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Decision support handbook for recovery of contaminated inhabited areas

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Abstract

The handbook is aimed at providing Nordic decision-makers and their expert advisors with required background material for the development of an optimised, operational preparedness for situations where airborne radioactive matter has contaminated a Nordic inhabited area. The focus is on the mitigation of long-term problems. It should be stressed that the information given in the handbook is comprehensive, and many details require careful consideration well in time before implementation of countermeasures in a specific area. Training sessions are therefore recommended. The handbook describes the current relevant Nordic preparedness (dissemination routes) in detail, and suggests methods for measurement of contamination and prognoses of resultant doses, and data for evaluation of countermeasures and associated waste management options. A number of non-technical aspects of contamination in inhabited areas, and of countermeasures for its mitigation, are discussed, and a series of recommendations on the application of all the handbook data in a holistic countermeasure strategy are given. A part of the handbook development has been a dialogue with end-user representatives in each of the Nordic countries, to focus the work of the specific needs of the users.

Key words

Radiation dose, radiocaesium, urban, inhabited areas, preparedness, decontamination, countermeasures, nuclear emergency, cost-benefit analysis, nuclear power plant, accident, dirty bomb, decision-making, waste management, kitchen garden

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URBHAND

Decision support handbook for recovery of contaminated inhabited areas

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Abstract:

The handbook is aimed at providing Nordic decision-makers and their expert advisors with required background material for the development of an optimised, operational preparedness for situations where airborne radioactive matter has contaminated a Nordic inhabited area. The focus is on the mitigation of long-term problems. It should be stressed that the information given in the handbook is comprehensive, and many details require careful consideration well in time before implementation of countermeasures in a specific area. Training sessions are therefore recommended. The handbook describes the current relevant Nordic preparedness (dissemination routes) in detail, and suggests methods for measurement of contamination and prognoses of resultant doses, and data for evaluation of countermeasures and associated waste management options. A number of non-technical aspects of contamination in inhabited areas, and of countermeasures for its mitigation, are discussed, and a series of recommendations on the application of all the handbook data in a holistic countermeasure strategy are given. A part of the handbook development has been a dialogue with end-user representatives in each of the Nordic countries, to focus the work of the specific needs of the users.

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Short summary:

In the event of a serious nuclear emergency affecting inhabited areas, it is essential to have state-of-the-art information on how to deal with the contamination situation available as early as possible, so that countermeasures can be initiated as early as possible. Equally importantly, such information would contribute to make it possible to avoid wrong decisions, which could have irreversible unnecessary adverse effects. The scope of the present handbook is to support responsible decision-makers and their expert advisors in making the right decisions to mitigate the long-term problems associated with an airborne contamination of inhabited areas.

The handbook starts with an introduction explaining the general scope and structure of the handbook. The second chapter gives suggestions regarding the establishment of a strategy for measurements and mapping. It suggests methods for prioritisation in situations where timing and resources can place constraints on the scale of countermeasure implementation. It also describes a general methodology to obtain the data that are necessary to evaluate the situation and introduce the right countermeasures. Out of a large number of previously suggested countermeasures, a total of 17 methods have been selected for reduction of long-term external doses (Chapter 3). These cover the 6 different important types of surfaces in an inhabited environment: open (grassed) soil areas, paved areas (streets), house walls, house roofs, vegetation (trees, shrubs, bushes), and indoor surfaces. Each countermeasure has been described in a standardised format facilitating intercomparison of method features (Appendix A). Apart from a short general explanation of the method, the primary method data reported in the standard templates relate to requirements, effectiveness, waste and constraints. Non-technical factors (e.g., legal, social, information-related) to be considered and management schemes for wastes produced by countermeasures are often of a general nature and not suitable for discussion in a stringent datasheet format. These have therefore been addressed separately in Chapters 6 and 7. It is important that any waste problems are considered in connection with the choice of countermeasure strategy, as the waste production is a direct implication of the countermeasure selection. Although the primary focus is on emergencies involving major nuclear power plant accidents, also the implications of some ‘plausible’ types of malicious radioactivity dispersion devices are discussed. The fourth chapter demonstrates a simple methodology for calculation of the various dose contributions that would be received by inhabitants of an area contaminated by radionuclides from a nuclear power plant accident or a so-called ‘dirty bomb’ dispersion device. This type of data is an essential requirement in the decision-making process. This dose assessment chapter specifically excludes consumption doses, as food products are mostly produced outside the inhabited areas. However, it is recognised that some food products may be produced in inhabited areas, in small kitchen garden lots. The doses that these products could result in, as well as countermeasures for their reduction, are discussed separately in Chapter 5, with specific kitchen garden countermeasure descriptions in Appendix B. In Chapter 8, the application of the content of the handbook is discussed in relation to the process of countermeasure strategy formation. For reference, Appendix C presents the current organisation of the relevant emergency management in the Nordic countries. This is of value, for instance in ensuring correct dissemination of knowledge at different information levels and to foster mutual understanding within Nordic countries.

Preface:

The work was carried out under the NKS-B / URBHAND project (contracts AFT/NKS-B(04)4 and AFT/NKS-B(05)4) under the framework of the Nordic Nuclear Safety Research Programme (NKS) in 2004-2005 (NKS-B Programme Manager: Sigurður Emil Pálsson). NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

The authors wish to thank Mr. J. Roed (formerly Riso National Laboratory, Denmark) for his participation in project meetings during the first year of the project. Thanks are also due to Kyllikki Aakko (STUK, Finland), Jeppe Vöge Jensen (DEMA, Denmark), Charlotta Källerfelt (SRV, Sweden), Yngvar Bratvedt (NRPA, Norway) and Sigurður Emil Pálsson (Geislavarnir Rikisins, Iceland) for valuable contributions to the description of national emergency management structures in each of the Nordic countries (Appendix C). The contributions of Karl-Johan Johansson (SLU, Sweden) and Eila Kostiainen (STUK, Finland) to the descriptions of problems associated with contamination of kitchen garden products (Chapter 5) is also gratefully acknowledged.

In 2006-2007, a prototype version of the handbook was presented to end-user fora in each of the Nordic countries, and its contents were discussed in a step towards better addressing the specific requirements of end-users. This process comprised an exercise aimed at securing that the applicability of the various parts of the handbook was considered by the Nordic end-user representatives. The present version of the handbook is the result of a revision process in the light of the end-user viewpoints. The end-user participants in the interaction process are listed in the text below:

End-user participants in the URBHAND interaction process:

Sweden:

1. Statens strålskyddsinstitut
Swedish Radiation Protection Authority
SE-171 16 Stockholm.

2. Statens Räddningsverk
Avdelningen för stöd till räddningsinsatser
Enheten för beredskap mot farliga ämnen
SE-651 80 Karlstad .

3. Statens Jordbruksverk
Marknads avd. Beredskapsenheten
SE-551 82 Jönköping.

4. Statens Livsmedelsverket,
Box 622,
SE-751 26 Uppsala.

5. Krisberedskapsmyndigheten
Swedish Emergency Management Agency
Box 599
SE-101 31, Stockholm.

Denmark:

1. National Institute of Radiation Hygiene (SIS)
Knapholm 7
DK-2730 Herlev

2. Danish Emergency Management Agency (DEMA)
Nuclear Preparedness
Datavej 16
DK-3460 Birkerød

3. Danish Veterinary and Food Administration
Division for Chemical Food Safety and Veterinary Medical Products
Mørkhøj Bygade 19
DK-2860 Søborg

4. The Danish Fire Brigades (facilitated through DEMA)
DK-1553 Copenhagen-V

Finland:

The Finnish end-user representatives were all from STUK, as this is in all aspects the central authority that would be the key end-user.

The experts involved in the end-user group are:
Hannele Aaltonen
Riita Hänninen
Kyllikki Aakko
Tarja Ikäheimonen
Kari Sinkko
Juhani Lahtinen
Eila Kostiainen

Norway:

In Norway, the leading organisation responsible for the nuclear and radiological preparedness is NRPA. They are thus the key end-user in Norway, and will decide on distribution of information to other actors of relevance to contaminating incidents. Therefore, the Norwegian end-user representatives were the personnel within NRPA, who are in charge of such matters.

Contents:

1. Introduction

This introductory section is aimed at providing a general overview of the handbook, its scope, features and structure. It also gives generic recommendations on how the handbook should be used, and how this handbook and the European EURANOS handbook, which was created in parallel, are complementary to each other and can be used together by the Nordic end-users.

1.1 Scope, context and audience

The Chernobyl accident tragically revealed that large accidents at nuclear power plants may lead to significant contamination of vast land territories, including urban areas. As efforts to identify suitable countermeasures for such accidents had in the past focused on agricultural production, it became apparent that there was a need for new work to test and analyse countermeasures that would be applicable to reduce doses to inhabitants of urban areas. A series of experimental programmes were conducted to address this need (Roed et al., 1996; Andersson & Roed, 2006). At the same time efforts were made to improve the understanding of urban radioecology in general, and processes governing the doses that would be received in inhabited areas of different characteristics (e.g., population densities) were scrutinised (Andersson et al., 2002). The Chernobyl accident further provided a unique opportunity to examine the various responses of affected persons and impacts on society of a major emergency situation (Howard et al., 2005). Knowledge of this type is essential in emergency decision-making, to address requirements for information and dialogue and evaluate the situation in a holistic perspective.

This handbook aims to utilise state-of-the-art knowledge to provide a platform for decision-makers and their advisors (particularly radiation specialists), which can facilitate the process of selecting the right countermeasures to improve the situation in an inhabited area that has been contaminated by an airborne release of radionuclides. The handbook deals with decision support for the 'recovery' time phase when the contamination has occurred, air contaminant levels have gone down considerably, and the task is to improve the long-term conditions for people staying in the affected area. It specifically addresses the various aspects of emergency management in relation to Nordic conditions (e.g., with respect to selection of potentially suitable countermeasure types, evaluation of risk perception and other non-technical aspects). Whereas previously published compilations of countermeasures (e.g., Andersson et al., 2003, Andersson, 1996; Roed et al., 1995) have solely dealt with the consequences of airborne releases from nuclear power plants, this handbook goes a step further, in enabling the consequences of some 'likely' types of malicious radionuclide dispersion devices ('dirty bombs') to be assessed.

The URBHAND handbook was developed in parallel with the generic European EURANOS handbook for inhabited areas (Brown et al., 2007). The EURANOS handbook is in a sense comparatively much more comprehensive, as it is aimed at providing decision support in relation to *all* time-phases of contaminating incidents that might occur in *all* regions of Europe, where for instance traditional practice differs considerably, and environmental conditions can put different constraints on countermeasure application. Acknowledging that considerable location-specific parameterisation and contextualisation is required to integrate the EURANOS handbook in any operational national emergency management system, the authors of the EURANOS handbook strongly recommend that its contents be 'customised' and as such only form the background material for more focused handbooks for use in specific countries or regions.

The URBHAND handbook is aimed at presenting information that is directly applicable in the event of an accident contaminating a Nordic inhabited area. It is targeted on the specific Nordic conditions, which is for instance reflected in the focused selection of countermeasures and a section describing the structure of the emergency management organisation in the Nordic community. This focusing and limitation makes the URBHAND handbook much easier to overview and handle in relation to a crisis situation. Moreover, it is important to be aware that in spite of its highly generic approach, the EURANOS handbook has some inherent shortcomings and restrictions. One of these is that due to the initial definitions of the EURANOS project, none of the dose calculations are suited for handling smaller scale contamination events like ‘dirty bombs’, although it is clear from calculations made elsewhere that consequences of ‘dirty bombs’ can be very severe and extend out over large inhabited areas (Andersson, 2005a). It is clear that models that can predict the radiological consequences outside the immediate vicinity of the blast are crucial, both to ensure that the preparedness systems are adequate to handle this type of situations (training and development) and to enable optimised countermeasure implementation (Astrup et al., 2005; Andersson et al., 2007). Measurements of any kind are slow to perform in an inhabited area, where many complex surfaces are present, and dose rate measurements do not alone yield applicable information on which surfaces should be treated. For non-gamma emitters (e.g., ^{90}Sr) this need is even more pronounced, as ‘screening’ measurements could take very long time.

Compared with the EURANOS handbook, the URBHAND handbook provides more refined dose calculations for different inhabited environments, enabling direct evaluation of averted doses by introducing a countermeasure on a given environmental surface. As agricultural products would primarily be produced outside the inhabited areas, the primary focus is thus on the long term external doses. However, it is recognised that some food products may be produced in residential areas, e.g., in kitchen gardens, and the inclusion of the impact of a contaminating incident on kitchen garden products in decision-support handbook material is a completely new implement.

To maximise the applicability of the handbook for the end-user community, a ‘prototype’ version of the handbook was presented to a wide range of Nordic end-user representatives (see participant organisation list in the Preface section of this report). These commented on the handbook in free format, as well as in relation to an exercise that was conducted in 2006-7 to ensure that the use of as many corners as possible of the handbook would be carefully considered by the end-user community in relation to different types of hypothetical contaminating situations. The end-users welcomed the handbook and found it useful. They also did a thorough reviewing job, giving many useful comments and recommendations for changes, and it is on this background that amendments were made, so that the present version more closely reflects the specific wishes and requests of the Nordic end-users. In some cases requests made by different end-users conflicted, though rarely on important issues. The amendments that were made are those that the work group found it reasonable to make, to deliver a product which is deemed to be as coherent, comprehensive and targeted as possible, considering the budget frames. The changes made in the light of the feedback from the URBHAND end-user exercise comprise clearer description of scope and audience, improved discussion of countermeasure justification and optimisation, clearer table headings, guidance on how to apply standard dose calculation factors for situations involving ‘untypical’ dwellings, more focus on the characteristics of ‘dirty bomb’ incidents, a new section on calculation of doses from resuspended radionuclides, discussion of time aspects of waste handling, substantial revision and movement to appendices of both information on Nordic emergency management structures and countermeasure datasheets, as well as an additional worked example of use of the handbook material..

1.2 The handbook structure

An important step in any emergency management strategy is to assess the nature and extent of the contamination problem, as far as possible through measurements. The second chapter gives an introduction to methodologies and systems for measurement and mapping. It outlines the many different roles of monitoring in connection with an emergency affecting inhabited areas, including those measurements that would need to be carried out to optimise decision-making and practical implementation of countermeasures, which is the primary objective of this handbook. Suggestions are made regarding prioritisation of measurements, as time and resources may be restricted in an emergency situation. The described measurement procedures outline the need for equipment to be used in the vital processes of securing optimal remediation.

The third chapter gives detailed descriptions of countermeasures to reduce long-term external dose, in a standardised format which facilitates comparison of method features. Descriptions are given of 17 selected countermeasures that are deemed to be most suitable in general for the Nordic countries (the schematic descriptions are placed in Appendix A). Compared with the EC-STRATEGY database (Andersson et al., 2003), the countermeasure template format has been simplified, so that non-technical factors to be considered (also in connection with formation of whole dose reduction strategies), which are often of a general nature and not suitable for discussion in a stringent datasheet format, have been addressed separately in Chapter 7. This is believed to make the presentation easier to overview. The database is also very simplified compared with that given in the EURANOS handbook (Brown et al., 2007), which contains further information on, e.g., worker doses, environmental impact as well as a series of tabulated data excerpts and examples, which can be used to facilitate comparison of method features. The EURANOS handbook also contains a lot of material in the form of diagrammes and figures aimed at guiding the user through some important aspects of the countermeasure selection for a given scenario. However, since the URBHAND selection of countermeasures deemed to be particularly useful for Nordic conditions is very much smaller than the suite of countermeasure descriptions in the generic European EURANOS handbook, such information is of much less interest in the present context.

One of the essential requirements in developing an optimised countermeasure strategy is the evaluation of doses that can be averted. For this purpose, it is necessary to estimate the various contributions to dose that would be likely to be received in inhabited environments of different characteristics. A simple method facilitating these dose calculations is described in Chapter 4, with data tables that can be applied in uncomplicated calculations. Although the focus is, as mentioned above, on the long-term external dose contributions, also other dose contributions to inhabitants of contaminated areas (excluding contributions from agricultural products, which would have been produced elsewhere) have been estimated, so that the total *residual* dose following the implementation of countermeasures can be estimated.

As mentioned above, also doses from those food products that are produced inside inhabited areas in kitchen gardens are considered in the handbook. Chapter 5 gives an introduction to the problem, and some calculations that can be used to assess the extent of its local importance. Also some additional countermeasures specifically targeted at reducing doses received from consumption of contaminated kitchen garden products are described here.

A number of the countermeasures suggested in Chapter 3 (Appendices A and B) will generate waste, which must be managed in a safe way. The handling of waste must be considered as an inherent part of the countermeasure optimisation process, so that costs and other problems in connection with the waste are not overlooked. A series of relatively simple, but generally sufficient waste management strategies are described in Chapter 6, outlining important aspects to be considered in connection with the strategy formation.

Countermeasure strategy perspectives of legal, ethical and communication-related nature are discussed in Chapter 7, with a view towards practical implementation issues. The needs for communication and avoidance of violation of public rights are some of the key aspects. These perspectives could be of great importance in securing the continued maintenance of societal functions.

As mentioned above, the formulation of an optimised countermeasure strategy is indeed complex. In Chapter 8, two examples are given, pinpointing the use of the data from the handbook and the requirements from other, case-specific evaluations, in the identification of elements of a total cost-benefit analysis for countermeasure optimisation.

For reference, Appendix C of the handbook gives an overview of the structure of the organisation of the relevant emergency preparedness in the different Nordic countries for dealing with the consequences of radioactive contamination in inhabited areas. It provides important information on the key players and their various responsibilities in the preparedness process and pinpoints similarities and differences between the Nordic countries. The information given can be used to assess possibilities for collaboration across borders and thereby homogenise decision-making in the Nordic area as a whole, thus reducing the risk of making ‘contrasting’ decisions that could be perceived as illogical and possibly lead to disruption in society.

1.3 Recommendations for preparation before use of the handbook

It should be stressed that it is not the aim of this handbook to suggest a rigid framework for decision-making. As outlined by the ICRP (1999) in their latest recommendations, the process of selecting the optimal protection options is by no means unambiguously determined by factors that can be quantified on a generic scale. It is therefore the aim of the handbook to clarify which factors need to be taken into account in the decision matrix, and as far as possible provide the required data. However, this leaves a series of open questions, e.g., on the value that a saved unit of dose should be assigned, and the (positive or negative) impacts that a countermeasure might have on property value, productivity or the psychological well-being of a specific population affected by the contamination. Obviously the relative importance of such quantities would depend on the exact situation, and a monetary assignment of their value would reflect a political choice. Incorporation of such aspects in an operational preparedness should therefore benefit from dialogue with the potentially affected population groups, to assess local prioritisation. This dialogue should be initiated well in advance of a contaminating incident. A countermeasure is justified only if the *total* benefits outweigh the *total* costs.

It is important that responsible planners go through the comprehensive countermeasure descriptions and make sure that all knowledge concerning requirements of the selected countermeasures is disseminated out to those organisations that would participate in the countermeasure implementation, to ensure that everything is in place if an emergency occurs. The handbook also provides some basis material for consideration in connection with an information dissemination process to the public and other affected groups, which also needs consideration in the local context in advance of an emergency. Further information for this purpose can be found in the generic European EURANOS handbook (Brown et al., 2007). Moreover, e.g., requirements for the measurement strategies and waste management strategies scheduled in this handbook need consideration. The handbook is thus not something that can be picked up for the first time, on the day that an emergency occurs. It should be seen as a first step in a process towards the establishment of an optimised, operational preparedness. The handbook aims to give *comprehensive* information, to keep the user, as far as possible, from the numerous potential pitfalls in emergency management for inhabited areas. Training sessions using the handbook would be recommended to identify the local ‘politically’ driven decision matrix that is needed to enable implementation of the handbook data in an operational preparedness system.

