation is a recommended practice for a sustainable energy production. The constraints employed by SSI’s policy, which are motivated from radiation protection, have the side effect that approximately 6 – 7% of the produced ashes are not recycled.[2] This loss of nutrients is compensated by the fact that

[1] Recommended maximum spreading rate for ashes by the Swedish National Board of Forestry

[2] The total amount of ashes produced with levels over 5 kBq/kg can be less than estimated due to dilution of the ^{137}Cs when the biofuels from different forests are blended.

some of the ^{137}Cs deposited by fallout will be removed from the environment until it has decayed and stabilised.

7.5 Working environment

7.5.1 Doses to power plant workers

Although greatly reducing a potentially severe environmental problem, the firing in a power plant with biomass from forest areas contaminated after a major nuclear accident may lead to increased doses to some critical worker groups. In terms of extra external dose contributions, it is clear that dose-rates from spending time near biofuel storages will be low compared with the dose-rates received from spending time near ash containers. The reason for this is that compared with the biofuel, the specific activity is increased by a factor of some 10-100 in the ash generated by the combustion process, and the significant radiation self-attenuation in contaminated wood and ash makes the specific activity the crucial factor in this context. The contaminant concentration factor by combustion has in Sweden been reported to typically be approximately 40 (Gutiérrez et al., 1999), depending on the biomass and boiler type. For a generally conservative estimate of the health impact a concentration factor of 100 can be assumed. According to Hedvall (1998), great differences are not expected between the specific activities of fly ash and slag.

To investigate the magnitude of these dose contributions a series of modelling calculations has been made, based on the work of Andersson et al. (1999). Here the Monte Carlo method was applied to calculate the total dose impact from staying near various ash containers at a power plant. The MCNP model (Briesmeister, 1993) was used for this purpose, and all dose contributions (incl. secondary radiation) due to the photon emission from the contaminated ash were included. The geometry and material data applied in the calculations were based on the actual conditions at a biomass-fired power plant at Måbjerg in Denmark (I/S Vestkraft and Elsamprojekt A/S, 1994).

After consultation with power engineering experts, it was recognised that the dose rate might be particularly high in six different types of locations at the power plant. These locations were near the following elements:

1. The boiler. The sides of the boiler were on average assumed to be covered by a 5-10 mm thick ash slag layer, and in the bottom, a thicker layer of approximately 25 mm of slag was on average assumed to be present. The height of the boiler is 17.15 m, and the side lengths of the boiler are respectively 14.25 m and 6.70 m. The boiler side material is aluminium (approximately2 mm) and Rockwool (approximately 200 mm).
2. The ash-conveyors. These are various types of conveyors for transport of ash from the boiler to a bottom ash container. Only the type that would give the highest dose rate (a belt-type slag conveyor) is considered. This has a length of 8 m, a height of 90 cm and a width of 55 cm. It is made of 5 mm thick steel and it is assumed that its three sides are all covered by a 5 cm layer of slag.
3. The slag containers. This is where bottom ash from the boiler is transported. At the Måbjerg plant, there are two such rectangular containers, which are both 1.6 m high and cover a ground area of 5.8 m^2. These containers have 5 mm thick steel walls. The containers are assumed to be about half-filled on average.

4. The bag filter. The bag house containing the filter consists of 4 chambers, each having side-lengths of 3.5 m and a height of 6 m. Inside each chamber, there are 240 filter bags of a length of 6 m and a diameter of 12.7 cm. The filter bags are on average assumed to be covered by a 0.75 cm layer of fly ash. The walls of the bag house are made of 5 mm steel.
5. The fly ash silo. The fly ash emptied from the bag filter is led to this silo. The silo has 5 mm thick steel walls, and half of the silo is on average assumed to be filled with fly ash.
6. The so-called 'Big Bags'. These are large plastic bags, into which the fly ash is discharged from the fly-ash silo for transport to a final, well-shielded repository near the plant. Usually two of these bags are being filled at the same time. The bags each contain 1.7 m^3 of fly ash.

Estimated dose rates received from standing at a distance of respectively 0.5 m and 5 m from these various ash containers are given in Table 4. In the calculations of dose from staying near the bag filter, it is assumed in the calculations that the target person is standing inside the bag house, directly under the filter. As the bag house is closed during operation, it would only be possible to receive doses of this magnitude from the filter during repairs. Based on measurements in the contaminated areas of the former Soviet Union, fly ash from combustion of wood from an area with a ground contamination level of 1 MBq m^{-2} of ^{137}Cs is estimated to have a ^{137}Cs content of 20 Bq cm^{-3}. Due to the higher density of slag, its corresponding ^{137}Cs content is assumed to be 40 Bq cm^{-3}.

Table 4. Dose rates (µSv h^{-1}) potentially received by individuals standing at different distances from various places in a power plant fired with wood from an area with a ground contamination level of 1 MBq m^{-2} of ^{137}Cs.

Distance (m)	Boiler	Slag conveyor	Slag container	Bag filter	Fly ash silo	'Big Bags'
0.5	0.13	0.13	1.17	0.07*	1.38	1.13
5	0.06	0.002	0.08		0.29	0.03

*Standing immediately under the filter bags in the bag house (see text above).

As can be seen, with the possible exception of the fly ash silo, which is very large and contains much contamination, workers would under the given circumstances have to stand rather near (< 5 m) the above sources to receive dose rates exceeding 0.1 µSv h^{-1}. The probability that the workers would stay very close to any of the sources over long periods of time must be considered to be very low, as workers should be informed of the potential health impact of staying in these locations. The maximum doses received at a distance of 0.5 m from slag containers, fly ash silos and 'Big Bags' are of the order of 1 µSv h^{-1} per MBq m^{-2} of ^{137}Cs ground contamination. According to Jacob & Paretzke (1986), the dose rate from an open soil area contaminated by 1 MBq m^{-2} of ^{137}Cs is in the early phase after a contamination of the order of 2 µSv h^{-1}. The power plant buildings will provide significant shielding against dose contributions from the ground contamination (Jacob & Meckbach, 1987). Therefore, the total dose rate received at a distance of 0.5 m from the highest contaminant concentrations in the power plant would be comparable to that which is received outside the power plant, provided that the power plant is situated in an area with the same level of ground contamination as that from which the wood fuel is taken. However, the possibility exists that doses to power plant workers will be somewhat higher, if the plant is co-fired with duff, which is more strongly contaminated than wood.

A simple calculation (Andersson et al., 1999) shows that inhalation doses received during routine operation of the plant are negligible.

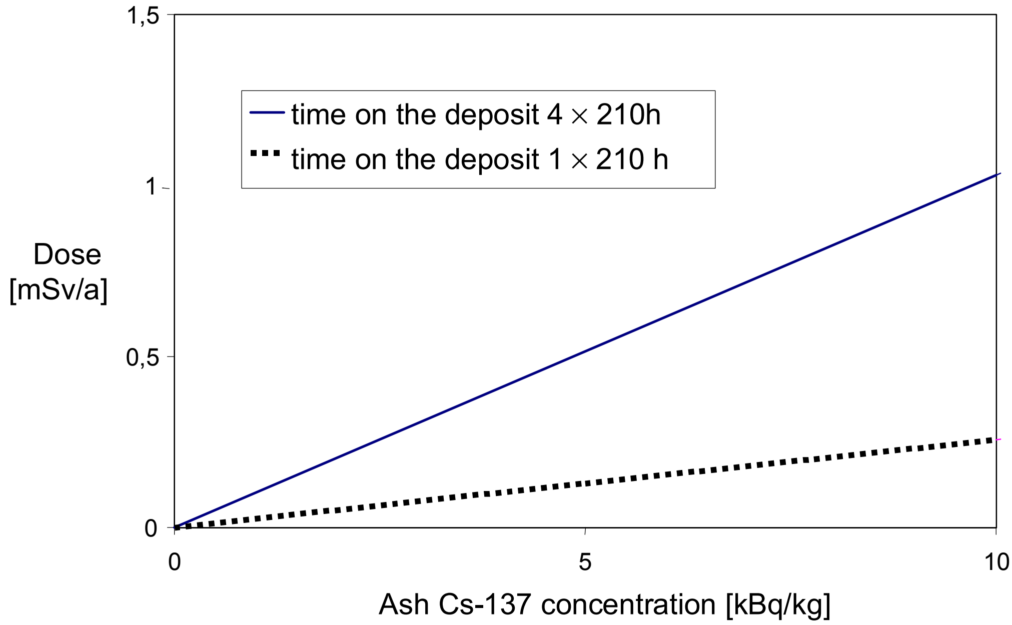
7.5.2 Estimated dose to workers at an ash deposit

The additional dose received when working at an ash deposit depends on several factors, such as the length of time and placement of the worker at the deposit, the concentration of ^{137}Cs and naturally occurring radionuclides in the ash, and the density and the humidity in the deposit. The doses estimated here correspond to the additional dose that originates from ^{137}Cs in the ash. The placement of the worker is assumed to be on the top of the deposit.