It can not be stressed strongly enough that the information given in this handbook should be made familiar to the Nordic end-user community (responsible preparedness organisations and advisors) well in advance of any emergency situation, for which it is to be used. For instance, the descriptions given in Appendix C of the current organisation of emergency management in each of the Nordic countries could serve to pinpoint illogical differences, which may be perceived as conflicting, and thus, depending on the nature of an emergency, could cause severe communication problems / social disruption. That appendix also outlines the key actors on various levels of the emergency management process and could be helpful in providing an overview of responsibilities for different sub-tasks specifically in relation to remediation of contaminated inhabited areas, while also visualising any needs for extension of the current system of inter-organisational interaction pathways.

The second chapter of the handbook gives a generic recommendation on strategies for monitoring. This is also important to carefully address well in advance of an emergency, so as to apply resources optimally for equipment and training that will be particularly useful in an emergency situation, and to incorporate monitoring prioritisation aspects into an operational strategy. This also highlights the role that the handbook information could have as background material in preparedness exercises. By the time where countermeasures for reduction of long-term external doses would typically be implemented, the measurement procedures mentioned in section 3.6 would have been carried out, and contamination levels on the various surfaces in contaminated locations would have been estimated.

As mentioned in section 1.1, the URBHAND handbook has been developed in parallel with the European EURANOS handbook (Brown et al., 2007). As stressed in that section, the URBHAND handbook is in a number of ways complementary to the EURANOS handbook, and addresses some of the recommendations made in the EURANOS handbook in relation to customisation to match the specific requirements of a country or region. Moreover, it is important to stress that potential Nordic users of the URBHAND handbook can benefit from the EURANOS handbook material in a number of ways. For instance, the scope of the EURANOS handbook is broader, with respect to emergency time phases, and it contains further useful advice for generic contextualisation of data. The EURANOS handbook also contains a series of sections with generic background information on, e.g., radiological protection principles, radionuclides and radiation hazards, which can be useful in building up competence for all persons participating in the decision making and related processes. The radiation ‘primer’ or ‘crash course’ sections in the EURANOS handbook would be particularly useful to potential users of the URBHAND handbook who might have little specific knowledge in the field of environmental radiation and its implications.

Assuming that appropriate measures have been taken to establish an operational preparedness on the basis of the handbook material, a first logical step of application of the handbook in an emergency situation is the assessment of the contamination problem (general levels), identification of priority areas, and assessment of the distribution of the deposited contaminants in the area (Chapter 2). On the basis of these measurements, the doses that the affected population would be subjected to over time can be identified from the information in Chapters 4 and 5. This latter step, in turn, is a requirement to identify an optimised countermeasure strategy (see Chapter 3). Other requirements in this context are an identification of possible legal, social, ethical and communication perspectives (Chapter 7), identification of suitable countermeasure options (Chapter 3 and Section 5.4), and identification of applicable routes of waste management (Chapter 6). The implementation of the countermeasures should be carried out in accordance with the results of the optimisation process, and in dialogue with affected population groups. Measurements need to support the practical implementation work, to ensure that it is carried out with the desired effect (Section 2.6).

2. Methodologies, systems and equipment for contamination measurements and mapping

This chapter contains a description of methodologies, systems and equipment for contamination measurements and mapping after fallout of radioactivity in urban/inhabited areas. Some end-users with experience and knowledge in this field will find this description unnecessarily specific and detailed. The authors of this handbook have chosen to retain the level of details in order to comply with the needs of end-users without detailed knowledge of environmental monitoring and measurements. The users are assumed to have some basic knowledge of detector types and their application (a good account of these is given by Knoll, 2002). One of the objectives of this handbook is to describe methodologies for harmonized management in the Nordic countries of fallout situations in urban areas. In this way it will be easier for one country having a contamination problem to seek assistance and help from other countries. It should also be mentioned that there may be some legal restrictions or requirements for measurements of certain areas or objects. Such legal aspects should be clarified before measurements are performed.

2.1 Important dose pathways

The main purpose of mapping and measurements of contamination and dose rates is to provide data to decide if countermeasures to avert doses should be carried out and the type and the priority of such countermeasures. Both in planning of emergency preparedness and in choosing the measurement strategy in a fallout situation it is important to keep in mind the main dose pathways that are:

- External radiation from fallout:
    - Doses from outdoor activities
    - Doses indoors from fallout on roofs, walls, contamination around houses and from contaminated dust indoors.
- Doses from consumption of contaminated fresh water sources.
- Doses from consumption of locally produced food on contaminated land areas, i.e. kitchen garden products.
- Doses from inhalation of airborne contaminated dust:
    - Outdoor from traffic and wind.
    - From contaminated dust indoors.
- Doses from contamination of humans
- Doses from handling of contaminated tools and equipment.

Some of these pathways are more important than others. The strategy and priority of measurements and mapping should reflect this.

2.2 Objectives of measurements

As soon as possible after the acute phase of a fallout period after a nuclear accident or other serious situations causing radioactive contamination in an urban area a plan for mapping the dose rate levels and contamination levels should be made and carried out. The main objectives of this work are:

- Define areas where relocation of people is necessary.
- Define areas where temporary evacuation of people is necessary.
- Define areas where other countermeasures are justified.
- Define areas where the accumulated doses, dose rates or radioactivity concentrations are below levels recommended for countermeasures.

Further objectives of measurements and mapping are:

- Make data available for calculation of doses and further decisions on interventions.
- Provide data for planning and optimisation of countermeasures.
- Provide data for calculation of the effects of countermeasures.
- Personal monitoring of directly exposed persons.
- Long time following up of doses to the population.

2.3 Important factors in planning of measurements

In planning and prioritising mapping and measurements a lot of factors must be taken into consideration, some are:

- Localisation of the source of the contaminating accident.
- The source term, i.e. nuclides and activity levels released in the contaminating accident.
- Atmospheric conditions and dispersion.
- Weather condition in the urban area, i.e. wet deposition and/or dry deposition.
- Time of the year.
- Information of the urban area:
    - Population and age distribution.
    - Type of settlements and buildings.
    - Location of kindergartens, schools, playgrounds, parks and recreation areas.
    - Location and types of fresh water sources.
    - Psychological factors.

Some of this information may not be immediately available after the acute phase of an accident but all available information should be used in planning and prioritising measurements. Of special importance in planning and prioritising is of course:

- Available instruments, numbers and types.
- Personnel resources.

It is important as far as possible to use simple methods and readily available instruments to avoid delays of mapping and other measurements requiring early implementation.

2.4 Strategy and priority of measurements

Since the main purpose of countermeasures is to avoid or reduce doses to the population the strategy and priority of measurements must be to localize areas where dose pathways and radiation concentrations make countermeasures necessary according to prevailing recommendations. The priority should therefore be:

1. Mapping to define areas where:
    - Relocation is necessary
    - Temporary evacuation is necessary

2. Measurements in areas where people still live and some kind of countermeasures and interventions must be decided to avert doses to the population and to minimize other harmful consequences of the accident to people and society. A suggested priority is given in Section 2.7 below.

Doses to emergency response personnel should be measured by personal dosimetry. Doses to relocated and evacuated people should be measured if possible and calculated to evaluate the need for medical treatment.

If the fallout requires relocation and evacuation of some areas the first priority must be to locate these areas and carry out these countermeasures as soon as possible. When this has been done it is no immediate need to do further measurements in these areas until later but before people are allowed to move back.

The priority should then shift to areas where people still live and introduction of countermeasures will reduce doses to the population. To be able to make optimal use of instrumentation and personnel it is important that measurements make it possible to distinguish these areas from areas where no immediate action is necessary.

2.5 Methods and equipment for measurements

There are several methods for rough determination of the fallout pattern and contamination levels. Choice of method depends on available detector systems and instrumentation and size and location of the contaminated area. The methods described here are:

- Measurements by use of instruments mounted in aeroplanes of helicopters.
- Measurements by use of instruments mounted in cars.
- Reference points measurements.
- Measurements by use of hand held instruments.

In many cases fallout from nuclear accidents will contain a variety of γ-emitting nuclides. In such situations NaI-detector systems often do not have the necessary energy resolution to provide necessary spectroscopic information of the fallout. In these cases mobile germanium-detector instruments should be used.

Most radiological laboratories in the Nordic countries are equipped with stationary Ge-detector systems that can be used to measure the content of γ-emitting nuclides in samples taken from contaminated areas.

Measurements to get a complete picture of the contamination levels and dose rates in urban areas can be very time consuming and there can also be limitations on what can be measured. In many situations a combination of measurements and model calculations based on some photon transport code will be less time consuming and give sufficient information of the situation in complex urban areas to decide upon necessary countermeasures.

2.5.1 Measurements by use of instruments mounted in aeroplanes of helicopters

Mapping of large areas is most effectively done by detector systems mounted in aeroplanes or helicopters. This type of measurements is most effective for large towns and densely populated areas of large sizes. Instruments normally used are NaI-detector systems or Ge-detector systems. Data must be stored digitally together with data of positions for later analysis.

The systems should be calibrated to provide figures for the contamination levels on the ground surface. From this information it will be possible to provide rough calculations of the dose rates at ground level. Some uncertainty in the measurements must be accepted from variation of the ground level compared to the flight path and shielding structures on the ground. Houses in towns and settlements will also introduce some uncertainty in the measurements.

Guidelines and information of measurements by airborne instruments are described in ICRU (1994) and IAEA (1999).

2.5.2 Measurements by use of instruments mounted in cars

For towns and settlements including suburbs car mounted instrument systems will provide more reliable data of relevance for decision-making than aeroplane or helicopter mounted instruments. Measurements are then made at the ground level along roads where people live. It is then possible to select areas of priority for further measurements from this mapping.

Car-mounted instruments can be NaI-detector systems, Ge-detector systems, ionisation-chamber instruments, GM-tube instruments or some combinations of these. By adjusting the car velocity and the data sampling time for the detector systems mean values, dose rates and spectroscopic information over selected distances can be obtained. Data from the instruments must be stored digitally together with GPS information for later analysis and use.

2.5.3 Reference point measurements

Reference point measurements refer to the method of measurements in predefined locations. The selection of locations should be made as a part of the emergency preparedness work. The locations should be selected in such a way that they form a sufficient network of points for mapping in case of a fallout situation. Representative dose rate measurements require some open spaces at the selected locations. In this way the detector will “see” a representative radiation field in the location. By doing measurements in pre selected locations as a part of the emergency preparation work reference values in the points can be recorded. In a fallout situation repeated measurements in the same locations will give information of the temporal development of dose rates and contamination levels in the proximity. This information can be used to introduce and select proper countermeasures and to withdraw countermeasures.

In addition to dose rate measurements all other types of measurements should also be made in reference points. Measurements at reference points can be:

- Dose rate measurements: For mapping and evaluation of countermeasures.

- Spectroscopic measurements: By portable Ge-detector systems or NaI-detector systems to obtain information of the radionuclides in the fallout.

- Sampling of grass, soil and vegetation in the location: Laboratory analysis of these samples by γ-spectroscopy will provide information of the activity levels of radionuclides in the environment. Radiochemical analyses of samples will also provide information of activity levels of α- and β- emitting nuclides not accessible by γ-spectroscopy.

2.5.4 Measurements by hand held instruments

For small areas up to 1 km x 1 km mapping by hand held portable instruments can be performed. Instruments used for this can be dose rate meters, portable NaI-detector systems or portable Ge-detector systems. There should be some way of storing the data together with information of the location of measurements. This measuring method can be used after applying airborne screening or car-mounted systems to obtain more detailed information of contamination levels and dose rate levels within specified areas.

Measurements can be made in different ways to obtain necessary information of the situation:

- Pre selection of locations within a specified area where measurements are to be made. For mapping purposes the selection of points should be of relevance for assessment of doses to the population in the area and for evaluation of countermeasures. Measurements can be made as described in Section 2.6.3 above but without available reference information.

- Divide the area into tracks. By accumulating data from measurements at selected distances along the tracks average values of dose rates or spectroscopic information can be obtained. As pointed out above the tracks should be chosen in such a way that this information could be used to assess doses to the population in the area and for evaluation of countermeasures. This method can also be used to locate radioactive sources or fragments if necessary.

2.6 Priority of measurements in inhabited areas, exposure pathways

When further priority of measurements is evaluated dose pathways must be considered:

1. Fresh water sources
2. Where people live and work
3. Foodstuffs from local gardens
4. Tools and equipment: Equipment and remedies used in everyday life.

The suggestion for priority of measurements is therefore:

1. Measurements of fresh water sources.
2. Measurements in kindergartens indoor and outdoor.
3. Measurements in schools indoor and outdoor.
4. Measurements inside and outside dwellings in residential areas
5. Measurements in parks, playgrounds and recreation areas.
6. Measurements of kitchen garden products.
7. Measurements inside office buildings.
8. Measurements in streets and pavements.
9. Measurements of tools, equipment used in everyday life

The arguments for this suggested priority list are given below.

2.6.1 Fresh water sources

Surface water sources used by communities are especially exposed to fallout and later runoff from surrounding areas. This also includes private wells. Such fresh water used for drinking or in food preparation is an important part of the diet. Measurements of fresh water sources for towns and communities and also private wells should be repeated regularly to detect contamination by runoff from the surrounding environment. Ground water sources are to a less extent vulnerable but should also be checked.

The fresh water source for some cabins is runoff from the roof and surfaces collected in tanks. Experience from the Chernobyl accident shows that this water can be highly contaminated. Stores of water collected from roofs and surfaces should be emptied and washed.

Exposure pathway: Intake of contaminated water.

2.6.2 Kindergartens, schools and playgrounds

The doses received by children from contamination on surfaces are generally higher than for adults and the health risk per unit dose is also higher. The reason for this is that organs in children are closer to the ground than for adults and they have a higher rate of cell division because of the growth process. Small children in kindergartens are especially exposed since they are often in close

contact with the ground. In general children and adolescents also have a long life ahead of them to accumulate doses and therefore have a higher probability for development of cancer diseases compared to elderly people. Doses accumulated during childhood and in the fertile period of life can also cause hereditary effects in progeny. Altogether measurements to evaluate and introduce countermeasures to reduce doses to children and adolescents must have a high priority.
Many children spend many hours a day in kindergartens. Measurements should therefore be performed both indoor and outdoor to evaluate necessary countermeasures to reduce doses. All children and young people spend many hours at school and also outdoor in playgrounds. Measurements in these places should also be performed for protection of young people.

Exposure pathways by indoor residence:

- Gamma radiation from fallout on the ground/snow cover around the houses, dry and/or wet deposition.
- Gamma radiation from fallout on the roofs from dry and/or wet deposition and on the ground from runoff from the roofs by precipitation.
- Gamma radiation from contamination on the walls.
- Inhalation of radioactive dust inside houses.
- In some cases (dry deposition) contamination on indoor surfaces.

Exposure pathways by outdoor residence:

- Gamma radiation from fallout on the ground/snow covers, from lawns, playgrounds, sand boxes, schoolyards etc.
- Gamma radiation from trees (spring, summer and autumn).
- Inhalation of airborne radioactive dust.
- Contaminated toys outdoor.
- Contamination of skin and cloths from playing.

2.6.3 Inside and outside dwellings and in recreation areas

People normally spend most of their time at home after work in the afternoons and during the nights. Single-family houses usually have garden areas where they spend some of their time for recreation or tending their kitchen garden. Small children often play outdoors in this area. Semi-detached houses, terrace-houses and also apartment buildings often have lawns surrounding the houses and nearby recreation areas.

Doses received by children and adults in the afternoons and nights from outdoor and indoor activities during their spare time give a major contribution to the overall doses from fallout and contamination. We therefore suggest that priority should be given to measurements indoor in dwellings and outdoor in gardens and nearby recreation areas. However, as explained in section 3.8 of this chapter, also other measurements will be valuable in evaluating the consequences of the contamination and in optimising implementation of countermeasures.

Exposure pathways: See Section 2.6.2 above

2.6.4 Kitchen garden products

The problem of contaminated food depends on the season. Fallout in the autumn after the harvest period, in the winter and in the early spring will contaminate the soil. Contamination of the vegetables grown in this soil occurs by uptake through the roots. If the fallout occurs during the growth period in the late spring, in the summer or in the autumn before the harvest the products are usually contaminated directly from the fallout by contamination on the leaves of the plants. The contamination levels will then be higher then by uptake though the roots alone.

Following a major nuclear power plant accident, the most important radionuclides in food products are likely to be ^{137}Cs and ^{131}I on leafy vegetables during some weeks after the fallout. It is recommended to avoid eating products from kitchen gardens in a fallout area before sufficient information of radioactivity in the garden products is known. Measurements of radioactivity in the products must be made in order to recommend adequate countermeasures according to prevailing intervention levels. It is normally not necessary to measure products from all kitchen gardens in an area. Based on the results of a mapping of the fallout level in an area a sufficient plan for random sampling and measurements of kitchen garden products can be worked out. The various local areas should be selected and defined with due regard to the similarities between dwellings and properties in the area.

Exposure pathway: Intake of contaminated food.

2.6.5 Office buildings

Most people spend many hours each day at work. Doses received during working hours can therefore be a significant fraction of the total dose received per day from fallout. Some measurements inside and outside office building should therefore be performed with priority on one and two story buildings.

Exposure pathway: As for indoor residence given in Section 2.6.2.

2.6.6 Streets and pavements

Fallout on streets and pavements represents radiation sources for traffic and transportation activity. Drivers of transportation vehicles are the most exposed persons by these radiation sources. By precipitation a fraction of the radioactivity will be drained away into ditches or down the drainage system. In the winter clearing of snow from streets and pavements will concentrate the radioactivity along the side of the streets. Snowfall at the top of the fallout will to some extent reduce the radiation level because of the shielding effect of the snow.

Exposure pathway:

- Gamma radiation from fallout on the streets and pavements.
- Inhalation of airborne dust by traffic.

The most efficient way to map the radiation levels and contamination along streets and pavements is to use car-mounted instruments described in Section 2.6.2 above. Taking air samples by filtration provide information of the content of radioactive dust in the air. Note that contamination levels on streets are expected to decline greatly over a period of some months, due to 'natural' processes (weathering, traffic).

2.6.7 Tools and equipment used in everyday life

After a fallout situation many tools and remedies used in everyday life will be contaminated. This will include all equipment located outside during this period and will also include all types of transportation vehicles parked outside. All this equipment and remedies should be cleaned before use. Removal of contamination from smooth surfaces by washing is quite efficient. Contamination measurements of tools and equipment should be given low priority and only performed if use is likely to give a significant dose contribution to individuals. Special attention should be given to outdoor toys in playgrounds and mentioned in Section 2.7.2 above.

2.7 Procedures for measurements

The main objective, i.e. protection of the population and decision of countermeasures, should always be kept in mind when methods for measurements are selected. The simplest and fastest methods to assess the doses to the population should be used. Complicated and time-consuming methods should be postponed or used only if necessary to provide important information for decision-making. Simple methods for measurements are:

- Dose rate measurements by use of dose rate instruments.
- Contamination measurements by use of contamination monitors.

If information of radioactive nuclides is necessary to assess the situation, spectroscopic measurements need to be performed. This will be the case if there are several different radionuclides involved (e.g., after a major nuclear power plant accident).

Dose rate measurements can give information of the radiation hazard at the time of the measurement to a person located in the exact position where the measurement is made. They can thus give an indication of the local extent of an emergency, but yield no information that can be used to estimate doses over longer time periods, nor of which surfaces in the urban complex that contribute most to the dose rate and therefore should have priority in a decontamination strategy.

It is in this context useful to determine the level of contamination on a reference surface in the area (an area with short grass is generally the most suitable reference). Grass samples should be cut as closely to the ground as possible from a representative area (e.g., 1 m^2), and at least 5 soil samples of, e.g., 50-100 cm^2 should be taken in different representative locations in the same area. These samples should be analysed in a gamma spectrometer. If the grass sample contains less contamination per unit sampled area than does the soil sample, the contamination is likely to have taken place in precipitation – otherwise the area can be assumed to have been dry-contaminated. On this basis, an estimate of the contamination levels on other surfaces in the area can be made according to Table 4.5 in Chapter 4. It should however be noted that the figures in that table are specific to the ca. 1 µm aerosol released from the Chernobyl accident.

During winter time with snow covering of the ground the contamination level can be determined by snow sampling and measurements by the same method as described above.

Dose estimates and prognoses made with decision support tools can in general very significantly be improved by incorporation of measured contamination levels on the different types of surface in the environment. This will often require the use of collimated germanium detectors. Collimated shields, usually made of lead, can be designed for all spatial orientations (ICRU, 1994). It is important that the responsible decision-makers consider potential monitoring requirements well in advance of a contaminating incident, so that equipment and trained operators are in place as early as possible.

In most cases in the inhabited environment, decontamination procedures do not require very rapid implementation to be effective. It is here important to consider that many potentially very useful countermeasures could have only very little positive, or even negative, net effect if applied wrongly. For instance, removal of a thin topsoil layer containing practically all the deposited contamination can be a very useful dose-reducing countermeasure. However, soil contamination levels after wet deposition would in some cases peak a few centimetres down in the soil. This means that the removal of a thin topsoil layer could imply the removal of shielding rather than contamination, and the countermeasure could thus result in an increase in dose rate, if the thickness of the removed layer is not optimised according to measurements of the contamination profile in the soil. This problem was demonstrated by the very poor outcome of the effort of the Russian army in 1989 to decontaminate 93 settlements in the Bryansk region, which had been contaminated by the Chernobyl accident. This example highlights the importance of measuring the location and level of the contamination *prior* to implementation of countermeasures.

Measurements of dose rate or contamination level after countermeasure implementation would also be desirable to demonstrate that the desired effect has actually been obtained.

Analysis of samples in a laboratory is normally a time consuming process and is often not suitable for fast decision-making, but may be useful for some of the decision processes that do not require immediate action. In some cases as for monitoring of fresh water sources and measurements of kitchen garden products, this is the only reliable method to assess the content of radionuclides and must therefore be used. Sampling of soil, grass and vegetation and analysis in laboratories can be used to supplement other measurements.

Procedures for continuous survey of exposure of people in inhabited areas can be distinguished between:

- Indoor measurements.
- Outdoor measurements.
- Personal monitoring
- Sampling and analysis of samples

2.7.1 Indoor measurements

In general the radiation fields inside houses are caused by fallout in the environment around the houses and on the roofs, and in some situations inside the houses. Indoor measurements should therefore be supplemented by outdoor measurements and measurements of the contamination levels on the roofs to assess the sources of the situation indoor.

- Dose rate measurements in rooms ordinarily occupied by people during days and nights. Measurements in the centre of the room and in the corners for calculation of the average dose rate level.

- Contamination measurements by smear tests of surfaces (floors and benches) to provide information of the concentration of radioactive dust indoor.

If information of the γ-energies in the radiation field is needed, a spectroscopic measurement in the centre of a room in the same position as the dose rate measurement should be performed.

2.7.2 Outdoor measurements

Dose rate measurements:

- Along house walls at the centre and at the corners for small houses, several measurements along long walls. Note that washout from the roof can give high contamination in the ground along the walls and at the outlet of the gutters.

- In the centre and at the corners of the lawns and yards.

- In kindergartens, schoolyards and playgrounds at 5 – 10 meter intervals to obtain sufficient information of the radiation levels.

- In parks and recreation areas at 50 – 100 meter at intervals to obtain sufficient information of the radiation levels.

Contamination measurements:

- Direct measurements of surfaces in kindergartens, schoolyards and playgrounds.

- Direct measurements on the roof tiles.

2.7.3 Personal monitoring

In the early phase after a contamination has occurred, persons in strongly contaminated areas may have been contaminated on the body or through inhalation. These may include emergency response workers, who should be equipped with personal dosimeters. Contamination on the human body can in some cases give rise to significant beta and gamma doses, which will be received over a period of few days, unless active decontamination (e.g., thorough washing and scrubbing) is carried out early. Persons suspected to have received high doses should be sent to medical examination.

2.7.4 Sampling and analysis of sample

In the following situations it is necessary to take samples for analysis in a laboratory:

- Fresh water samples for monitoring of radionuclides in drinking water. Samples should be taken from fresh water sources for towns and communities and also from local wells.

- Analysis of ^{137}Cs and ^{131}I concentrations in kitchen garden products and food products produced locally in urban areas. Samples should be taken for every type of products. The necessary number of samples of products within a specified area depends on information of the fallout level in that area. It is normally not necessary to measure products from every kitchen garden in an area. Density of sampling points within an area should be selected to provide statistically significant results and a firm basis for comparison with recommended intervention levels.

2.8 Training and exercises

Measurements and mapping of the contamination levels and dose rate levels in an urban area often require a wide group of workers not necessary familiar with the use of radiation protection instruments and detector systems. Measurements by complicated instruments such as NaI-detector - and Ge-detector systems require knowledge and skill for correct use. Training sessions and exercises in measurements and identification of radioactive sources should therefore be organized regularly to establish and maintain the know-how and skill among the work force.

3. Countermeasures and strategies for implementation

This chapter is aimed at introducing a number of countermeasures, which are believed to be particularly useful for reduction of the long-term (recovery phase) radiological consequences of a contaminating incident. The first section also addresses the potential benefits of introducing countermeasures on a 'self-help' basis. The second section of the chapter gives advice on the application of groups of countermeasures in a remediation strategy for a given area. Optimisation and justification of intervention is discussed, stressing the importance of balancing a host of more or less easily quantifiable factors in the optimisation process, and pinpointing practical concerns that may determine the timing or sequence of countermeasure introduction.

3.1. Descriptions of individual countermeasures

Countermeasure descriptions in standard formats facilitating intercomparison of methodological features can significantly speed up the decision making process and at the same time ensure that issues that could be important to consider are not overlooked in the process of optimisation. Such descriptions also allow planners to assess in time whether some countermeasures would in a local area be more suitable or acceptable than others. Further, the descriptions show local planners which equipment, consumables, skilled personnel, etc. must be available to carry out the countermeasures, and the local availability of these resources can thus be secured prior to an emergency.

In Appendix A, descriptions are given for a total of 17 countermeasures, which are believed to be the most suitable options for reduction of long-term external doses in Nordic contaminated inhabited areas. The selected countermeasures cover the 6 different important types of surfaces in an inhabited environment: open (grassed) soil areas, paved areas (streets), house walls, house roofs, vegetation (trees, shrubs, bushes), and indoor surfaces. The generic URBHAND countermeasure template format that has been applied is a further development of that used in the EC-STRATEGY project (Andersson et al., 2003; Howard et al., 2005). The descriptions are based on state-of-the-art knowledge from experimental work carried out to test the individual methods on various scales and under different conditions. Each datasheet includes a number of references to the most important background information. It should be stressed that a more comprehensive description of for instance additional doses received by workers and environmental impact can be found in the parallel EURANOS handbook (Brown et al., 2007). It also needs to be noted that decontamination efficiencies stated in these datasheets (and in all other methodological descriptions published to date) are to a great extent based on practical experience obtained from experimental work with radiocaesium from the Chernobyl accident. It is likely that for instance larger insoluble contaminating particles that might be produced by some types other types of incidents, particularly where physical fractionation rather than evaporation/condensation is the dominant aerosolisation process, would be easier to remove from impermeable surfaces in the environment.

Some of these countermeasures (specifically denoted in 'operator skills' section in the individual datasheets) have potential to be implemented by the affected local population themselves, as a 'self-help' measure. Generally, such measures should be based on generally available and simple equipment and resources. They should not require specific skills, nor expose members of the public to significant additional risk (e.g., from falling from heights or use of potentially dangerous equipment). It is important that it is ensured that also these workers are adequately protected (as outlined in the individual countermeasure datasheets) and carefully instructed/supervised, so as to ensure the success of the operation. Although some simple countermeasures can be implemented by unskilled workers, they may have an inherent risk of irreversible failure, if not implemented correctly. For instance, a method like triple digging requires much hard labour, and the extra labour resource is thus very useful (the extra labour resource would also be useful for measures like grass cutting, which must be carried out in large scale over limited time to be effective). However, if the digging layer thicknesses are not optimised according to assessments (made by skilled workers) of the vertical contamination distribution, and care is not taken to avoid layer mixing, the result of the implementation could have far from optimal effect, and whatever the effect might be, it would be permanent, unless a very thick layer (40-50 cm deep) of topsoil is subsequently removed. It should also be noted that not all persons are sufficiently physically fit to participate in the implementation of a method like triple digging. In general, ‘self-help’ countermeasures can only be carried out on a *voluntary* basis. Important points making ‘self-help’ methods attractive are that they involve the affected persons more directly in the effort to improve their own situation. This gives insight on how exposures can in general be avoided, and provides a better feeling of control. The knowledge obtained can function to avoid undue anxiety, and as the population know exactly what has been done in the area, the arising of myths is effectively prevented. The response from affected population that have participated in ‘self-help’ countermeasures in areas of the former Soviet Union that were contaminated by the Chernobyl accident has generally been positive (Beresford et al., 2001).

3.2. Formation of countermeasure strategies

As demonstrated in Chapter 4, dose contributions in an inhabited area may come from numerous pathways. A countermeasure *strategy* for a given area will thus often be constituted by several countermeasures targeted at reducing different dose contributions. The basic principle that should always be fulfilled with respect to justification of any countermeasure strategy is that the advantages of intervening offset the disadvantages. Among the justified options, the optimum protection option is the action which results in the maximum net-benefit. Consequently, the optimum protection option is not necessarily the option that results in the lowest residual individual or collective dose (ICRP, 1999). It is thus not possible to give generic recommendations for contamination or dose threshold levels above which countermeasures should be implemented, or below which countermeasures should not be recommended. In agreement with the ICRP system of protection, it can be beneficial to reduce even a low dose if the associated *total* costs are outweighed by the *total* benefits of the action. However, vague indications of a classification system based on dose limits have been suggested (IAEA, 1997). Any rigid threshold values for intervention are *politically* determined and not the result of an optimisation process. On the use of such values, the view of the ICRP (1999) is: ‘The use of predetermined specific reference levels can facilitate timely decisions on interventions and the effective deployment of resources; however, an improper use may lead to inconsistencies with the principles of justification and optimisation’. It is thus clear that their consideration requires great caution.

As indicated in the above paragraphs as well as in the countermeasure description datasheets, selecting the optimal countermeasure for a specific emergency situation is by no means an easy task, as countermeasure implementation can impact on society in a wide range of more or less foreseeable ways. Some aspects can relatively unproblematically be quantified in for instance monetary terms, thereby facilitating intercomparison. Such aspects include the use of machinery, consumables, transport, and worker wages, although due attention must be paid to local and temporal variation. However, as stated by the ICRP in their latest recommendations (ICRP, 1999), also problems like social disruption, loss of property value and loss of income due to the contamination situation as well as due to countermeasure implementation should be taken into account (see Chapter 7). Depending on the specific scenario, there may be a wealth of such 'indirect' factors, the importance of which is very difficult to describe. When evaluating the possible implications of a countermeasure strategy, it is important always to measure these against the implications of doing nothing. If nothing is done to reduce the contamination problems there will be an equally long (quite possibly longer) list of different types of adverse effects on society, both radiological and non-radiological.

In the European project STRATEGY (Howard et al., 2005), a series of choice experiments were conducted to assess how groups of affected populations would rank various adverse effects of a countermeasure implementation. Such effects could include disruption, heritage and the aesthetic value of a landscape. The experiments were based on the persons' willingness to allocate money from a limited budget in a way they felt would maximise utility. Although in these experiments, which took place in Spain and the UK, for instance the preservation of a landscape was generally found to rank somewhat higher than disruption, it was not possible to draw any firm conclusions that would be considered valid in a generic sense. A problem with questionnaires made in ‘peace times’ is in general that it is difficult to imagine how far people would in reality go to eliminate a given threat that may possibly have the undivided attention of the media.

Various approaches have been suggested to equate averted doses with a monetary value (e.g., Guenther & Thein, 1997; Eged et al., 2001; Hedemann Jensen & Yatsalo, 1998). Also such values may vary considerably between Nordic countries and with time. Such a value may be based on economical analyses, for instance relating to what is paid in other contexts to save a human life, and is essentially politically determined. According to the ICRP (1990), an effective dose of 1 Sv is estimated to result in a probability of 5 % for the exposed person to develop fatal radiation-induced cancer.

In addition to securing that any strategy for remediation is justified and optimised in relation to a wide range of aspects, it is of course essential to secure that the strategy achieves the ultimate goal of implementation: that the adverse health consequences of the contamination are reduced sufficiently to allow the affected population and society as a whole to resume their lives and functions in the area. In extreme cases, contamination levels might be so high that even the most effective existing countermeasures would be insufficient in reducing exposure to an acceptable level that would permit a population to remain and function in the area, and any clean-up effort would thus then be in vain. Although clean-up may, as discussed above, be justified at much lower exposure levels, the most important goal of intervention remains to secure that evacuation and removal of (parts of) a population for shorter or longer time periods can be avoided, as this can have immense societal repercussions, which would generally justify the use of any remedial means for mitigation.

It must be stressed that the sequence of implementation of the different countermeasures in a strategy is important. As explained in the datasheets, some countermeasures should be carried out before others. For instance, a method for cleaning of walls may wash contamination down into the ground next to the building. Here it may come closer to the humans living in the area than it was when it was still on the wall. It is therefore important that the contaminated soil surrounding the building is removed *afterwards*, so that this extra soil contamination is also removed.

Finally, it should be noted that some countermeasures, such as snow removal and lawn mowing, need to be carried out over a short time period after the contamination, to be effective. However, due consideration needs to be made of the higher doses that might be received by clean-up workers in an early phase, due to the possible occurrence (depending on the contaminating event) of short-lived radionuclides. Also, it should be stressed that some of the more complex countermeasures that impinge on long-term doses should not be implemented before adequate assessments (see Chapter 2) have secured that there will be a positive net benefit of the intervention - particularly as some countermeasures will have irreversible effect. A number of countermeasures may if required be postponed for years and still save much dose (see the individual countermeasure descriptions for details).

Concerning worker protection, not only extra doses that they may receive needs to be considered (described in section 4.6). Also other types of risks that workers may be exposed to must be taken into account in the justification and optimisation of a countermeasure strategy. Specific implements that may be required to protect workers include:

- Shielding against highly concentrated waste (e.g., from grass cutting or road sweeping).
- Ventilation (if indoor contaminant concentrations exceed those outdoors).
- Limitation of worker time in particularly exposing locations.
- Respiratory protection, protective clothing, glasses, helmets, lifelines and scaffolds where necessary (see countermeasure descriptions in Appendices A and B).
- Fixation of radioactive contaminants to avoid resuspension in air and extra inhalation hazard.
- Delaying of countermeasure implementation to reduce worker doses from shortlived radionuclides (note: some countermeasures *must* be implemented early to be effective).

Legislative aspects of worker protection are treated in section 7.1.

4. Estimation of doses received in a contaminated inhabited area

The aim of this chapter is to present simple methodologies that can be used by decision-makers and their expert advisors to gain an overview of the radiological consequences of contamination in a residential area. The focus is also here on the time phases, where the contamination has occurred, and the contaminating plume has passed. It should be stressed that detailed models for calculation of many of these dose contributions are under development and will be integrated in European decision-support systems (ARGOS and RODOS). These models will give the user more flexibility in describing the scenario in detail than can be provided in this section. However, simple methodologies have the strength that they may be easier and less time-consuming to use.

4.1. Introduction

As shown in Fig. 4.1, doses to humans in inhabited areas exposed to airborne contaminant releases can come from a variety of different pathways. Contamination on outdoor and indoor surfaces will contribute to external dose. An other contribution to external dose is received from contaminants deposited on humans (skin, clothing, hair). Inhalation of contaminated air and consumption of food produced locally in contaminated inhabited areas (e.g., in kitchen gardens of living areas – see separate description in Chapter 5) can give important contributions to internal dose. Food products imported into the inhabited area (e.g., from agricultural / industrial areas) are not considered here, as their level of contamination depends on the distribution of contamination in a different area.

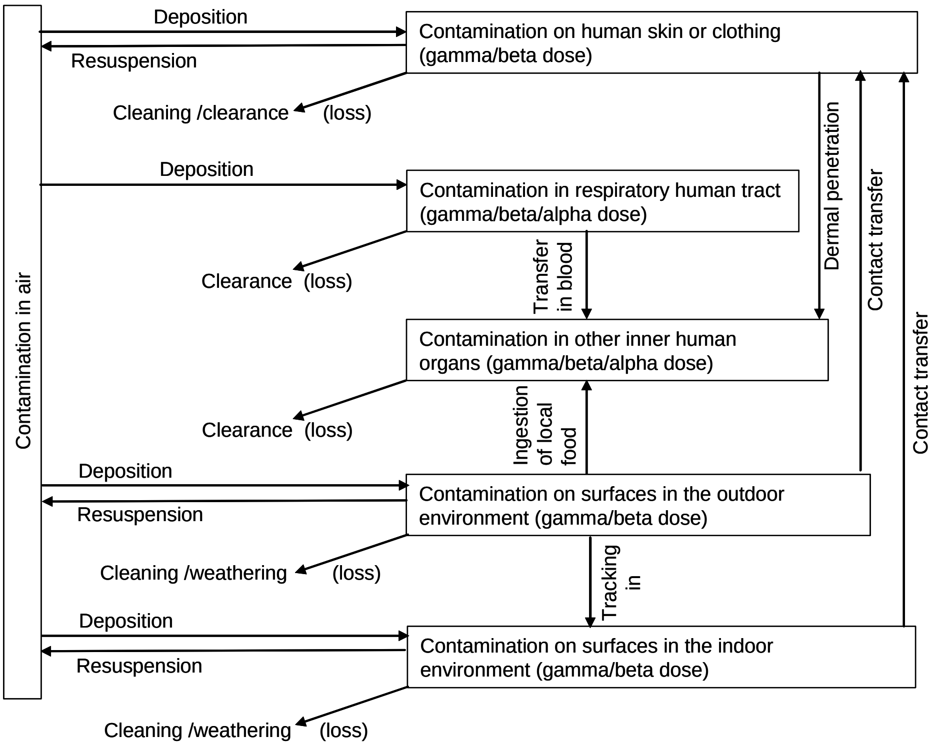

Fig. 4.1. Some potentially significant pathways of radionuclides in a residential area.

In the event of a contaminating incident it is important to be able to rapidly estimate the magnitude of the doses people may receive. This is valuable in judging the severity of the situation and its future implications. Detailed estimates of dose contributions can form a platform for decision making, ensuring the identification of optimal countermeasure strategies.

4.2. External doses from contamination on outdoor surfaces

External doses from outdoor contamination will be important to consider in all contaminating scenarios, unless the contaminants only emit alpha radiation. The focus is here on *long-term* doses, as these will determine the needs for remediation of outdoor surfaces. Radiocaesium (^{137}Cs and ^{134}Cs) has importance, as it is likely to govern long-term external doses after a large accident at a nuclear power plant. This was illustrated by the Chernobyl accident. Moreover, radiocaesium is among the key contaminants of concern in relation to malicious airborne dispersion of radionuclides, e.g., through the use of so-called 'dirty bombs'. Also particularly three other radionuclides are considered in this context since they have had widespread use, e.g., for powering thermoelectric generators, have comparatively high radiotoxicity, and comparatively long half-lives (Sohier & Hardeman, 2005; Ferguson et al., 2003). These are: ^{60}Co, ^{192}Ir, and ^{90}Sr. Both ^{137}Cs, ^{134}Cs, ^{60}Co and ^{192}Ir emit beta as well as gamma radiation, but it is the gamma radiation that will generally dominate external doses. ^{90}Sr differs from the other of these radionuclides in that it only emits beta radiation.