When calculating the dose, the deposit is assumed to have an infinite extension. This will result in an overestimation of the dose of approximately 9 percent compared to a deposit with circular geometry and a diameter of 10 meters (Finck 92). At a constant concentration of caesium in the ashes, the dose rate decreases with increasing humidity in the deposit (Ravila 92). The naturally occurring radionuclides in the ash will contribute to the dose rate. If ash with the concentration of 5 kBq/kg is laid on an ash deposit with a thickness greater than 1 meter, the calculated additional effective dose rate at 1 meters height over the ground will be 0.6 µSv/h. In figure 1 the annual dose is given when working on a deposit as a function of the concentration of caesium in the ash at two different working times per year, one at 4 hours times 210 working days the other at 1 hour times 210 working days.

The dose has been calculated for unprotected work at 1 meter above the surface of the deposit. It's common practice to work in a machine, which will reduce the dose.

Figure 1. Additional dose to workers at an ash deposit as a function of the concentration of Cs-137 in the ashes, at two different working times



Vehicles can give an attenuation factor of between 0.3 and 0.7 (Lauridsen 83). The calculations reported here only aim at estimating the approximate order of magnitude of the dose. To achieve values that are more precise, measurements should be performed at the place in question.

7.6 Ash deposit specifications: summary of Swedish legal demands on the construction of an ash deposit that contains ^{137}Cs from biofuels

The Swedish Radiation Protection Authority has issued the following requirements to minimize the environmental impact of depositing ashes from the burning of bio-fuels containing high concentrations of ^{137}Cs.

Ashes with a ^{137}Cs concentration of 5 kBq/kg or more shall be deposited in a specially designed ash deposit. The deposit shall fulfil the demands of the class: "landfill for non-hazardous waste" (EU Council directive 1999/31/EC and Swedish legislation Förordning 2001:512). Additionally the following demands shall be met:

1. the bottom part of the deposit shall consist of soil containing clay minerals, and this soil shall be regularly mixed with the deposited ashes,
2. deposition shall be done in separate cells that are successively covered to keep infiltration to a minimum,
3. leachates shall be collected during the active phase of deposition and they shall be purified as far as reasonably possible.

In addition to the demands mentioned above the following points should be considered:

1. The release of leachates should be kept as low as reasonably possible. Caesium is easily soluble in water when the ashes are newly produced. Under the influence of air and water, the ashes age and the solubility decreases.
2. When the active measures taken to control the deposit have ceased and no collection of the leachates is performed, special attention should be given to create a tight top cover with long-time integrity on the deposit.
3. Soil with clay minerals should be part of the geological barrier under and around the deposit where the ^{137}Cs in the leachates can be absorbed.

Further background information can be obtained from SSI in the publication SSI Dnr 822/172/00.

7.7 Power plant construction to minimise atmospheric emissions

After a major nuclear accident, it may be desirable to reduce the potentially severe environmental problems in the forest by firing power plants with the contaminated forest biomass. In general, a main concern in energy production from biofuels is to keep atmospheric contaminant releases from the power plant stack to a level that is acceptable. This concern is more acute when using contaminated forest biomass as fuel.

The magnitude of atmospheric contaminant releases depends on the temperatures in the boiler system, the applied filter technique, and, of course, the contamination level in the biomass used as fuel. Generally, the caesium contamination is expected to be mainly associated with the fine aerosol fraction. However, the comparatively great surface-to-mass relationship and more rapid cooling rate of the small particles in the fly ash increases the probability of association with condensed vapours (Ravila & Holm, 1994). In addition, the electrical charge of ash particles influences the association with other charged particles or volatilised elements.