Tables 4.1-4.4 show estimates, based on detailed calculations made with Monte Carlo models (Briesmeister, 1993), of integrated external gamma dose contributions (per unit contamination on each surface) from respectively ^{192}Ir, ^{60}Co, ^{137}Cs and ^{134}Cs on different types of surface in inhabited environments (Andersson, 2005). Based on a number of independent surveys in Western Europe and in California (Jenkins et al., 1992; Andersson, 1996; Long et al., 2001; Kousa et al., 2002), it seems that the assumption that people on average spend some 15 % of their time outdoors is generally reasonable. The remaining 85 % of the time would be likely to be spent practically evenly between the various residential floors of the building, and this was assumed in the calculations. It was assumed that the contamination occurred in the form of small particles in the ca. 0.5-5 µm range, as was for instance observed over large areas of Europe after the Chernobyl accident. If the deposited particles were larger and insoluble, the contaminant weathering processes on the surfaces might well be faster, and the given dose estimates would thus then be conservative. Note that the trees are assumed to be coniferous, shedding needles over a period of four years. If the trees were deciduous, the resultant dose contributions would be limited to the first year. The data in the tables can be used to obtain information on the doses that would be received over various time spans from a given level of contamination on a surface, if nothing is actively done to reduce doses. The data thus gives a dynamic overview of the importance of cleaning a particular type of surface in the environment. Four different types of housing environment are represented, to reflect different conditions (e.g., different sizes of open areas, heights of buildings, construction materials), which will affect the doses received from contaminants in the area. It is believed that these types of environment together reflect a large part of the building tradition in the Nordic countries.

The four environments are:

Area with single storey detached houses

These single-family houses are constructed of light materials (wood, glass wool and gypsum). The floor area is about 11 m by 11 m. The distance from the ground to the roof apex is 6.5 m. The area of each lot is about 1000 m^2. Streets are not modelled here, as they are assumed to be far from the building.

Area with two storey semi-detached houses (double house)

These houses have thicker walls constructed of brick and breeze block, but also a slightly higher window fraction. The land area covered by a pair of semi-detached houses is about 14 m by 16 m. The distance from the ground to the roof apex is 9 m. The area of each lot is about 800 m^2. Streets are not modelled here, as they are assumed to be far from the building.

Area with rows of two storey terrace houses

Each house accommodates four families. The terrace houses are in many ways similar to the semi-detached house area, but longer. The house-walls and window fractions are practically identical. The differences between the two environments in terms of dose mainly illustrate that people living in the middle of the long terrace house are better shielded through internal walls. Further, the influence of road contamination was assumed to be negligible in the semi-detached housing environment, but becomes important in the terrace house environment, where relatively wide roads have been modelled close to the buildings.

Area with multistorey blocks of flats (5 stories)

The 5-storey urban centre block of flats has very thick outer walls (30 cm brick). Further, the grassed areas are here smaller, the street areas are increasingly important, and some of the inhabitants are living high above the ground and most of the time get a comparatively small dose rate contribution from the many contaminated ground level surfaces.

These four different environments should not only be regarded as four distinct options. Interpolations between the data for two or more of these environments could be made to for instance evaluate the situation in areas with buildings resembling one of the standard house types, but perhaps with slightly larger gardens, as modelled in an other of the 4 standard environments. For instance, the semi-detached house area is clearly much less trafficked than is the terrace house (row house) area. If, however, guidelines were requested for an area of houses resembling the semi-detached standard house, but in a more urban type of environment with roads near the buildings, the impact of the roads could be evaluated from the data sheets for treatment of roads in the standard environment of row houses, which has many similarities. As the garden areas would then become smaller, it would be necessary to diminish the dose contribution from these slightly. Some guidance as to the influence on dose rates of the size of open areas can be deduced from calculations made with the MCNP Monte Carlo photon transport code, which have shown that with a normal initial distribution of a ^{137}Cs contamination, about 13 % of the dose rate in an infinitely large field can be ascribed to the contamination within a circular area of the soil with a radius of 1m. It was found that 34 % of the dose rate is due to the part of the contamination that is more than 16m away, and 13 % comes from contaminated areas more than 64m away. Likewise, it is possible to generate alternative row-house-like environments from the same two standard environments.

In some Nordic urban areas, there are row houses in similar surroundings to those assumed in the terrace house standard environment, but with two or three more storeys. Since some of the inhabitants would then get to live higher above the ground, modifications would need to be made to the figures for the standard terrace house area to reflect an averaging over all storeys. One obvious effect of putting a few more storeys on the terrace house would be that it is still practically only the people staying on the top floor who get a significant dose rate contribution from the contamination on the roof. This means that the average (over all floors) person in the building gets a much smaller dose rate contribution from the roof. The magnitude of this contribution can be assumed to be about the same as that for people living in the 5-storey block standard environment. Note that as the calculated doses are averaged over the local population in the particular type of environment, some dose rate contributions to individuals in the environment may be significantly higher or lower.

A more detailed description of the four environments (exact dimensions and material compositions) is given by Meckbach et al. (1988). By looking at the raw data for the dose response (from Meckbach et al.'s presentation of the standard environments), it can be deduced that by adding a couple of storeys the dose rate contributions from the grassed areas, vegetation and roads to an average person in a terrace house environment would decrease to some three-fourths to four-fifths of those from the standard terrace house environment. The dose rate contributions from walls would practically be unaffected.

In any case, the objective of dose modelling in strategy formation is merely to obtain a sufficiently detailed image of the local dose rates and doses to enable a prioritising of countermeasures to be effected together with a rough overview of the potential health-effects of the situation in question. Significant local features should be identified, but it would be impracticable to consider in great detail the specific dose burden for the inhabitants of each single house.

Table 4.1. Integrated external gamma dose contributions from ^{192}*Ir contamination on different surfaces in the environment. Integration periods range from 10 days to 70 years. 15 % of the time is assumed to be spent outdoors. Doses are given in Sv per 1 Bq m*$^{-2}$ *deposited on each surface type, thus permitting scaling according to the actual level of contamination. Results are shown for four different area types, with different types of buildings, ranging from single storey detached houses with rather thin construction to multistorey houses with thick walls.*

Area type	Surface	10 days	30 days	90 days	1 year	2 years	10 years	30 years	70 years
Single storey detached	Walls	6.8E-11	1.9E-10	4.3E-10	7.2E-10	7.4E-10	7.5E-10	7.5E-10	7.5E-10
	Roof	4.6E-11	1.3E-10	2.9E-10	4.8E-10	4.9E-10	4.9E-10	4.9E-10	4.9E-10
	Grass/soil	1.7E-10	4.7E-10	1.1E-09	1.8E-09	1.9E-09	1.9E-09	1.9E-09	1.9E-09
	Trees	3.8E-11	1.0E-10	2.3E-10	3.8E-10	3.9E-10	3.9E-10	3.9E-10	3.9E-10
Two storey semi-detached	Walls	1.7E-11	4.6E-11	1.1E-10	1.8E-10	1.8E-10	1.8E-10	1.8E-10	1.8E-10
	Roof	3.0E-11	8.2E-11	1.9E-10	3.1E-10	3.2E-10	3.2E-10	3.2E-10	3.2E-10
	Grass/soil	6.3E-11	1.7E-10	4.0E-10	6.7E-10	6.9E-10	6.9E-10	6.9E-10	6.9E-10
	Trees	9.6E-12	2.6E-11	6.0E-11	9.6E-11	9.8E-11	9.8E-11	9.8E-11	9.8E-11
Rows of two storey terrace houses	Walls	1.3E-11	3.4E-11	7.9E-11	1.3E-10	1.4E-10	1.4E-10	1.4E-10	1.4E-10
	Roof	1.8E-11	4.8E-11	1.1E-10	1.8E-10	1.8E-10	1.8E-10	1.8E-10	1.8E-10
	Grass/soil	3.9E-11	1.1E-10	2.5E-10	4.1E-10	4.3E-10	4.3E-10	4.3E-10	4.3E-10
	Trees	8.5E-12	2.3E-11	5.3E-11	8.5E-11	8.7E-11	8.7E-11	8.7E-11	8.7E-11
	Street	2.0E-11	5.2E-11	1.1E-10	1.5E-10	1.5E-10	1.5E-10	1.5E-10	1.5E-10
Multistorey blocks of flats (5 stories)	Walls	1.0E-11	2.8E-11	6.4E-11	1.1E-10	1.1E-10	1.1E-10	1.1E-10	1.1E-10
	Roof	2.3E-13	6.3E-13	1.4E-12	2.4E-12	2.4E-12	2.4E-12	2.4E-12	2.4E-12
	Grass/soil	1.3E-11	3.7E-11	8.5E-11	1.4E-10	1.5E-10	1.5E-10	1.5E-10	1.5E-10
	Trees	3.1E-12	8.3E-12	1.9E-11	3.1E-11	3.1E-11	3.1E-11	3.1E-11	3.1E-11
	Street	3.7E-11	9.7E-11	2.0E-10	2.8E-10	2.8E-10	2.8E-10	2.8E-10	2.8E-10

Table 4.2. Integrated external gamma dose contributions from ^{60}Co contamination on different surfaces in the environment. Integration periods range from 10 days to 70 years. 15 % of the time is assumed to be spent outdoors. Doses are given in Sv per 1 Bq m^{-2} deposited on each surface type, thus permitting scaling according to the actual level of contamination. Results are shown for four different area types, with different types of buildings, ranging from single storey detached houses with rather thin construction to multistorey houses with thick walls.

Area type	Surface	10 days	30 days	90 days	1 year	2 years	10 years	30 years	70 years
Single storey detached	Walls	2.3E-10	6.9E-10	2.0E-09	7.5E-09	1.4E-08	3.3E-08	3.6E-08	3.6E-08
	Roof	1.7E-10	4.9E-10	1.4E-09	5.1E-09	8.7E-09	1.6E-08	1.7E-08	1.7E-08
	Grass/soil	6.2E-10	1.8E-09	5.4E-09	2.0E-08	3.6E-08	8.7E-08	9.7E-08	9.7E-08
	Trees	1.3E-10	3.9E-10	1.1E-09	3.8E-09	6.2E-09	1.0E-08	1.0E-08	1.0E-08
Two storey semi-detached	Walls	8.5E-11	2.5E-10	7.5E-10	2.8E-09	5.0E-09	1.2E-08	1.3E-08	1.3E-08
	Roof	9.6E-11	2.9E-10	8.3E-10	3.0E-09	5.0E-09	9.4E-09	9.7E-09	9.7E-09
	Grass/soil	2.5E-10	7.4E-10	2.2E-09	8.1E-09	1.5E-08	3.5E-08	3.9E-08	3.9E-08
	Trees	4.0E-11	1.2E-10	3.4E-10	1.2E-09	1.9E-09	3.1E-09	3.1E-09	3.1E-09
Rows of two storey terrace houses	Walls	6.0E-11	1.8E-10	5.3E-10	2.0E-09	3.5E-09	8.5E-09	9.5E-09	9.5E-09
	Roof	7.7E-11	2.3E-10	6.6E-10	2.4E-09	4.0E-09	7.5E-09	7.7E-09	7.7E-09
	Grass/soil	1.3E-10	3.9E-10	1.2E-09	4.3E-09	7.7E-09	1.9E-08	2.1E-08	2.1E-08
	Trees	3.3E-11	9.8E-11	2.8E-10	9.7E-10	1.6E-09	2.5E-09	2.5E-09	2.5E-09
	Street	5.5E-11	1.6E-10	4.1E-10	9.3E-10	1.1E-09	1.1E-09	1.1E-09	1.1E-09
Multistorey blocks of flats (5 stories)	Walls	3.4E-11	1.0E-10	3.0E-10	1.1E-09	2.0E-09	4.9E-09	5.4E-09	5.4E-09
	Roof	6.6E-12	2.0E-11	5.7E-11	2.0E-10	3.4E-10	6.4E-10	6.6E-10	6.6E-10
	Grass/soil	3.7E-11	1.1E-10	3.2E-10	1.2E-09	2.2E-09	5.2E-09	5.8E-09	5.8E-09
	Trees	9.8E-12	2.9E-11	8.4E-11	2.9E-10	4.6E-10	7.5E-10	7.5E-10	7.5E-10
	Street	6.9E-11	2.0E-10	5.1E-10	1.2E-09	1.4E-09	1.4E-09	1.4E-09	1.4E-09

Table 4.3. Integrated external gamma dose contributions from ^{137}Cs contamination on different surfaces in the environment. Integration periods range from 10 days to 70 years. 15 % of the time is assumed to be spent outdoors. Doses are given in Sv per 1 Bq m^{-2} deposited on each surface type, thus permitting scaling according to the actual level of contamination. Results are shown for four different area types, with different types of buildings, ranging from single storey detached houses with rather thin construction to multistorey houses with thick walls.

Area type	Surface	10 days	30 days	90 days	1 year	2 years	10 years	30 years	70 years
Single storey detached	Walls	9.1E-11	2.7E-10	8.1E-10	3.1E-09	5.9E-09	1.9E-08	2.6E-08	2.7E-08
	Roof	6.3E-11	1.9E-10	5.5E-10	2.0E-09	3.6E-09	8.4E-09	9.1E-09	9.1E-09
	Grass/soil	2.3E-10	6.8E-10	2.0E-09	8.0E-09	1.6E-08	6.0E-08	1.1E-07	1.2E-07
	Trees	5.0E-11	1.5E-10	4.3E-10	1.5E-09	2.6E-09	4.8E-09	5.0E-09	5.0E-09
Two storey semi-detached	Walls	2.3E-11	6.9E-11	2.0E-10	7.9E-10	1.5E-09	4.8E-09	6.7E-09	6.9E-09
	Roof	4.3E-11	1.3E-10	3.7E-10	1.4E-09	2.4E-09	5.7E-09	6.1E-09	6.1E-09
	Grass/soil	8.4E-11	2.5E-10	7.5E-10	3.0E-09	5.8E-09	2.2E-08	3.9E-08	4.4E-08
	Trees	1.3E-11	4.0E-11	1.2E-10	4.1E-10	7.0E-10	1.3E-09	1.3E-09	1.3E-09
Rows of two storey terrace houses	Walls	1.8E-11	5.5E-11	1.6E-10	6.3E-10	1.2E-09	3.9E-09	5.3E-09	5.5E-09
	Roof	2.5E-11	7.6E-11	2.2E-10	8.2E-10	1.5E-09	3.4E-09	3.7E-09	3.7E-09
	Grass/soil	5.1E-11	1.5E-10	4.5E-10	1.8E-09	3.5E-09	1.3E-08	2.3E-08	2.7E-08
	Trees	1.2E-11	3.4E-11	1.0E-10	3.5E-10	6.0E-10	1.1E-09	1.1E-09	1.1E-09
	Street	2.1E-11	6.0E-11	1.6E-10	3.7E-10	4.3E-10	4.5E-10	4.5E-10	4.5E-10
Multistorey blocks of flats (5 stories)	Walls	1.2E-11	3.7E-11	1.1E-10	4.2E-10	7.9E-10	2.6E-09	3.6E-09	3.7E-09
	Roof	7.4E-13	2.2E-12	6.5E-12	2.4E-11	4.3E-11	9.8E-11	1.1E-10	1.1E-10
	Grass/soil	1.0E-11	3.0E-11	8.9E-11	3.5E-10	6.8E-10	2.6E-09	4.6E-09	5.2E-09
	Trees	3.3E-12	9.9E-12	2.9E-11	1.0E-10	1.7E-10	3.2E-10	3.3E-10	3.3E-10
	Street	2.8E-11	7.9E-11	2.1E-10	4.9E-10	5.7E-10	5.9E-10	5.9E-10	5.9E-10

Table 4.4. Integrated external gamma dose contributions from ^{134}Cs contamination on different surfaces in the environment. Integration periods range from 10 days to 70 years. 15 % of the time is assumed to be spent outdoors. Doses are given in Sv per 1 Bq m^{-2} deposited on each surface type, thus permitting scaling according to the actual level of contamination. Results are shown for four different area types, with different types of buildings, ranging from single storey detached houses with rather thin construction to multistorey houses with thick walls.

Area type	Surface	10 days	30 days	90 days	1 year	2 years	10 years	30 years	70 years
Single storey detached	Walls	2.3E-10	6.9E-10	2.0E-09	6.9E-09	1.1E-08	1.9E-08	1.9E-08	1.9E-08
	Roof	1.6E-10	4.8E-10	1.4E-09	4.5E-09	7.1E-09	1.0E-08	1.0E-08	1.0E-08
	Grass/soil	5.9E-10	1.7E-09	5.0E-09	1.7E-08	2.9E-08	4.8E-08	4.8E-08	4.8E-08
	Trees	1.3E-10	3.8E-10	1.1E-09	3.4E-09	5.2E-09	6.9E-09	6.9E-09	6.9E-09
Two storey semi-detached	Walls	5.9E-11	1.8E-10	5.1E-10	1.8E-09	2.9E-09	4.8E-09	4.9E-09	4.9E-09
	Roof	1.1E-10	3.2E-10	9.3E-10	3.1E-09	4.8E-09	7.0E-09	7.0E-09	7.0E-09
	Grass/soil	2.2E-10	6.4E-10	1.9E-09	6.4E-09	1.1E-08	1.8E-08	1.8E-08	1.8E-08
	Trees	3.5E-11	1.0E-10	2.9E-10	9.2E-10	1.4E-09	1.8E-09	1.8E-09	1.8E-09
Rows of two storey terrace houses	Walls	4.7E-11	1.4E-10	4.0E-10	1.4E-09	2.3E-09	3.8E-09	3.9E-09	3.9E-09
	Roof	6.6E-11	1.9E-10	5.5E-10	1.8E-09	2.9E-09	4.2E-09	4.2E-09	4.2E-09
	Grass/soil	1.3E-10	3.9E-10	1.1E-09	3.9E-09	6.4E-09	1.1E-08	1.1E-08	1.1E-08
	Trees	3.0E-11	8.7E-11	2.5E-10	7.9E-10	1.2E-09	1.6E-09	1.6E-09	1.6E-09
	Street	5.4E-11	1.5E-10	3.9E-10	8.5E-10	9.6E-10	9.7E-10	9.7E-10	9.7E-10
Multistorey blocks of flats (5 stories)	Walls	1.2E-11	3.6E-11	1.0E-10	3.6E-10	5.8E-10	9.8E-10	9.9E-10	9.9E-10
	Roof	1.9E-12	5.6E-12	1.6E-11	5.3E-11	8.3E-11	1.2E-10	1.2E-10	1.2E-10
	Grass/soil	2.6E-11	7.6E-11	2.2E-10	7.6E-10	1.3E-09	2.1E-09	2.1E-09	2.1E-09
	Trees	8.6E-12	2.5E-11	7.1E-11	2.3E-10	3.4E-10	4.6E-10	4.6E-10	4.6E-10
	Street	7.1E-11	2.0E-10	5.2E-10	1.1E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09

As local initial contamination levels would often be measured on a grassed reference surface, it may be convenient to express initial contamination levels on other surfaces as fractions of that on the reference surface. Table 4.5 shows the contamination levels of radiocaesium that were typically recorded on different types of outdoor surface immediately after the Chernobyl accident, relative to the levels deposited by respectively dry and wet deposition on short grass/soil. Values for trees are given per unit of garden area covered by the trees. Note that the dry deposition values should *not* be compared with the wet deposition values. Precipitation is generally very efficient in washing contaminants out of a plume, whereby wet deposition levels generally become much higher than dry deposition levels, assuming the same plume and locality. It should however be stressed that the factors given in Table 4.5 constitute a crude background material for evaluation of contamination levels on different outdoors surfaces, as various forms and intensities of precipitation would lead to differences in deposition, and also dry deposition to, e.g., snow covered pavings would be influenced by other mechanisms. Indoor deposition is treated separately (in Section 5.3), as it can not be directly linked to outdoor deposition, due to the strong dependence on dwelling parameters.

Table 4.5. Relative source strengths on different types of outdoor urban surface immediately after a deposition of ^{137}Cs with or without precipitation (Bq m^{-2} on surface per Bq m^{-2}on grassed reference surface). Averages over observations in different European countries after the Chernobyl accident. Note that levels for trees are given per unit projected garden area covered by the tree.

Surface type	Rel. dry deposition	Rel. wet deposition
Short grass and soil	1.0	1.0
Walls	0.1	0.01
Roof	1.0	0.4
Trees	3.0	0.1
Street	0.4	0.5

Other airborne particulate contaminants of about same aerosol size would be expected to distribute similarly. It is difficult to say anything in general about the aerosol sizes that would result from a malicious dispersion incident, as this could occur in many ways (e.g., explosion, nebulisation).

The values in Table 4.5 for instance show that if a dry deposition of 1 MBq per m^2 of ^{137}Cs has been measured on a shortcut lawn, the ^{137}Cs contamination level on a wall in the same area would be expected to be about 0.1 MBq per m^2, whereas the contamination level on a tree would be 3 MBq per m^2 soil area covered by the tree. Table 4.6 shows estimates of the doses that would be received in the four environments, over different periods, from a contamination that resulted in an initial contamination level of 1 Bq m^{-2} on the (grassed) reference ground surface and relative contamination levels on other surfaces as given by the figures in Table 4.5.

Table 4.6. Integrated external gamma dose contributions from respectively ^{192}Ir, ^{60}Co, ^{137}Cs and ^{134}Cs contamination on different surfaces in the environment. Integration periods range from 10 days to 70 years. Doses are given in Sv per 1 Bq m^{-2} deposited on the reference surface (a cut lawn). Results are shown for four different area types, with different types of buildings, ranging from single storey detached houses with rather thin construction to multistorey houses with thick walls. 15 % of the time is assumed to be spent outdoors.

Nuclide	Area	Mode	10 days	30 days	90 days	1 year	2 years	10 years	30 years	70 years
^{192}Ir	Single storey	WET	2.0E-10	5.3E-10	1.2E-09	2.1E-09	2.1E-09	2.1E-09	2.1E-09	2.1E-09
		DRY	3.4E-10	9.2E-10	2.1E-09	3.5E-09	3.6E-09	3.6E-09	3.6E-09	3.6E-09
	Semi-detached	WET	7.6E-11	2.1E-10	4.8E-10	8.0E-10	8.3E-10	8.3E-10	8.3E-10	8.3E-10
		DRY	1.2E-10	3.4E-10	7.8E-10	1.3E-09	1.3E-09	1.3E-09	1.3E-09	1.3E-09
	Terrace houses	WET	5.7E-11	1.6E-10	3.5E-10	5.7E-10	5.8E-10	5.9E-10	5.9E-10	5.9E-10
		DRY	9.1E-11	2.5E-10	5.7E-10	9.2E-10	9.4E-10	9.4E-10	9.4E-10	9.4E-10
	Blocks of flats	WET	3.2E-11	8.6E-11	1.9E-10	2.9E-10	2.9E-10	2.9E-10	2.9E-10	2.9E-10
		DRY	3.9E-11	1.0E-10	2.3E-10	3.6E-10	3.7E-10	3.7E-10	3.7E-10	3.7E-10
^{60}Co	Single storey	WET	7.0E-10	2.1E-09	6.1E-09	2.3E-08	4.0E-08	9.5E-08	1.1E-07	1.1E-07
		DRY	1.2E-09	3.6E-09	1.0E-08	3.7E-08	6.5E-08	1.4E-07	1.5E-07	1.5E-07
	Semi-detached	WET	2.9E-10	8.7E-10	2.6E-09	9.5E-09	1.7E-08	4.0E-08	4.4E-08	4.4E-08
		DRY	4.7E-10	1.4E-09	4.1E-09	1.5E-08	2.6E-08	5.5E-08	5.9E-08	5.9E-08
	Terrace houses	WET	1.9E-10	5.7E-10	1.7E-09	5.8E-09	1.0E-08	2.3E-08	2.5E-08	2.5E-08
		DRY	3.4E-10	9.9E-10	2.9E-09	1.0E-08	1.7E-08	3.5E-08	3.8E-08	3.8E-08
	Blocks of flats	WET	7.5E-11	2.2E-10	6.1E-10	1.9E-09	3.0E-09	6.3E-09	6.9E-09	6.9E-09
		DRY	1.0E-10	3.1E-10	8.7E-10	2.8E-09	4.6E-09	9.2E-09	9.8E-09	9.8E-09
^{137}Cs	Single storey	WET	2.6E-10	7.7E-10	2.3E-09	9.0E-09	1.7E-08	6.4E-08	1.1E-07	1.2E-07
		DRY	4.5E-10	1.3E-09	4.0E-09	1.5E-08	2.8E-08	8.5E-08	1.3E-07	1.5E-07
	Semi-detached	WET	1.0E-10	3.1E-10	9.2E-10	3.6E-09	6.8E-09	2.5E-08	4.2E-08	4.7E-08
		DRY	1.7E-10	5.1E-10	1.5E-09	5.7E-09	1.0E-08	3.2E-08	5.0E-08	5.5E-08
	Terrace houses	WET	7.3E-11	2.2E-10	6.3E-10	2.3E-09	4.3E-09	1.5E-08	2.5E-08	2.8E-08
		DRY	1.2E-10	3.6E-10	1.1E-09	3.9E-09	7.0E-09	2.1E-08	3.1E-08	3.4E-08
	Blocks of flats	WET	2.5E-11	7.2E-11	2.0E-10	6.2E-10	1.0E-09	3.0E-09	5.0E-09	5.6E-09
		DRY	3.3E-11	9.7E-11	2.8E-10	9.2E-10	1.5E-09	4.2E-09	6.3E-09	6.9E-09
^{134}Cs	Single storey	WET	6.7E-10	2.0E-09	5.7E-09	2.0E-08	3.2E-08	5.3E-08	5.3E-08	5.3E-08
		DRY	1.2E-09	3.4E-09	9.8E-09	3.3E-08	5.2E-08	8.1E-08	8.1E-08	8.1E-08
	Semi-detached	WET	2.7E-10	7.9E-10	2.3E-09	7.8E-09	1.3E-08	2.1E-08	2.1E-08	2.1E-08
		DRY	4.4E-10	1.3E-09	3.7E-09	1.2E-08	2.0E-08	3.1E-08	3.1E-08	3.1E-08
	Terrace houses	WET	1.9E-10	5.5E-10	1.6E-09	5.1E-09	8.1E-09	1.3E-08	1.3E-08	1.3E-08
		DRY	3.1E-10	9.2E-10	2.6E-09	8.6E-09	1.3E-08	2.0E-08	2.0E-08	2.0E-08
	Blocks of flats	WET	6.3E-11	1.8E-10	4.9E-10	1.4E-09	2.0E-09	2.8E-09	2.9E-09	2.9E-09
		DRY	8.3E-11	2.4E-10	6.7E-10	2.0E-09	2.9E-09	4.2E-09	4.2E-09	4.2E-09

The figures in Table 4.6 can be used to directly estimate the dose implications of an airborne contamination resulting in a certain level of contamination on a grassed surface. For instance, if a wet contamination of 2 MBq m^{-2} of ^{192}Ir occurs to the grassed 'reference' surface in a single storey housing environment, the values in Table 4.6 suggest that the integrated dose received over the first year from this contamination would be of the order of 2 MBq m^{-2} * 2.1 10^{-9} Sv per Bq m^{-2} = 4.2 mSv. Due to the physical half-life of ^{192}Ir of only 74 days, doses received over longer periods will be negligible in comparison. Note that although the values given in the table for dry deposition are generally higher than those given for wet deposition, dry deposition will in a given area generally lead to much lower doses than will wet deposition, because the initial contamination levels from wet deposition will be much higher than those resulting from dry deposition.

Finally, it should be noted that over the first few months after a large nuclear power plant accident, important external gamma doses could be received from other, short-lived radionuclides – particularly ^{131}I and ^{103}Ru (Kelly, 1987). Table 4.7 shows a rough estimate of dose rates that would be received outdoors from contamination with these radionuclides on a large ground area. This data may be of importance in optimising restrictions of access to the area and protection of clean-up workers, who would spend much time outdoors.

Table 4.7. Estimates of outdoor dose rates [Sv h^{-1}] above a large ground area contaminated with 1 Bq m^{-2} of respectively ^{131}I and ^{103}Ru.

Radionuclide	10 days	30 days	90 days	1 year
^{131}I	3.0E-13	5.8E-14	2.1E-15	1.1E-22
^{103}Ru	8.7E-13	6.2E-13	2.2E-13	2.1E-15

The external beta dose contributions from strontium deposited on outdoor surfaces would in connection with a nuclear power plant accident be insignificant in comparison with the above external gamma doses. However, as strontium might well be a candidate for malicious dispersion, and resulting contamination levels could locally be very high, also this dose contribution needs consideration. Beta particles have short range in practically any material, so beta radiation from contaminated surfaces in the environment could only possibly have significance if the distance between the exposed person and the source is short (max. a few metres). Also, the energy of the emitted beta particles must be high, and there must be virtually no shielding material other than air between the person and the contaminated object. Even thin cotton clothing protects well against most types of beta radiation (ICRU, 1997). A highly conservative estimate of the dose rate to the skin from the high energy beta particles emitted from a uniform ^{90}Sr contamination on a ground surface would be of the order of *4 10^{-11} Sv h^{-1} per Bq m^{-2}* (Eckerman and Ryman, 1993). Doses to inner organs would be expected to be some 3 orders of magnitude lower, and thus most likely of very little significance (Eckerman and Ryman, 1993). A requirement to reach as high dose rates as this would be that the contamination lies on the very surface of the ground. If it is 1 cm down in soil, as would be expected shortly after an airborne contamination – particularly if it occurred in rain - the shielding effect is so great that the dose rate to the skin would be about 3 orders of magnitude lower. Contamination on impermeable surfaces may however give contributions to dose over longer periods of time. An example could be asphalted playgrounds for children. Although the natural decline in contamination on such surfaces is slower than that on trafficked roads, most of the contamination on these asphalt surfaces will however typically have been weathered away through natural processes within one year (Andersson, 2005a).

4.3. External doses from contamination on indoor surfaces

Only in locations with *dry* deposition of contaminants, the indoor contamination will contribute significantly to the dose because in locations with wet deposition, the dose contribution from the comparatively much higher levels of outdoor deposition will dominate.

Based on experimental work (Andersson et al., 2004), it is assumed that the natural removal process of contamination on interior walls as well as on the ceiling has a half-life in the region of 10 years for 1 µm particles and 3 years for 5 µm particles. Also on the basis of this work, the half-life of natural removal from the floor is assumed to be of the order of 0.5 years. Much shorter half-lives have been reported for Chernobyl contamination on a floor (Allott et al., 1994). However, it should be noted that the indoor contamination was here almost exclusively associated with large soil particles that had inadvertently been brought in from the garden. This latter contamination problem could in practice be eliminated by taking off shoes at entry.

Table 4.8 shows the results of calculations of the gamma doses that would be received from contamination on indoor surfaces over a lifetime by a person staying all the time in a contaminated 4m by 4m room with a ceiling height of 2.5 m (Andersson et al., 2004). Data are given per unit contamination on the outdoor grassed reference surface, for a number of potentially important radionuclides. In reality, a person would, as mentioned above, probably be indoors some 90 % of the time. As doses from indoor contamination to people staying *outdoors* would be of comparatively little importance, the doses in the table should thus be multiplied by a factor of about 0.9 to obtain an estimate for a person living in the contaminated area.

Table 4.8. Gamma dose conversion factors (total time-integrated dose) for the various contaminants and surfaces considered. Doses are given per unit of surface contamination on the outdoor grassed reference surface, as both indoor contamination levels are proportional to those outdoors, and measurements are most likely to have been made on the outdoor grassed reference surface. Dose conversion factors are given separately for walls, floor and ceiling, as the specific technologies that would be applied for forced decontamination of these would often differ (see Appendix A), and be carried out at different times and frequencies.

Radionuclide	Dose conversion factor (walls) [Sv per Bq m^{-2}]	Dose conversion factor (floor) [Sv per Bq m^{-2}]	Dose conversion factor (ceiling) [Sv per Bq m^{-2}]
Sr-90	0	0	0
Zr-95	1.2 E-08	2.8 E-08	3.2 E-09
Mo-99	3.0 E-12	1.6 E-11	4.7 E-13
Ru-103	1.7 E-10	6.4 E-10	2.3 E-11
Ru-106	5.6 E-10	9.4 E-10	7.5 E-11
I-131*	5.1 E-10	3.6 E-10	2.8 E-10
Te-132	6.0 E-12	2.8 E-11	8.4 E-13
Cs-134	7.2 E-09	7.8 E-09	9.7 E-10
Cs-137	1.4 E-08	4.2 E-09	1.9 E-09
Ba-140	4.9 E-10	1.3 E-09	1.3 E-10
Ce-141	6.7 E-10	1.6 E-09	1.7 E-10
Ce-144	1.6 E-09	2.2 E-09	4.1 E-10

* Elemental iodine

For instance, if a person is staying permanently in an area with a 2 MBq m^{-2} contamination level of ^{137}Cs on grassed reference surfaces, that person will be likely to receive a time-integrated dose contribution from contamination on the floors in buildings of 0.9 * 4.2 10^{-9} Sv per Bq m^{-2} * 2 MBq m^{-2} = 7.6 mSv.

It has been measured that the total deposition in a furnished room may be higher than that to the same room without furniture, by a factor of about 1.3-2 (Lange, 1995). However, the furniture will also constitute elements that will shield against contamination on other surfaces in the indoor environment. It has been demonstrated (Andersson et al., 2004) that even the most vigorous physical impact can only be expected to lead to resuspension in the air of a very limited fraction of the contamination initially deposited indoors. The resulting redistribution of contaminants on the various indoor surfaces will thus have little significance for the external dose contributions from these surfaces.

Beta doses from indoor surfaces might have significance in connection with, e.g., a ^{90}Sr contamination. Crucial factors in this context would be the shielding and distance between the source and exposed person. Over a given period of time, migration of contaminants into indoor surfaces (e.g., furniture) could well result in less shielding than would for instance migration into soil. The closest contact between sources and exposed persons would be in situations where persons are sitting or lying on contaminated surfaces. In such cases, the beta doses can be compared with the corresponding contributions from the same source density deposited directly on human skin/clothing (see section 4.3). The natural removal half-life of contamination on skin is generally much shorter than that on most building interior surfaces. On the other hand, initial contamination levels on for instance indoor walls would be much lower than those to human skin (Andersson et al., 2004). As even thin fabric offers some protection against beta radiation, the most critical situations would be those where unshielded skin comes into direct or close contact with a contaminated surface. This is for instance the case at night, when part of the body is in direct contact with a possibly contaminated bed surface for hours. However, ordinary machine washing is efficient in removing contaminants from clothing (Andersson et al., 2002), so if bed sheets are washed regularly, these doses would be limited to a short period after the contamination took place. On the background of current state-of-the-art knowledge, it can not be ruled out that frequent use of chairs or sofas, if contaminated, may give a beta dose that is significant. It is recommended that this be investigated further.

4.4. Doses from contamination on humans

Contaminated aerosols will also dry deposit directly on humans in the affected areas. If the contaminants are of outdoor origin, indoor air concentrations of contaminants will often be lower than outdoor air concentrations, particularly if air ducts in the dwelling are closed off when outdoor air concentrations are high.

Gamma radiation emitted by radionuclides deposited on the human body will contribute to the effective dose to the exposed persons. Beta particles have short range in human tissue, and even high energy beta radiation will generally lead to negligible doses at a depth of one centimetre (Cross et al., 1992). However, most beta particles can penetrate into the basal layer of the epidermis, where proliferating cells in the skin are mostly located. As the energy of the beta particles is transferred to a thin layer of tissue, local doses can be very high. The result is an increased risk of skin cancer. The risk of skin cancer mortality is according to ICRP (1991) estimated to be 2 10^{-4}

Sv^{-1}, whereas the skin morbidity risk is 9.8 10^{-2} Sv^{-1}. Deterministic health effects on the skin will only occur at beta doses exceeding ca. 15 Sv. The depth at which the proliferating cells are located can vary somewhat, for instance according to body sites. In an investigation it has been found to be 50 ± 22 µm on the face, but 85 ± 26 µm on the back of hands (ICRP, 1992). Recognising that adverse effects may arise in deeper layers, the ICRU recommends that doses to skin be determined at a depth of 70 µm (ICRU, 1997). The calculations of Rohloff and Heinzelmann (1996) clearly show that the dose rate contributions to the basal layer of the skin epidermis from gamma radiation are generally not significant compared with the contributions from associated beta radiation. Alpha particles emitted from contaminants deposited on skin have too short range in human tissue to penetrate the stratum corneum layer of dead cells.

Clearance by natural removal processes of particulate skin contamination is strongly dependent on the size of the contaminating particles. Particles greater than ca. 10 µm would largely be removed from the skin surface over a period of only few hours. However, small particles in the 1 µm range would lodge in skin cavities (e.g., hair follicles), and can be difficult to get rid of without very thorough washing/scrubbing. The size of the contaminant particle thus has an important bearing on dose.

Contaminants of different physical and chemical characteristics would result from different types of contaminating incidents. Table 4.9 shows estimates of skin beta doses that would be received over various periods per unit of contamination of some radionuclides that would be likely to contribute particularly much to dose after a major nuclear reactor accident. Based on observations made after the Chernobyl accident, it was assumed that all the selected radionuclides were associated with small particles in the 1 µm range. Also elemental iodine gas has been included in this table, since it deposits very strongly on surfaces. As can be seen, even a thin layer of clothing protects the skin well. It was assumed in these calculations that the small contaminants to some extent remain on the skin until the surface layer of dead skin cells has shed over a period of ca. 2 weeks (Hession et al., 2006). Contaminated clothes are assumed to be washed at intervals of 2 days (Andersson et al, 2002).

For instance, if a person receives a contamination on skin of 100 Bq cm^{-2} ^{137}Cs, that person will over the first two days receive a beta dose to the freely exposed skin of 7.5 10^{-5} Sv per Bq cm^{-2} * 100 Bq cm^{-2} = 7.5 mSv.

Table 4.10 shows the corresponding skin beta doses from deposition of 5µm particles carrying a number of contaminants that may be of importance in connection with various other types of incidents. Particles of this size would for instance be likely to play a key role in connection with a conventional bomb explosion dispersing radioactive matter (Stradling et al., 1998; Eriksson, 2002). Larger particles would also be released from this type of incident, but would for instance to a much lesser extent be able to penetrate into buildings (Andersson, 2005a). Also, the natural clearance half-life of particles in the size range of tens of µm would be likely to be exceedingly short. A survey has been conducted of published values of AMAD's of radioactive aerosols measured in working environments (Dorrian & Bailey, 1995). The results covered 52 publications and included a wide variety of industries and other work places. The results were found to be well fitted by a log-normal distribution with a median value of 4.4 µm, supporting the choice of the ICRP Task Group on Human Respiratory Tract Models of a 5 µm default AMAD for occupational exposure.

Tables 4.11 and 4.12 show the corresponding effective doses from gamma radiation from the same contaminants.

Based on available data, amounts of contaminants that could be transported through the skin and into the body would in general be considered to be very low, although some studies have reported penetration of trace amounts (Andersson et al., 2004).

In connection with a contaminating incident, radionuclides could also be lodged on the skin as a result of the skin touching a contaminated surface (contact transfer). It has been demonstrated that if the contamination was airborne, doses from contact transfer from environmental surfaces would generally be small compared to doses from direct skin contamination during the passage of the contaminated plume (Andersson et al., 2004). However, skin contamination may be highly important in other scenarios, such as handling/spilling of open sources or decommissioning. It could also be worth considering in connection with work at repositories for highly concentrated waste from countermeasure implementation.