A variety of power plant designs have been applied in the different Nordic countries. Mustonen et al. (1989) described a number of relatively large power plants, each with a capacity in the range of 120-240 MW. Some of these plants were fuelled with peat from areas that had received a contamination of some 100 kBq m^{-2} of ^{137}Cs after the Chernobyl accident. Of the six power plants examined, one had no fly ash precipitation filter, and another was equipped with a multicyclone, which would be expected to efficiently remove larger particles, but not the smaller, to which much of the caesium would be attached. Four plants were equipped with electrostatic filters for fly ash precipitation, with collection efficiencies (mass) in the range between 71 % and 99.7 %. However, the fractions of the total caesium released from these plants would be expected to be greater, as much of the caesium would be in the form of small particles, for which these filters would be least efficient. In comparison, Hedvall et al. (1996) found that in Swedish biomass-fuelled power plants between 1.4 % and 10 % of the caesium in the applied fuel was emitted to the atmosphere from the stack in the form of flue gas.

A means for increasing the capture efficiency for the smaller, caesium-containing particles may be the introduction of baghouse filters. These types of filters have in practice shown to be very efficient in reducing fine particle emissions from Danish power plants. A baghouse filter design for reduction of caesium emissions from a power plant fired with radiocaesium-contaminated biofuel has been proposed by Junker et al. (1998). This filter consists of two parallel sections, each comprising a series of four modules. Each of these modules contains 250 filter bags (each being 6 m long and having a surface area of about 2 m^2) and a hopper for collection of fly ash removed from the filters. The recommended filter material is GORE-TEX membrane needle felt. According to the manufacturer, this material has a filter efficiency of 99 % for particles smaller than 0.1 µm, and the filter efficiency for the total fly ash mass is estimated to be better than 99.9 %.

The filters work according to the so-called surface filtration principal, that is: fly ash only deposits on the outer surfaces of the filter bags. Cleaning of the filter system is accomplished through compressed air pulses through the bags, removing the ash attached to the outer surface of the bags. This filter cleaning system is automatically activated when the pressure across the filter reaches some 1800 Pa. When the pressure again reaches a lower threshold the cleaning automatically stops. The automatic filter cleaning greatly reduces the need for stop of operation. The filter described is about 18 m high, and covers a ground area of some 90 m^2. It is designed for a flue gas rate of about 200,000 $Nm^3\ h^{-1}$, with a maximum dust load at the filter of 26 g Nm^{-1} and a maximum flue gas temperature of 200 °C.

A filter of a similar design has been tested in practice in Rechitza, Belarus (Roed et al., 2000). The purpose of this test was to investigate whether a safe energy production could be established in Belarus based on biomass, which is locally available in vast amounts. Belarus currently has a great need for national energy resources, as the country imports about 90 % of its energy supply. A problem that makes this case study particularly interesting in relation to Nordic nuclear emergency preparedness is of course that the Chernobyl accident contaminated very large Belarussian forest areas. Approximately 4.6 10^5 ha of forest is contaminated by ^{137}Cs levels exceeding 200 kBq m^{-2}, and in 4 10^4 ha, the ^{137}Cs contamination level exceeds 1.5 MBq m^{-2}. If this contaminated biomass could be safely applied in energy production, also an environmental problem could be solved, as the forests would be partially cleaned, and the mass of the waste generated would be reduced by a factor of 10-100 by the combustion. The ashes would have to be disposed of appropriately, depending on the concentration of ^{137}Cs in the ashes.

The boiler applied in the test was constructed by a Finnish company, TAMPELLA, more than 50 years ago. It is designed for a wood fuel consumption of 11 $m^3\ h^{-1}$, producing 9 tonnes h^{-1} of steam at a temperature of 230 °C and a pressure of 10 bar. It is normally fired with wood residues from a sawmill operated at the site. The boiler was, prior to the test, not equipped with any flue gas treatment system. For the test, a cyclone filter was constructed which the flue gas from the boiler would pass through before entering the bag filter. This was to reduce the total mass of the flue gas dust, and at the same time prevent sparks from reaching the bag filter. From the bag filter the flue gas was led to the 70 m high stack, from which it was released to the atmosphere.

Aerosol laser spectrometry measurements showed, as was expected, that the cyclone had rather little effect on the smaller particles. The cyclone was found to have removed less than half of the caesium in the flue gas. The bag filter had a much better result. The particle mass size distribution before the bag filter was found to be

Gaussian-like shaped with a GMD of about 0.25 µm (see Fig. 2). The shape of this distribution had changed a bit after the bag filter. The mass maximum was still found in the stage corresponding to a size of about 0.2 µm, but the distribution showed a slight tendency towards bimodality (see Fig. 3, below), as this filter was most efficient in retaining submicron particles.