It should also be noted that beta radiation from contaminants deposited on the human eye can lead to opacity of the lens or capsule of the eye, causing impairment of vision or blindness. Representative conversion factors from eye contamination level to doses to the lens of the eye range from about $2\ 10^{-2}$ nGy per beta particle emitted per cm^2 for 0.1 MeV beta particles to some $4\ 10^{-1}$ nGy per beta particle emitted per cm^2 for 2 MeV beta particles (ICRP, 1996). Linear interpolation is allowable between these values. The dose to the eye lens from beta particles emitted with a specific energy from a specific radionuclide can be calculated from the equation: D [nGy] = C [nGy per beta particle cm^{-2}] * f * d [Bq cm^{-2}] * t [s], where C is the conversion factor, f is the number of beta particles emitted by the radionuclide per disintegration, d is the contaminant concentration on the eye, and t is the amount of time that the contaminants are on average present on the eye (taking into account also reduction in concentration through radioactive decay). The concentration of particle contaminants on the eye can be calculated from knowledge of the time-integrated air concentration (C_t) over the period of exposure: d [Bq cm^{-2}] = C_t [Bq s cm^{-3}] * V_d [cm s^{-1}]. A probably conservative estimate of V_d is ca. $3\ 10^{-2}$ cm s^{-1} for 1 µm particles and $2\ 10^{-1}$ cm s^{-1} for 20 µm particles (Gudmundsson et al., 1997).

It should be mentioned that the dose limit for the public for exposure of the eye is 15 mSv annually, whereas it is for skin 50 mSv, signalling a difference in the sensitivity of these organs to radiation.

Table 4.9. Estimates of skin beta dose [Sv] from 1 Bq cm^{-2} deposited on human skin and clothing of various selected radionuclides originating from a large reactor accident. Doses received over respectively 2 days and 2 weeks following contamination of skin / clothing.

Radionuclide	Skin dose (2 weeks) freely exposed skin	Skin dose (2 days) freely exposed skin	Skin dose (2 weeks) covered skin$^{1)}$	Skin dose (2 days) covered skin$^{1)}$
Ru-103	1.6E-04	2.8E-05	3.2E-05	1.1E-06
Ru-106/Rh-106	5.2E-04	8.6E-05	1.5E-04	5.0E-05
I-131 elem.	2.4E-04	5.9E-05	1.4E-05	1.4E-05
I-131 aerosol	2.4E-04	5.9E-05	2.7E-05	1.1E-05
Te-132	8.8E-05	3.5E-05	4.0E-07	2.2E-07
Cs-134	3.1E-04	5.1E-05	3.2E-05	1.1E-05
Cs-137/Ba-137m	4.6E-04	7.5E-05	4.8E-05	1.6E-05

1) The skin is here assumed to be covered by a thin layer of cotton, corresponding to a T-shirt. If a part of the body is covered by thick clothes, the dose to the skin from contamination on that part of the body can be considered to be negligible compared with the above.

Table 4.10. Estimates of skin beta dose [Sv] from 1 Bq cm^{-2} deposited on skin or clothing of various radionuclides originating from a contamination event involving radioactive 5 µm aerosol. Doses received over respectively 2 days and 2 weeks following contamination of skin / clothing.

Radionuclide	Skin dose (2 weeks) freely exposed skin	Skin dose (2 days) freely exposed skin	Skin dose (2 weeks) covered skin$^{1)}$	Skin dose (2 days) covered skin$^{1)}$
P-32	9.4E-06	9.4E-06	1.0E-05	1.0E-05
Co-60	5.8E-06	5.8E-06	2.7E-06	2.7E-06
Sr-90	8.2E-06	8.2E-06	3.5E-06	3.4E-06
I-131	7.4E-06	7.4E-06	3.0E-06	3.0E-06
Cs-137/Ba-137m	8.9E-06	8.9E-06	4.0E-06	4.0E-06
Ir-192	8.2E-06	8.2E-06	3.2E-06	3.1E-06
Ra-226	No beta dose	No beta dose	No beta dose	No beta dose
Am-241	No beta dose	No beta dose	No beta dose	No beta dose

1) The skin is here assumed to be covered by a thin layer of cotton, corresponding to a T-shirt. If a part of the body is covered by thick clothes, the dose to the skin from contamination on that part of the body can be considered to be negligible compared with the above.

Table 4.11. Estimates of contributions to effective dose [Sv] from 1 Bq cm^{-2} deposited on human skin and from 1 Bq cm^{-2} on clothing of various selected radionuclides originating from a reactor accident. Doses received over respectively 2 days and 2 weeks following contamination of skin / clothing.

Radionuclide	Effective dose (2 weeks) from skin contam.$^{2)}$	Effective dose (2 days) from skin contam.$^{2)}$	Effective dose (2weeks) from clothing contam.$^{2)}$	Effective dose (2 days) from clothing contam.$^{2)}$
Ru-103	3.8E-07	6.9E-08	9.7E-07	3.4E-07
Ru-106/Rh-106	1.6E-07	2.6E-08	3.8E-07	1.3E-07
I-131 elem.	2.0E-07	5.0E-08	2.9E-07	2.9E-07
I-131 aerosol	2.0E-07	5.0E-08	5.8E-07	2.5E-07
Te-132	5.9E-08	2.3E-08	2.1E-07	1.1E-07
Cs-134	1.1E-06	1.8E-07	2.7E-06	8.9E-07
Cs-137/Ba-137m	5.0E-07	8.2E-08	1.2E-06	4.0E-07

2) A total of 15 % of the skin was assumed to be freely exposed to contamination, whereas the rest was assumed to be covered by clothing.

Table 4.12. Estimates of contributions to effective dose [Sv] from 1 Bq cm^{-2} deposited on skin and from 1 Bq cm^{-2} on clothing of various radionuclides originating from a contamination event involving radioactive 5 µm aerosol. Doses received over respectively 2 days and 2 weeks following contamination of skin / clothing.

Radionuclide	Effective dose (2 weeks) from skin contam.$^{2)}$	Effective dose (2 days) from skin contam.$^{2)}$	Effective dose (2weeks) from clothing contam.$^{2)}$	Effective dose (2 days) from clothing contam.$^{2)}$
P-32	No gamma dose	No gamma dose	No gamma dose	No gamma dose
Co-60	4.3E-08	4.3E-08	4.5E-07	4.5E-07
Sr-90	No gamma dose	No gamma dose	No gamma dose	No gamma dose
I-131	6.3E-09	6.3E-09	6.6E-08	6.6E-08
Cs-137/Ba-137m	9.7E-09	9.7E-09	1.0E-07	1.0E-07
Ir-192	1.1E-08	1.1E-08	1.2E-07	1.2E-07
Ra-226	1.3E-10	1.3E-10	1.4E-09	1.4E-09
Am-241	3.4E-10	3.4E-10	3.6E-09	3.6E-09

2) A total of 15 % of the skin was assumed to be freely exposed to contamination, whereas the rest was assumed to be covered by clothing.

4.5. Doses from inhalation of resuspended contaminants

Inhalation doses may also be received after the passage of the contaminate plume, due to inhalation of contaminant particles resuspended in the air. Doses from inhalation of resuspended contaminants would greatly depend on the processes leading to the resuspension. Also, for instance dust concentrations on surfaces, dust particle sizes, mechanical disturbances (e.g., by heavy traffic) and weather conditions will influence how large a fraction of the deposited contamination will be resuspended. Resuspension factors (ratio of aerosol concentration in air at a relevant reference height above a surface to the aerosol particle loading per unit area of the surface) have been reported to vary by many orders of magnitude for particles deposited in inhabited areas (Sehmel, 1980). After the Chernobyl accident, the resuspension factor due to wind and weather on open soil areas was generally found to decrease by about a factor of 2 over the first 2 days, and something of the order of a factor of 10 over the first 10 days following the deposition. Since variation is thus obviously considerable from case to case, and depending on time, these dose contributions should be evaluated by experts taking into account the relevant factors for the given case. Generic dose conversion factors for resuspension in inhabited areas (e.g., as reported by Walsh, 2002 - see Table 5.13) should be used with great caution. Indicative, rough (probably highly conservative) dose estimates can be made for a number of radionuclides using Table 4.13 and the formula:

D [Sv] = Committed integrated effective dose from inhalation [Sv per Bq m^{-2} on the ground] * Ground contamination level [Bq m^{-2}].

It should be noted that particles greater than about 10 µm are rapidly cleared from the human respiratory tract through a natural process and will thus not lead to significant inhalation doses (ICRP, 1995). Also, most dwellings would provide a significant protective effect against contaminant particles of outdoor origin (e.g., through filtration), again depending on particle sizes. All this would make the values in Table 4.13 even more conservative, particularly if the incident involves a ‘dirty bomb’, which could lead to dispersion of large particles, depending on the exact construction. Resuspension from indoor contaminated surfaces is generally negligible, compared with resuspension from outdoor contaminated surfaces.

Table 4.13. Assumed integrated committed effective doses from inhalation [Sv per Bq m^{-2} on the ground]assuming lung type S (according to ICRP, 1995) and an inhalation rate of 2.3 10^{-4} m^3 s^{-1}(for adults) and 1.8 10^{-4} m^3 s^{-1} (for children) .

Adults	^{239}Pu	^{241}Am	^{137}Cs	^{106}Ru	^{103}Ru	^{244}Cm
1 day	3,8E-10	3,8E-10	9,3E-13	1,6E-12	7,2E-14	3,1E-10
10 days	1,3E-09	1,3E-09	3,1E-12	5,2E-12	2,3E-13	1,0E-09
30 days	1,7E-09	1,7E-09	4,1E-12	6,9E-12	2,8E-13	1,4E-09
90 days	2,1E-09	2,1E-09	5,1E-12	8,4E-12	3,1E-13	1,7E-09
1 year	2,6E-09	2,6E-09	6,4E-12	9,9E-12	3,2E-13	2,1E-09
2 years	2,9E-09	2,9E-09	7,0E-12	1,0E-11	3,2E-13	2,3E-09
10 years	3,5E-09	3,5E-09	8,4E-12	1,1E-11	3,2E-13	2,7E-09
Children	^{239}Pu	^{241}Am	^{137}Cs	^{106}Ru	^{103}Ru	^{244}Cm
1 day	3,6E-10	3,6E-10	9,0E-13	1,7E-12	7,8E-14	3,2E-10
10 days	1,2E-09	1,2E-09	3,0E-12	5,6E-12	2,5E-13	1,0E-09
30 days	1,6E-09	1,6E-09	4,0E-12	7,4E-12	3,1E-13	1,4E-09
90 days	2,0E-09	2,0E-09	4,9E-12	9,1E-12	3,4E-13	1,7E-09
1 year	2,5E-09	2,5E-09	6,2E-12	1,1E-11	3,5E-13	2,2E-09
2 years	2,7E-09	2,7E-09	6,8E-12	1,1E-11	3,5E-13	2,4E-09
10 years	3,3E-09	3,3E-09	8,1E-12	1,1E-11	3,5E-13	2,8E-09

4.6. Additional doses to clean-up workers

If the dose rate is in the early phase of a contaminating incident dominated by short-lived radionuclides, workers implementing countermeasures in the short term (some countermeasures greatly influencing long-term doses need to be implemented within short time to be effective; see Appendix A) may receive comparatively high doses. These doses should be taken into account in the decision of the optimal countermeasure strategy. However, if the initial contamination level is such that cleaning could permit humans to subsequently stay permanently in the area, the doses received by workers over the comparatively short cleaning period would in general be low compared to doses received over longer times by inhabitants of the cleaned area. In general, workers in a contaminated area will be subjected to the same dose pathways as will the inhabitants in that area. However, as much of the countermeasure work would be conducted outdoors, the clean-up workers are likely to be less protected by the shielding effect of dwellings than is the average inhabitant of the area. Simply because of the extra time spent outdoors, it would typically be expected that the external dose rate to workers would in the cleaning period exceed that to inhabitants by about a factor of 2-3 (Andersson et al., 2003), and due to the limited duration of the cleaning period be of little significance.

It should be noted that some countermeasures, such as vacuum sweeping of streets and mowing of lawns, generate waste with high specific activity. This means that for instance operators of lawn mowers and vacuum sweepers equipped with waste collection vessels can receive rather relatively doses over short periods of time. These problems can be reduced, e.g., by reducing the individual operator time or inserting a metal shielding between the operator and the waste vessel. For instance, an operator of a vacuum sweeper, a seated lawn-mower or a waste transport truck would over one hour receive a dose of some 50 µSv, if the waste in the vessel of the vehicle is collected from an area with a ^{137}Cs contamination level of 1 MBq m^{-2}. This is about the same external dose as an average inhabitant in the area would receive over 4 days (Andersson, 1996). This type of problems would be likely also to arise in connection with waste management at repositories, where it may well be more difficult to achieve a shielding effect to protect workers.

By the time where the countermeasures suggested in this handbook could be considered for implementation, worker doses from resuspension of contaminants would be unlikely to constitute a significant problem. It has been found after the Chernobyl accident that contaminant resuspension is reduced proportionally with t^{-1}, where t is time in days after the initial deposition. Naturally, methods like ploughing could generate much dust, but the resuspended soil dust particles, to which contaminants would be attached, would be so large that they would be rapidly cleared from the respiratory tract by ciliary action (ICRP, 1993).

Contamination on the human body can result in beta doses to the skin and gamma doses to the body (see section 4.4). Workers in areas with elevated airborne contaminant concentrations should be instructed to wear protective clothing, change/wash the clothes regularly and wash any freely exposed skin thoroughly and regularly.

5. Doses and countermeasures for kitchen gardens

Countermeasures in kitchen garden can be more important in some situations than in other- if there is not sufficient food available in the market. Another situation is when people do not trust the authority and the market to have safe food with low concentration of radionuclides (Bq). In this situation the production in kitchen garden will probable increase. People will also in this situation have possibility to measure crops from the gardens in their neighbourhood in the municipality.

5.1. Kitchen gardening in Sweden

Gardening is one of the most common leisure activities in the country. There are ca 2.5 million gardens in Sweden distributed between houses, summer houses and allotments. The total cultivatable area is estimated to ca 266 000 hectares, Table 5.1.

In Sweden ca 44% of adults say that they are very interested in gardening. There is a clear connection between an interest in gardening and the type of housing: the more people who live in detached houses, both large and small, the greater the interest in gardening. Men and women usually garden to the same extent. But women are more likely to look after growing plants. Approximately 70% of children under 16 have access to a garden where they live. Whereas gardening has increased in recent decades, interest from society as a whole has decreased because gardening contributes less to the economy and food supply than it used to. Nevertheless, kitchen gardening provides a reserve capacity for food supply in times of emergency.

Table 5.1. Types of cultivation and area of the most important cultivation units for kitchen gardening in 2000.

Type of cultivation	Houses/allotments in 2000	Total garden area, ha, estimated/potential	Cultivated area per house, m^2 estimated
Detached house	1 280 000	165 000	800
Terraced house	255 000	5 100	150
Summer house	683 000	95 400	200
Allotment	42 000	1 125	250
Farm cottage	245 000	49 500	1 000
Total for the country	2 505 000	316 125	-

Source: Björkman (2001)

The total area suitable for kitchen gardening in Sweden is estimated to 316,125 hectares. Approximately 200,000 hectares of this is in the countryside and the remainder (ca 100,000 hectares) in urban areas.

5.1.1. What is grown in Sweden?

In most gardens there is a small kitchen garden, as well as fruit trees and berry bushes. Common products are apples, potatoes, carrots, onions, lettuce and dill. Table 5.2 shows that each household consumes 57 kg home-grown vegetables. In terms of value, total home production makes up approximately 11% of households' consumption of these products. This corresponded to about 2.73 million SEK in 1996.

Potatoes are the main product with 25 kg produced per household per year. For the whole country this corresponds to 93 million kg (Mkg) potatoes. Vegetable production is calculated to 30 million kg and fruit and berry production to 80 million kg for the whole country. There is also a great interest in cultivating flowers and decorative plants and establishing lawns in our gardens.

Table 5.2. Households' consumption of home-grown products in 1996. (Home-grown products are potatoes, white cabbage, lettuce, cucumber, tomatoes, onions, leeks, carrots, apples, pears, strawberries, raspberries, currants, plums, fruit syrups and sauces. The number of households in Sweden in 1986 were ca 3 686 000).

Crop/product	Kg/household 1996	Total Mkg 1996
Potatoes	25.0	92.4
Carrots and onions	4.6	16.8
Apples	6.8	25.2
Berries	5.1	18.9
Fruit syrups and sauces	10.3	37.8
Other products	5.1	18.9
Total	57	209.5

M = million. Source: Statistics Sweden expenditure barometer (*utgiftsbarometern)* 1996

5.1.2. Can a kitchen garden produce all the food you need?

Research has been done at the Swedish University of Agricultural Sciences in Uppsala (Ekhaga experimental farm, Ullmark, 1999) into how large an area is needed to produce enough vegetables to feed one person for an entire year. An area the size of a normal garden is sufficient to supply a year's requirement of food for one person. Potatoes, wheat, sunflower seeds, broccoli, carrots, turnips, chard, beans and other vegetables grown on ca 800 m^2 provide a balanced diet, Table 5.3. It is important that cultivation is carefully planned so that none of the harvest is wasted. The most intensive period is during sowing in spring and harvesting in autumn. Out of the total time involved over the growing season, ca one third is spent on tending the growing crops, a third on harvesting and a third on taking care of the harvested products.

Table 5.3. Total harvest from the experiment at Ekhaga farm and the dietary requirements for one person with a vegetarian diet.

Crop/product	Harvest 1998 Kg/1000m^2	Harvest 1999 Kg/1000m^2	Requirement/person year and kg
Root vegetables and onions	290	1 000	240
Cabbages	84	133	30
Leafy vegetables	92	266	6
Courgettes, tomatoes	10	200	21 (tomatoes)
Cereals (flour)	-*	3	180
Oil plants (seeds for fats)	-*	17	32
Peas and beans	10	20	30
Fruit and berries	-*	-*	200

*no harvest. Source: *SLU Forskning 75*, 1999, Ullmark.

Kitchen gardening plays a significant role in food production in many countries and in many countries, particularly in Eastern Europe, it is crucial for food supply. In the event of a nuclear accident this could cause considerable problems with protection from radiation. Authorities should provide clear recommendations for the measures to be taken regarding cultivation in the case of radioactive fall-out.

Crops grown in the other Nordic countries of Finland and Norway are described in sections 5.2 and 5.3. Information from Denmark and Iceland was unavailable.

5.2. Kitchen gardening in Finland

In Finland 59 % of households have their own gardens, and 25 % of households use their gardens for growing vegetables and potatoes for household use according to an interview study made by Gallup Food and Farm Facts Ltd, in 2004. The number of households growing some products in their gardens was 1 140 000 in 2004. Summer houses are included in this number of gardens. The number and percentage of households growing different types of vegetables, apples, berries or potato are given in Table 5.4-5.6*.

Table 5.4. The number of households with gardens, growing different types of products in Finland

Product type	Number of households	Percentage of households, %
Bush berries	755 000	49
Apple	600 000	39
Strawberry	416 000	27
Lettuce	570 000	37
Herbs	460 000	30
Onion	460 000	30
Potato	460 000	30
Root vegetables	355 000	23
Tomato	308 000	20
Cucumber	185 000	12
Cabbage	108 000	7
Others	123 000	8
Total number of households	1 140 000	74

*Gallup Food and Farm Facts Ltd, Home Gardening, 2004

The mean area of gardens is 882 m^2, and the mean area used for growing vegetables and potato is 291 m^2. The mean size of the area used for growing vegetables and potato varied from 218 m^2 to 465 m^2 according to the house type.

Table 5.5. Areas of gardens in Finland.

Area of garden, m^2	Percentage of households	Area for vegetables and potato, m^2	Percentage of households
< 100	26	< 20	16
100 - 250	18	20 - 40	24
251 - 500	17	41 - 60	14
501 - 1000	20	61 - 80	1
1001 - 2000	11	81 - 100	14
> 2000	8	101 - 200	11
		201 - 500	11
		> 500	10
Mean: 882	100	*291*	100

*Gallup Food and Farm Facts Ltd, Home Gardening, 2004

Ten percent of households in metropolitan area grew vegetables in their gardens, in the countryside 46 %. The mean areas for growing vegetables were also smaller in the metropolitan area (53 m^2) than in the countryside (465 m^2).

Table 5.6. Gardens by residential areas in Finland.

Residential area	Proportion of house-holds with garden, %	Area of garden, m^2	Percentage of households growing vegetables and potato	Area for vegetables and potato, m^2
Metropolitan area	36	382	10	53
Urban area	52	641	17	195
Densely populated area	78	1057	37	207
Countryside	83	1301	46	465

*Gallup Food and Farm Facts Ltd, Home Gardening, 2004

5.3. Kitchen gardening in Norway

A Norwegian kitchen garden refers to what is grown in the gardens of detached houses, summer houses and allotments. Approximately one million households in Norway have the use of a kitchen garden. The total cultivated area in Norway is 115 000 ha with the possibility of cultivating a further 300 000 ha, see Table 5.7. The calculations show that although ca 60% of the Norwegian population has access to kitchen gardens not everyone makes use of them.

Table 5.7. Cultivated area in kitchen gardens and harvest in tons in 1979 in Norway.

Crop/Product	Area hectares	Number of trees and bushes	Total harvest in tons (net)
Potatoes	13 500		31 860
Vegetables (Carrots and cabbage)	94 100		124 035
Strawberries	4 700		3 410
Raspberries	3 050		1 618
Fruit trees		2 695 000	33 015
Berry bushes		4540 000	1 802
Total	115 350		

Source: NLV F-145, 1984

The Norwegian data are from the end of the 1970s and the beginning of the 1980s, so it can be assumed that the situation is somewhat different today. The area under cultivation ought to be larger in Norway if calculated in the same way as for Sweden and Finland.

5.4. Countermeasures for kitchen gardens

The principles for recommendations and application of countermeasures issued by the International Commission on Radiological Protection (ICRP) are valid for contaminated kitchen garden land.

Justification: Countermeasures should be introduced if they are expected to achieve more good than harm. Optimisation: The quantitative criteria used for the introduction and withdrawal of countermeasures should be such that benefit for the public is optimised.

Countermeasures can be implemented at different times of the year. It is possible to avoid radioactive contamination of kitchen garden plants in the very earliest phase of emergency, before the fallout has taken place. The more common situation, however, will be to reduce the contamination after the fallout event, during the fallout year and also later in the following years. If the fallout takes place in winter there is a longer time for preparation and choice of countermeasures than if the fallout comes just before the vegetation period. If the fallout takes place during the vegetation period the situation will be most serious.

5.4.1. Avoidance of contamination before deposition

The time for avoiding contamination of plants prior to radioactive fallout is often very short. It will be a question of some hours up to some days. One measure to implement as quickly as possible is to harvest plant products, which are ready for consumption. Another measure is to cover soil or plant products with plastic sheets. Also pathways and grass lawns could be covered with plastic sheets. If fallout comes as wet deposition with rain, it would be valuable to prepare so that the contaminated water is drained from the kitchen garden area.

5.4.2. Reduction of contamination after fallout

The choice of measures depends on the magnitude of the fallout, in what season of year it takes place and when the garden plant products are to be harvested. Sampling and determination of activity concentration in growing garden plants should be the first step. This will make it possible to decide if the plant products can be used for consumption or if they should be discarded as waste.

Discarded plant products should be removed from the kitchen garden. It may be necessary to arrange a temporary deposit in a place outside or in a corner of the garden area. This temporary deposit can be covered by dose-reducing material to reduce external radiation and leaching. Another measure that can be recommended is to remove the contaminated soil layer from the garden land. Removal of a 5-cm surface soil layer within an area of 100 m^2 corresponds to a volume of 5 m^3. It may also be necessary to remove contaminated gravel on the surface of pathways within a kitchen garden. If contaminated pathways and drives to houses consist of bitumen or are stone-covered, they could be hosed and brushed down with water, and the contaminated water drained from the garden area.

If the initial radioactive fallout is low enough to allow continued use of kitchen gardens, or if this has been achieved by removal of contaminated soil, it is still possible to reduce the soil-to-plant transfer of radioactivity by K-fertilization and by liming (Rosén, 1991). This may be of special importance for berry bushes. Wood ash containing fallout nuclides should not be used as fertilizer in kitchen gardens. When cultivating the garden land, nuclides are mixed into a larger soil volume. This will reduce the soil-to-plant transfer.

If the fallout is deposited with snow or on a snow layer in winter, it is advisable to remove the contaminated snow layer as soon as possible. In such a case the municipality should allocate a suitable deposit for contaminated snow. This countermeasure is described in Appendix A.

5.4.3. Blanching

There are a few measures that can be taken to reduce the content of caesium in vegetables grown in kitchen gardens. Generally vegetables should be boiled and the water thrown away (Andersson et al, 2000). This will eliminate some of the caesium and in some cases also strontium present in the vegetables. Experiments have shown that Cs-134 can be reduced by up to 33% and Sr-85 by up to 38%, see Table 5.8 (Bengtsson, 1992). If blanching is repeated a couple of times there is an improved effect. The method has also been tested for fungi with high caesium contents. Similar experiments on fungi have been done in Finland at the Radiation and Nuclear Safety Authority (STUK) by Kostianen (2005).

Table 5.8. Reduction of Cs-134 and Sr-85 in vegetables after blanching

Vegetables	Reduction % Cs-134	Reduction % Sr-85
Peas	33	38
French beans	26	6
Carrots	31	5
Potatoes	27	-
Wheat (cereal)	6	-
Oats (cereal)	8	-

Source: Bengtsson, 1992

5.4.4. Countermeasure datasheet material for kitchen gardens

Appendix B presents some detailed information in datasheet format for some countermeasures that are deemed to specifically be suited for treatment of contaminated kitchen garden areas and their products. The information is based on a previous Nordic review (Andersson et al., 2000). In addition, also some of the countermeasures described in Chapter 3 / Appendix A are suited for application to reduce contamination in kitchen garden products. These are:

- Pruning/felling of trees and bushes
- Top soil removal (manually)
- Triple digging of soil
- Snow removal from open areas

5.5. Transfer of radionuclides from the kitchen garden to man in Sweden

Dose coefficients for ingestion of radionuclides for (children and) adults will be used for calculation of yearly intake of different kitchen garden products for the Nordic countries.

The question is whether products from the kitchen garden can be a radiation problem. Normally limits for food products contaminated with radiocaesium from Chernobyl apply to products which are bought on the market. Food products obtained by hunting, fishing, picking berries and mushrooms are usually consumed by the hunters' and the fishermen's families, and in such cases there are no limits – it is up to those concerned to decide whether they are going to consume the product or not. The same applies to those who produce food in kitchen gardens. The production of vegetables in private gardens is presented in Table 5.2. As can be seen the most important products are potatoes with 25 kg per family. In the following discussion we concentrate on two products representing food products with tuber or roots (potatoes and root uptake) or leafy products (lettuce and direct deposition on leaves). Production from the kitchen garden shown in Table 5.2 is in mean values and, as also can be seen in Table 5.3, it is possible to produce all the food needed during one year in the kitchen garden of 800 m^2. This includes an annual production of 240 kg of potatoes and 6 kg of leafy vegetables. Obviously there is a need for relevant recommendations and information giving answers to many questions, such as what kind of countermeasure can be taken and how dangerous is it to eat the products.

In Table 5.9 and 5.10 we have assumed that the deposition of radionuclides occurs in spring and the uptake of radionuclides is by root uptake for the potatoes and by interception on leaves for lettuce. The discussion only deals with radiocaesium and a ground deposition of Cs-137 of 10 000 Bq per m^2, which is a fairly low ground deposition.

The results of countermeasures are rather difficult to assess due to the variation in soil properties in kitchen gardens. The calculations are based on a fairly high transfer factor and apply to sandy and peaty soils. Generally the nutrient status in kitchen gardens is rather good.

The first question to answer is if the contamination of food products in kitchen gardens is important from the radiation protection point of view. In Table 5.9 we show a calculation of possible activity concentrations of Cs-137 in lettuce where we assume that 30 % of the deposition will be intercepted by the lettuce leaves. We assume the same activity and concentration during the first month, and thereafter acceptable levels from the radiation protection point of view.

Table 5.9. Calculation of transfer of and dose from Cs-137 by lettuce

Ground deposition of Cs-137 is 10 000 Bq m^{-2} coming in spring.

Lettuce or other leafy vegetables.

The interception by lettuce leaves is 30 %.

Biomass 1 kg (fw) per m^{-2}.

0.3 x 10 000 = 3 000 Bq kg^{-1} f.w.

Consumption per person during one month is 0.5 kg (fw) and the intake during one month is 0.5 x 3 000 Bq per kg = 1 500 Bq.

Intake of 1 500 Bq of Cs-137 per person during the critical period (one month after fall- out).

In the acute phase, (with Cs-137 and Cs-134) intake of 40 000 Bq of Cs-137 corresponds to a radiation dose of 1 mSv.

Intake of 1 500 Bq corresponds to 1 500/40 000 mSv = 0.0375 mSv.

If we assume that the whole Swedish population is affected, the collective dose will be 0.0375 x 10^{-3} x 9 x 10^{6} = 337 person Sv to the Swedish population.

According to ICRP risk estimates this corresponds to 17 cases of radiation-induced lethal cancers in the 50 years after the fallout.

Table 5.10. Calculation of transfer of and dose from Cs-137 by potatoes

Ground deposition 10 000 Bq m^{-2}.

Potatoes (Root Uptake).

Transfer factor TF_g 2.5 x 10^{-3} kg m^{-2} (IAEA,1994).

2.5 x 10^{-3} 10 000 = 25 Bq kg^{-1}.

The annual consumption of kitchen-garden-produced potatoes is 25 kg per family (Table 2).

25 x 25 = 625 Bq intake of Cs-137 per family.

The annual consumption is 240 kg per person (Table 3).

25 x 240 = 6 100 Bq per person.

The first example 625 Bq corresponds to 0.015 mSv per family or 0.005 mSv per person. If we assume that the whole Swedish population is affected, the collective dose will be 0.005 x 10^{-3} x 9 x 10^{6} = 45 personSv to the Swedish population.

The second example 6 100 Bq corresponds to 6100/40 000 Bq or 0.15 mSv. In the second case (6 100 Bq) the collective dose will be 1 350 personSv.

Table 5.11. Calculation of an optimization of the radiation protection action.

The farmer will receive 2 SEK per kg of potatoes.

To reduce the dose by 1 mSv could cost 500 SEK.

The farmer must deliver 250 kg potatoes to receive 500 SEK.

Intake of 40 000 Bq in the acute phase corresponds to 1 mSv.

An acceptable annual dose from Cs-137 is supposed to be 1 mSv.

A relevant limit for Cs-137 is 40 000 / 250 = 160 Bq per kg.

6. Management of waste generated by countermeasures

As shown in the datasheets in Appendix A, a suite of 17 countermeasures for dose reduction in radioactively contaminated inhabited areas have been selected as the generally most appropriate and applicable for Nordic conditions. Some of these countermeasures generate radioactive waste, which should be optimally managed and disposed of. The following sections describe a number of techniques identified for this purpose.

The descriptions are given according to the type of waste generated, as this will determine the management routes. It should be noted that in the texts below it is in general assumed that permanent waste disposal would be required. However, there may be situations where the dose rate from the waste is to a great extent governed by contributions from short-lived radionuclides. In such cases it may be advantageous to first store the waste for some time in temporary repositories and postpone any labour-intensive handling, e.g., to transport, treat and dispose of waste in permanent repositories, as worker doses could then be substantially reduced. Also, at least some types of permanent repositories could take considerable time to construct, which would give a demand for simple, yet safe temporary storage facilities (vessels of suitable material and dimensioning for the particular purpose, given the specific activity and physicochemical properties of the waste).

6.1. Waste from decontamination of open (soil) areas

Topsoil removal procedures, including turf harvesting, can results in the generation of very large volumes of waste, which must be handled in a way that is cost-effective and safe. As mentioned above, current legal demands in the Nordic countries may restrict the applicability of the most cost-effective waste disposal strategies, even though the solutions would be considered safe.

To provide an adequate degree of safety, repositories must be constructed with a view to several potentially problematic aspects.

The waste deposit must thus be constructed in a way that prevents effectively against external radiation. Since the self-attenuation of radiation in soil is great, this problem can generally be overcome even with very simple repository designs. An example of this is the creation of simple, uncovered waste pile 'hills' in connection with a decontamination exercise in the Chernobyl-contaminated Novozybkov area in Russia in 1995 (Roed et al., 1996). The primary radionuclide of concern was here ^{137}Cs. It was found that the dose rate to a person standing on top of one of these hills containing contaminated topsoil removed from a vast area was only 15 % higher than that in the surrounding contaminated area. By covering the contamination with, e.g., a layer of uncontaminated soil excavated from deeper soil layers of the same area, this dose rate can be greatly reduced. Further, the formation of a 'hill' or bank of earth in the area will shield well against radiation from contamination far away.

The waste deposit must also be constructed in a way that prevents effectively against downward contaminant migration, e.g., to the groundwater. It should further be ensured that the site will not be exposed to flooding (e.g., close to a river), and that the area is not prone to earthquakes. Old gravel pits should not be exploited for this purpose, as they will often provide too little distance to the groundwater. Several simple and inexpensive designs may be envisaged to achieve the objective, depending on the characteristics of the primary contaminants. For instance, Junker et al. (1998) suggested a construction of a repository, where the dominant problem was a radiocaesium contamination. Here, it was firstly assessed at the location in question that there is a distance of at least 3 m to the groundwater level. The radioactive waste was then placed on top of a 30 cm thick layer of clay. This clay layer will very effectively capture and retain any radiocaesium that may migrate downwards, due to the highly selective and very strong binding capacity of common clay minerals. A thick (ca. 1 mm) plastic membrane on top of the waste layer prevents rainwater from reaching the contamination and causing migration. On top of the plastic membrane a 30 cm gravel draining layer was constructed, to drain away rainwater. At the top of the repository, an at least 50 cm thick layer of fertile soil was placed. Grass was grown in this soil to prevent against erosion. The entire construction gives a shielding through a solid layer of at least 80 cm. This reduces the external radiation from the radioactive waste layer by at least 3 orders of magnitude (Jacob & Paretzke, 1986). In addition, as mentioned above, the self-attenuation of the contaminated soil will be great. A ditch should be dug around the repository to collect the drained-off rainwater. The dimensions of the repository could be as great as 400 by 400 metres.

Also other, more simple designs have been suggested and tested in limited scale in Norway and in large scale in the former Soviet Union (Lehto & Paajanen, 1994). Based on the work of Salbu et al. (1994), the total costs of disposal of contaminated soil in a relatively simple repository (including worker salaries and use of machines) is estimated to be of the order of 2000-3000 Euro for each ha of land from which a topsoil layer of ca. 3-5 cm thickness is removed. The estimate is assuming that repositories will be constructed in the contaminated area. Waste repositories should generally be constructed in the contaminated areas, to minimise transport expenses. Thereby, also doses to transport workers can be minimised. Further, it will probably be considered most reasonable by the population that the repository problems are shared by the whole affected population rather than imposed massively on a specific selected part of the inhabitants living near a large, centralised repository.

If other contaminants migrating more easily than caesium pose a problem, various stabilisation and solidification techniques can be applied to reduce this problem (Brodersen, 1993). It should however be stressed that such solutions will generally be expensive. The three classical matrix materials are cement, bitumen and polymers. Cement solidification of soil can however be problematic, as the properties of the resulting cement mixture are not very promising.

Due to the self-attenuation of the soil, the external dose rate to workers is unlikely to differ greatly from that to other people spending time outdoors in the area. However, the amount of time spent outdoors will be likely to be comparatively great for these workers, and as buildings provide a (highly variable) shielding against radiation, the dose rate is expected to be significantly higher outdoors than indoors.

If the open area was covered by a thick layer of snow at the time of the deposition, and the first subsequent thaw has not yet set in, there is a unique opportunity to remove the contamination before it reaches the underlying soil, with much more severe penalties. Removal of snow in an urban or industrial area may lead to extremely large amounts of waste (Qvenild & Tveten, 1984). It would generally not be considered realistic in practice to melt all this snow and extract the contamination, although simple filtration designs would be expected to have a large effect. Alternatively, the snow masses may be dumped in the vast oceans, where the impact on the ecosystem would be considered to be limited. It should be secured that the snow is not disposed of in, e.g., lakes where the waste may give rise to significant sediment contamination problems or lead to contamination of drinking water. As the snow may thus need to be transported over large distances, the transport expenses could well be high.

6.2. Waste from removal of vegetation

The removed vegetation may here be grass or turf or other vegetation (shrubs, bushes and trees) removed from lawns and parks. These wastes may have relatively high specific activity. This is particularly true for grass if it is cut early after a dry contamination has occurred. When the grass decomposes, it will compact, giving rise to even higher specific activity.

Also leaves on a tree or shrub may have high specific activity right after contamination. This problem and its impact on worker doses is described in detail under the heading 'operator safety' in the relevant datasheets. Protection of workers may occur either through shielding with metal between the worker and the waste, by increasing the distance (e.g., by remote controlled operation) and/or limiting the number of individual work hours.

A number of methods may be envisaged to make use of some types of the removed biomass, depending on the contamination level. For instance, aerobic degradation (composting) will produce material that may be useful for soil fertilising, whereas anaerobic degradation produces gas that may be used in energy production. Core wood from contaminated trees may, particularly early after an accident, where the contamination will largely be confined to the outer surface, be applied in industry, e.g., for making furniture. The IAEA have published a report, which provides estimates of the conversion factors between 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). In ICRP publication 82 (1999) it is recommended that the annual individual dose contribution from these sources does not exceed 1 mSv. However, it should be stressed that intervention exemption levels in use currently vary widely between countries, and may be considerably lower than the recommended 1 mSv limit.

The wood pulping process in connection with paper manufacturing may significantly reduce the contamination in the paper product. A special wood pulping treatment has been described by Roed et al. (1995) giving a decontamination factor of as much as 50-100.

An option for comparatively strongly contaminated wood, wood waste and other biomass (e.g., shrubs) is to chip it and combust it in safely designed power plants, which provide adequate protection of workers as well as of the environment. Thereby, energy is generated and at the same time the mass of the waste would be reduced by a factor of 10-100 by the combustion. The technology required to produce energy from biomass has been established a long time ago. In more forest-intensive European countries, such as Finland, wood combustion accounts for approximately 19 % of the energy consumption (15 % large scale and 4 % small-scale wood firing).

The magnitude of stack releases from a combustion plant depends on the boiler temperature as well as on the applied aerosol filter type. For instance, Mustonen et al. (1989) reported that four Finnish plants equipped with electrostatic filters for fly ash precipitation were found to have aerosol collection efficiencies (mass) in the range between 71 % and 99.7 %. According to Hedvall et al. (1996), Swedish biomass-fuelled power plants emit between 1.4 % and 10 % of the caesium in the applied Chernobyl-contaminated fuel to the atmosphere from the stack in the form of flue gas. Such releases may be greatly reduced by applying a baghouse filter. An efficient baghouse filter design has been proposed by Junker et al. (1998), essentially consisting of eight modules, each with 250 GORE-TEX membrane needle felt 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.

If 1,000,000 tonnes of biomass with a specific activity of 500 Bq kg^{-1} were combusted annually in a plant releasing as much as 10 % of the caesium in the fuel to the atmosphere, this would be expected to lead to an integrated dose over a life-time to individuals staying 1 km from the power plant of only some 20 µSv (Junker et al., 1998). This could be reduced several orders of magnitude by installing a baghouse filter (Roed et al., 2000).

Doses to workers at a power plant fired with contaminated biomass have been investigated in detail, assuming a typical bio-energy power plant construction (Andersson et al., 1999). It was concluded that if people are working throughout an entire working year only ½ m away from the locations at the power plant with the highest dose rate (which would grossly over-estimate the worker dose), annual doses of 2-3 mSv can be expected if the biomass (wood) is taken from an area contaminated by ca. 1 MBq m^{-2} of ^{137}Cs. In any case, worker doses should be assessed/minimised.

According to the recommendations of Junker et al (1998), the ash from combustion can be disposed of in thick plastic 'big bags' with typical volumes of ca. 2 m^3. These are placed in a ground repository of the type described for disposal of contaminated soil (see above). Without combustion, the biomass repositories would need to be 10-100 times bigger, and the wood would still need to be chipped.