Impactor measurements revealed that only some 0.5 % of the caesium in the original flue gas was left after the bag filter.

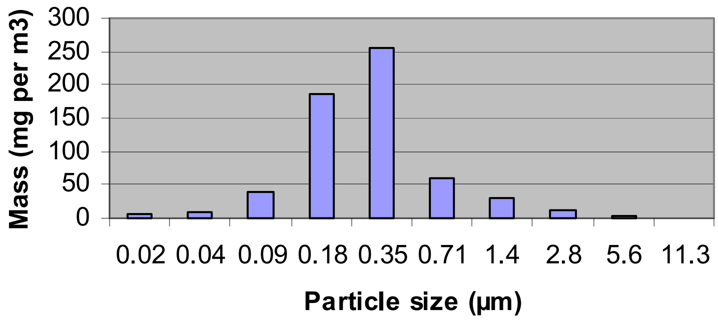


Figure 2. Particle mass concentration versus particle size in exhaust air before the bag filter at the Rechitza plant.

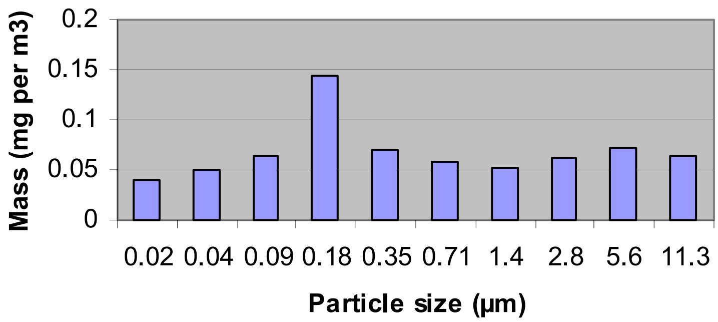


Figure 3. Particle mass concentration versus particle size in exhaust air after the bag filter at the Rechitza plant.

8. Radiological risks of forest fires and doses to forest workers

In the Ukraine and Belarus the annual number of forest fires is around 50, the average fire resulting in the destruction of some 10 ha of forest (Sukhoruchkin & Marchenko, 1996; Junker et al., 1998). For comparison, the total forest area of Belarus is some 8 million ha, (in Sweden it is about 22 million ha). The general state of preservation of Nordic forests is normally better than that in Belarus and the Ukraine. Thinning is carried out more regularly, and fire belts are to a greater extent kept clear. Therefore, the probability of a fire in a particular Nordic forest area must be considered low, although large Nordic areas lie within the boreal and semi-boreal zone, where much of the terrain is covered by a fairly flammable vegetation of coniferous trees, shrubs and mosses. According to Granström (1998) the overall forest fire risk in Sweden is comparable to that in the Ukraine and Belarus. In addition, in Sweden very few forest fires affect areas larger than 10 ha (Granström, 1998).

The radiological significance of a forest fire has been evaluated for a number of fire scenarios (Kashparov et al., 2000). It was found that a considerable fraction of the particles arising from forest fires is generally of the sub-micron size range. Both during the active burning, smouldering and post-fire (24 h) phases of the fire the size-fraction smaller than 2.8 µm, mainly constituted by resin and water, generally contained the greatest part of the radiocaesium. This is in line with the observations of Garger et al. (1998). Based on the experimental data and the ICRP respiratory tract model (ICRP, 1994), assuming solubility class F, Kashparov et al. (2000) estimated the radiological risk associated with a 10 ha forest fire. They found that the inhalation dose rate to individuals staying in the highest risk zone constituted less than 1 % of what the dose rate from external radiation in the corresponding area is. The radiological risk that fire fighters are exposed to is therefore not significantly greater than that resulting from staying in the contaminated forest area without a fire. In addition, the impact of contaminant resuspension during forest fires on terrestrial contamination was found to be small.

Modelling based on the US Department of Energy model RESRAD BUILD shows that the extra external doses to forest workers handling contaminated wood (and thereby getting close to the contaminated wood) are generally not much greater than external doses received by simply staying in the forest (Junker et al., 1998). Inhalation doses to forest workers from dust generating operations, such as sawing, were found to be negligible compared with external doses (Junker et al., 1998).

9. Conclusions

The methods discussed in this report are available to the forestry sector and radiation protection experts in their planning of specific strategies that can lead to an optimal use of contaminated forests. Decisions will depend on the site and the actual situation after radioactive deposition to forested areas, but preparing background information from investigations performed before an accident occurs is essential.

Normal and modified forest management practices are approaches that can be used in planning a strategy for contaminated forests. These practices must be tailored locally to consider the site qualifications and contamination situation of the forest biomass and soil. Appropriate uses of contaminated wood and advice on restrictions on consumption of contaminated forest foods are the simplest forms of reducing human radiation exposure in a wide variety of situations. In order to be realistic, management methods need further testing through long-term experiments for improved identification of the ranges of effectiveness and optimal application and timing.

Mechanical removal of some fractions of the contaminated biomass or soil can be considered for a limited land area after a heavy fallout. This approach can lead to the removal of a large fraction of the contamination, although protection of the workers must be considered and the waste must be deposited properly. Change of land use may be necessary after a radical mechanical removal of forest soil. Practices that are possible in a limited land area may not be realistic in large forests.

A realistic view on the relevance of soil removal in remediation of forests should be shared by a multidisciplinary panel before including it in any emergency preparedness plan for forests. The background on drastic soil-removal operations in decontamination is found in the methodology for restoration of sites used earlier for contaminating activities, both nuclear and non-nuclear. It has not been developed for remediation of large productive land areas contaminated through atmospheric dispersion of accidental releases of radioactivity. Both direct and secondary costs of soil removal as a countermeasure refer to a very limited use of the practice in forests of Northern Europe.

Operations in forests differ from those applied in urban parks. Park areas are not maintained for production of timber; they are mostly grown for landscape and recreation, and sometimes for picking berries and mushrooms. Protected forests, such as national parks and nature conservation areas, demand very delicate management methods due to their role as areas of minor human influence. The content and scale of operations is different in timber producing forests versus urban forests where local citizens visit.

The more drastic the forest treatments are to the ecosystem, the more harmful they are to the future use of forests, and for landscape. Therefore, we emphasise the scale of restoring operations in relation to the severity of the radiation situation. If an area becomes heavily contaminated and all normal use of forests are therefore excluded, cleanup operations should be carried out after sufficient time is given for a comprehensive planning process. Those who make decisions regarding restoration measures should also be assured of the net benefit to be achieved with them. Treatments that alter the environment in an irreversible way should be supported by several important attributes of local land use before their application, not forgetting the need for investments for establishing growth conditions again after remediation.

Residence areas in forests, camping sites, urban forests and parks visited frequently by citizens are of local concern and their remediation should be tailored considering the radiation exposure received at the different types of sites.

Biofuel production with forest biomass, and returning the ashes to the forest floor for nutrition, is a promising concept in the context of sustainable energy. If contaminated forest biomass is used as fuel, care must be taken to reduce radiation doses to forest, biofuel plant and ash deposit workers. When returning the biofuel ashes to the forest for nutrition, judgement must be made on the level of contamination that is acceptable. Although a few preliminary studies have given indication of a reduced ^{137}Cs uptake with fertilisation, more long-term studies with contaminated ashes used as fertiliser are need to gain an understanding of both the short-term and long-term effects of fertilising with ^{137}Cs-contaminated ashes.

Whatever the practical countermeasures in different forests are, the people planning intervention for their forests need basic knowledge on the time-dependent changes governing how the radioactive contamination in forests is distributed.

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Title	Tools for forming strategies for remediation of forests and park areas in northern Europe after radioactive contamination: background and techniques
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Abstract	This report compiles background information that can be used in planning appropriate countermeasures for forest and park areas in Denmark, Sweden, Finland and Norway, in case a nuclear accident results in large-scale contamination of forests. The information is formulated to inform the forestry sector and radiation protection experts about the practicality of both forest management techniques and mechanical cleanup methods, for use in their planning of specific strategies that can lead to an optimal use of contaminated forests. Decisions will depend on the site and the actual situation after radioactive deposition to forested areas, but the report provides background information from investigations performed before an accident occurs that will make the process more effective. The report also discusses the radiological consequences of producing energy from biomass contaminated by a major nuclear accident, both in the context of normal biofuel energy production and as a means of reducing potentially severe environmental problems in the forest by firing power plants with highly contaminated forest biomass.
Key words	Forests; Radioactive contamination; Remediation; Northern Europe; Countermeasures; Forest management; Mechanised forestry; Radiation protection; Biofuels

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