Also spreading of ash for fertilising fields has been suggested. The fertiliser may in some soils significantly reduce contaminant uptake to plants, and the total effect could thus reduce dose, depending on the ash contamination level. The legality and acceptability of this (or any other) solution should of course first be assessed.

6.3. Waste from decontamination of streets

Street cleaning by fire-hosing generates waste, which can not be collected, but must be led to the drains. In contrast, street vacuum sweeping leads to collection of the loosened contamination in a vessel. This material can be subjected to special waste management procedures. The removed street dust may have high specific activity. This is because the contamination on streets will largely be confined to the thin street dust layer (Andersson et al., 2002). It is therefore important that workers at a disposal site, as well as transport workers, are adequately protected against the radiation from this type of waste. Calculations have shown that in an area with a contamination level of 1 MBq m^{-2}, containers of street dust may give a dose rate to operators (drivers) of 50-100 µSv h^{-1} (Ulvsand et al., 1997). Further, modern vacuum sweepers are often equipped with a water tank in which the dust is collected. This type of vacuum sweeper is preferable, as the water attenuates the radiation from the contamination in the collected dust.

Disposal of street dust may occur in a repository similar to those suggested for contaminated soil (see above). It has been shown (de Preter, 1990) that the number of highly selective caesium sorption sites in street dust, which to some extent originates from erosion and weathering of urban surfaces, does not differ greatly from what was found in, e.g., micaceous tile samples. In other words, the same mechanisms in mica that strongly bind and retain particularly caesium in the soil are generally responsible for strong fixation also in street dust. This means that downward migration of caesium ions in a street dust layer will be very limited. If other contaminants migrating more easily than caesium pose a problem, various stabilisation and solidification techniques can be applied to reduce this problem (Brodersen, 1993).

6.4. Waste from decontamination of walls

Although contaminated waste will be generated by the two countermeasures suggested for treatment of walls, the waste will not be possible to collect, and so waste management is in this case as such not possible. However, as the cleaning liquid containing the contaminants will be washed down on/in the ground below the building, the waste can be subsequently removed together with, e.g., a topsoil layer, which would probably have to be removed anyway, since airborne contamination usually leads to much higher levels on ground surfaces than on walls.

6.5. Waste from decontamination of roofs

Solid waste removed by either one of the two suggested roof cleaning methods may include loosened particles from the roof materials, sludge (e.g., from the roof gutter, which would also be decontaminated), algae and moss. Many of these materials will normally retain contamination (particularly caesium, but also a range of other radionuclides such as ruthenium, barium and lanthanum) well, and the volume of this solid waste will thus be difficult to reduce by extraction. As the waste arises from wet roof treatment procedures, the solid waste will initially be present in rather large volumes of water. However, nearly all contamination (depending on radionuclides – not true for iodine) can be easily removed by simple filtration, as most of the contamination will be associated with the solid part of the waste (Fogh et al., 1999).

For filtration of caesium-contaminated matter, a filter material that has been successfully tested in practice (for water containing contaminants) is the commercially available polymer fibre textile called 'TYPAR', with a pore size of 0.14 mm. The cost of this material is only ca. 0.50 Euro per m^2 (Roed et al., 1996). Also a material like gauze might be applicable here. If the waste water from operation of a roof cleaning device on a mainly caesium-contaminated roof is filtered *in situ*, the water will be sufficiently clean of contamination to allow recycling in the decontamination operation (Roed et al., 1996). In practice the cleaning and recycling of water may be carried out through very simple means. Roed et al. (1996) described a set-up, where the waste water from cleaning a roof was collected in the roof gutter and led through a down-pipe into a large vessel. Inside this vessel, a plastic coated metal net was covered with 'TYPAR', which only the liquid fraction of the waste could penetrate. On the other side of the filter the water was pumped into another vessel, from which it could be recycled for the roof-cleaning operation.

The dry waste should be collected, e.g., in thick polypropylene bags, which may be disposed of in repositories in the ground (see above description for soil areas). The waste may in some cases have relatively high specific activity, and worker doses should be assessed/minimised. Legal demands concerning toxicity of asbestos materials must be taken into account in connection with handling and disposal of the waste.

6.6. Waste from indoor decontamination

The effect of cleaning procedures applied on indoor surfaces may be significant, particularly early after a contamination has occurred. The specific activity of dust collected in vacuum-cleaner filters or on cloths may vary greatly, mainly depending on the deposition mode (if contamination occurs in heavy rain, indoor contamination will generally not constitute a problem at all) and contaminant particle size (Roed, 1985). The contamination level in the vacuum-cleaner filters should in very heavily contaminated areas be assessed prior to disposal. If the contamination level exceeds the maximum permissible level, this waste should be collected, e.g., in thick polypropylene bags, which may be disposed of in repositories in the ground (see above description for soil areas). The waste may in some cases have relatively high specific activity, and worker doses in connection with disposal should be assessed / minimised.

7. Legal, social, ethical and communication implications of dose-reductive countermeasures in residential areas

This section is aimed at giving an introduction to the non-radiological factors that need to be considered by decision-makers in the development of a justified and optimised strategy for clean-up in inhabited areas. The first section addresses the legal concerns that might set constraints on possibilities for implementation of countermeasures. The second section deals with issues of social and ethical nature, as well as the very important communication strategies that need to accompany any remediation strategy. It should be noted that this chapter gives advice taking into account the findings of a number of case studies, mostly conducted by radiological experts together with experts on communication, social sciences and ethics. It should be mentioned that in connection with the URBHAND exercise, very different feedback was received to this chapter - mostly very positive, although a single end-user representative felt very strongly that advice of this type should not be given in a report authored by radiological experts. However, although only very few radiological experts are also experts at non-radiological sciences, they are generally the only ones that can introduce direct hands-on experience on such questions into the decision-making process, as they are the ones who have been in charge of implementing countermeasure trials on realistic scales in populated areas, and have often had extensive dialogue with the locals affected by the countermeasure implementation.

7.1. Legal perspectives

Although the radiation level in a contaminated residential area may in a given situation be deemed unacceptably high by the responsible authorities, the interests in mitigating this problem by introducing some dose-reductive countermeasures may conflict with other interests of society. These latter interests may have been expressed in the form of legislation, which seemed unambiguously reasonable prior to the contamination. The question of whether dispensation may be given in a particular case to bypass legislation, if the benefits clearly outweigh the disadvantages, can not be addressed in generic terms. However, it is certain that by current legislation, some methods that are legal in one Nordic country would not be legal in another. Although focusing on rural countermeasures rather than urban, the HUGINN exercise that was conducted in 2000 under the NKS framework showed clear differences in legislative restrictions on some countermeasures. An identified issue of relevance in the present context is that current Finnish legislation prohibits dumping of contaminated snow in the ocean. An other legal issue example is the simple high pressure water hosing method for roofs. Contrary to alternative techniques, this method may spread loosened roof material debris in the area, thereby possibly constituting a problem in relation to asbestos treatment legislation. This problem can be overcome by selecting a countermeasure that involves abrasion in closed media.

There could be a number of other problems in relation to legislation, depending on the specific circumstances, under which the countermeasures are applied. For instance, directives protecting habitats of flora or fauna in national parks may be violated by some soil treatment techniques, and it may not be allowable to subject protected historical buildings to very abrasive treatment. Legal restrictions could be of both local and international nature, and should be carefully studied in advance of an emergency by the responsible local authorities, so that any potential problems can be identified and eliminated from operational preparedness.

International legislation of possible relevance includes a number of European conventions and directives, and UN (e.g., IAEA) conventions and declarations, for instance on environmental issues. It should be stressed that international laws may be interpreted differently in different countries. Also legislation defining the rights of affected populations and workers must be respected. Here international agreements such as the Århus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters may place restrictions on the use of suggested countermeasures. This may again prompt a 'trade-off' decision that can be accepted by the involved parties, as countermeasure acceptability and effectiveness do not always go hand in hand.

Guidelines for worker protection and responsibilities are given through the EURATOM Basic Safety Standards Directive (EURATOM, 1996) (Council Directive 96/29/EURATOM - for full details see europa.eu.int/comm/energy/nuclear/radioprotection/doc/legislation/9629_en.pdf; an excerpt of the text is given in Brown et al., 2007). These articles concern radiological protection. Also, a number of international labour standards have been formulated by the International Labour Organisation (ILO, 2007), setting the minimum standards of basic labour rights in general, which can all be found on the organisation's web page (www.ilo.org). The ILO standards are generally ratified by the Nordic countries and must thus be followed. Of particular interest are here Convention C115 on radiological protection, Convention C29 on forced labour and Convention C155 on occupational safety and health. These Conventions have to a large extent been implemented in national legislations in the Nordic countries (see e.g., the Danish worker protection law: http://www.au.dk/da/regler/2005/lb268/#k8; the Swedish Work Environment Ordinance: http://www.av.se/inenglish/lawandjustice/workact/ordiance.aspx; Norwegian working environmental law: http://www.regjeringen.no/nn/dep/fad/Dokument/NOU-ar/2004/NOU-2004-5/13.html?id=384991#note11; national labour laws for all Nordic countries: http://www.fedee.com/natlaw.html#denmark).

It should specifically be noted that waste management options, which would from a technical perspective be deemed safe and sufficient, may not comply with current legislation. It is important in the event of a large emergency, where a requirement may be the removal of vast amounts of contaminated topsoil, that the waste is regarded as an inherent part of the strategy for dose reduction, and its management thus evaluated in the same optimisation process as the other elements of the strategy.

Some issues to consider in relation to legality:

- Does current national legislation permit application of the countermeasure?
- Could countermeasure implementation indirectly lead to violation of other legal issues?
- Might legality constraints change in an actual emergency situation?
- How are international legal aspects implemented / interpreted locally?
- Have legality aspects been considered of both countermeasures and associated waste management methods?

7.2. Social, ethical and communication perspectives

Social, ethical and communication-related issues in connection with a major emergency situation and the subsequent remediation are often closely interlinked, and it is important for the decision-maker to keep track of these perspectives throughout the different phases of an emergency to constantly be on top of the situation.

7.2.1. Different types of social problems

Social problems may arise as a direct consequence of the impacts on society, for instance in the form of adverse general effects on the infrastructure and restrictions on the use of contaminated areas, with resulting economical penalties, e.g., due to loss of production, tourism, and functionality of vital organisations such as hospitals. Such problems, although often difficult to quantify in terms that are comparable with other costs, are essential to include in the process of optimisation of remediation. Other, equally important, social problems may pertain to the psychological well-being of individuals living in or otherwise affected by the contaminated areas. These types of problems are among the most important of all to address, as they could ultimately lead to very significant social disruption.

7.2.2. Communication and risk perception

The key to preventing mass-desertion/disruption of contaminated areas is communication. A crucial issue in this context is maintaining the public's trust in the authorities' ability to cope with the situation and make the right decisions. Investigations have shown that radioactivity is something that Nordic populations generally have considerable fear of. However, compared with other populations, they also have a high awareness of the risks of radioactivity (Sjöberg et al., 2000).

It has been reported that personal and general risks are perceived rather differently, particularly when the hazards relate to situations where people believe that they have high control (Sjöberg et al., 2000). When an individual expresses confidence in an organisation, he exposes himself to the dangers that he expects the organisation to control (Dubreuil et al., 2000). In this context, it has been found that Nordic populations put their greatest trust in the key expert organisations in their country (Sjöberg et al., 2000). However, as they identify broadcast news on radio and TV as the most important and trusted sources of information in an emergency situation, they accept that the key advise is not given directly by experts, but through 'filters' of decision-makers and other implicated authorities. It is here problematic that only slightly more than half of the respondents to an inquiry in Sweden believe that authorities would give full and correct information on a nuclear emergency and its implications. A similar fraction of the Swedish population believe that the authorities would take appropriate measures to protect the public (Sjöberg et al., 2000).

7.2.3. Trust building

The above is the 'initial' situation that Nordic decision-makers face in the event of an emergency. Some key instruments for decision-makers in subsequently maintaining and increasing the trust are openness, correctness and consistency in decisions and information supplied to the public, and the inclusion of affected persons and organisations in dialogues to identify optimal solutions to the problems. It is imperative that people are not led to believe that something is hidden or that the truth about some important aspect has somehow been twisted. Also, if decisions (e.g., on countermeasures) implemented in one region differ significantly from those implemented in a neighbouring region (perhaps in a neighbouring country), the populations should immediately and carefully be explained why. The establishment of a common Nordic basis for decision making is an effective instrument in avoiding national decisions that may seem illogical by comparison.

Much can be learned from the Chernobyl accident, where communication efforts were generally inadequate, and misunderstandings and misinterpretations were frequent. For instance, when the authorities several times over increased or lowered intervention levels, it would have the natural effect that the population comes to believe that no level of radiation can be considered safe. Myths about neglected and deliberately hidden effects of the accident arose in great numbers. It is perhaps more surprising that an inquiry revealed that almost 2 % of the Swedish population believe they have an illness problem that was caused by the Chernobyl accident (Sjöberg et al., 2000). This shows that there is still room for improvements of the public perception and awareness of the effects of radiation. Answers to a Norwegian questionnaire indicate that well-educated people in general have a significantly lower risk perception than the rest of the population (Salt et al., 1999). This suggests that knowledge in general may reduce risk perception, and highlights the need for generally comprehensible information. This questionnaire also revealed that risk perception varies significantly between different communities in Europe.

Malicious radioactivity dispersion is likely to have a very different impact on society than accidents, depending on how the spreading is accomplished. If it is for instance released from an aeroplane, a rather large population may become affected. A small explosive is likely to spread contamination over a limited area, but individual doses could be very high (Andersson, 2005), depending on the construction. It is difficult to say anything general about the consequences of such terrorist acts, but the fact that such an emergency would be the result of an intentional action, which could in principle be repeated any time and anywhere, is bound to lead to a high level of anxiety. As the 'scare' effect is in such cases likely to be a disproportionately great source of social disruption, it is extremely important that decision-makers have developed an effective public communication strategy, which can rapidly be implemented.

7.2.4. Issues associated with ethical principles

An important ethical principle is the right of any individual to influence decisions that can impact on his well-being. For instance, it is the duty of any organisation involved in the remediation work to obtain the free, informed consent of any worker that is subjected to additional risk (Oughton, 2004; ILO, 2005). Economical compensation to volunteers is not an unproblematic solution, for instance because the opportunities thus given to some people to profit from the situation may be perceived negatively by others. A similar ethical (and legal) principle relates to the public rights to decide over how personal properties are treated. This principle was not violated when the Russian army in 1989 attempted to decontaminate 93 settlements with a total population of 90,000 in the contaminated Bryansk region. However, this was one of the reasons for the very poor dose-reductive effect obtained in this case. In these open, rural settlements a large fraction of the external dose rate comes from contamination outside the individual land-lot. This means that if a person disallows his area to be treated, then his neighbours will still receive a relatively high dose rate even though they have had their own areas treated.

An other concern of ethical nature is whether all individuals can/should be protected equally well against radiation resulting from an incident. Since people live in different types of areas, which do not offer equal opportunities to apply countermeasures to reduce doses equally, this is in practice impossible. It would also be reasonable to treat, e.g., schools, children's playgrounds, sand-boxes and indoor surfaces that toddlers are particularly likely to be close to exceptionally thoroughly. Children should be protected exceptionally well against radiation, as the probability of developing radiation induced fatal cancer is on average about twice as high for 0-10 year olds as for adults. As available resources could in practise well be limited, it would also make sense to prioritise treatment of densely populated areas before the less populated. For instance, some rural road surfaces would contribute very little to dose. It should however be stressed that ranking some living areas higher than other in a countermeasure strategy, for instance if limited resources are available, may be the cause of disputes, again pinpointing the need for continuous dialogue with the affected population.

It can also be argued that it is unreasonable that clean-up workers receive increased doses with the objective of reducing doses to other members of society (Oughton, 2004). If dose rates are dominated by short-lived radionuclides, implementation of countermeasures may be postponed to a suitable time, to avoid exposing workers unduly. In general, extra individual doses over a day to a clean-up worker would be estimated to be of the order of 2-3 times higher than that to an individual living in the area. Given that a dose rate reduction by a factor of 10 would be considered very high, doses received by the workers from long-lived radionuclides over the limited clean-up period would be rather small compared to the doses that an individual would subsequently receive by living in the area for some time. Higher doses may be received in connection with a few techniques, where waste is concentrated to contain a relatively high level of radioactivity. Examples are grass cutting and street vacuum sweeping. These additional worker doses are described in the relevant method datasheets. Possible solutions to limit individual exposure, if required, include provision of shielding between waste collector vessels and operators, and restrictions on individual working times.

7.2.5. Dissemination of technical knowledge

After the Chernobyl accident, a wide range of countermeasures were tested in the contaminated areas of the former Soviet Union. Under the European framework alone, sixteen research projects were conducted in the 1990's, involving some eighty Western European research groups and twenty research groups from the three most severely affected republics. On this background it has been concluded that 'the wider dissemination of the results will have very practical and positive implications for the affected populations of the three republics' (Roed et al., 2001). It was however also concluded that there was a great need for communication strategies to disseminate this knowledge not only to relevant authorities, but also very importantly to the public, to improve the public perception and awareness of remedial actions that can be initiated by the population, to improve their own conditions. Knowledge on what locals can do themselves to improve their situation may have great psychological value, and possibly prevent desertion of the affected areas. Such methods are generally perceived as positive as they would conform with the basic ethical principles of autonomy, liberty and dignity (Oughton, 2004). The countermeasure suite in this report comprises a number of such techniques, which can be implemented by local inhabitants on their own property. This, however, does not mean that it is in general a good idea for the local inhabitants to carry out as many of the countermeasures as possible. Clearly, some important countermeasures require a higher level of expertise in order not to jeopardise the result, and for instance procedures involving work on a roof top could introduce a comparatively high safety risk to inexperienced workers.

7.2.6. Preparing for optimal countermeasure implementation

To ensure that a countermeasure is applied correctly and optimised, it is necessary to make a series of investigations to determine the nature and extent of the contamination problem. For instance, in connection with the decontamination efforts of the Russian army in 1989, as mentioned above, a major problem was that when contaminated topsoil was removed, prior investigations as to how deep the contamination lay were neglected. In some cases, where the contamination peaked a few centimetres down, the removal of a thin layer of topsoil actually led to an increase in dose rate. An other problem is that the countermeasures are in practise not carried out by radiation experts who can easily comprehend the rationale behind the implementation of a countermeasure. For instance, topsoil removal would often be carried out by contractor companies, exploiting their expertise in manoeuvring a mini-bulldozer. However, such operators are used to carry out the procedure with a completely different objective. Whereas a typical 'contractor' task may be to remove soil so that the ground is plane, the objective in connection with a decontamination operation would be to remove a homogeneous, thin surface layer and avoid mixing of soil layers and smearing of contaminated topsoil on cleaned areas. Such differences should be explained carefully and it would be beneficial if at least the first runs could be supervised by persons that are well informed of the objectives and potential pitfalls and know how the countermeasure diverges from common practise. Therefore, an effective operational preparedness would comprise a number of methodological instructors, who have attended courses and are familiar with the special rationale of emergency management. Further, it would be beneficial to have leaflets with basic information on countermeasures available in the event of an emergency, so as to ensure that particularly those countermeasures that need to be implemented early to be effective will not be delayed unduly. Such basic information could be derived at different ‘user levels’ on the basis of the data sheet material in this handbook.

It is also extremely important to develop a public communication strategy to demystify the various implementations by explaining their rationales and discussing their implications and extent of application. The European STRATEGY project (Howard et al., 2005) has formulated a generic communication strategy, involving various stages of public dialogue, reviewing and entering dialogue outputs into a decision support model and various subsequent stakeholder reviews prior to implementation of countermeasures. A scheme of this type is desirable because it has the potential to ensure that all relevant aspects are brought up and any potential communication problems may be identified and resolved prior to countermeasure implementation. However, such a process is time-consuming and can only be considered for countermeasure strategies that do not require early planning. Some countermeasures which greatly impinge on long-term doses need to be implemented early to be effective.

Last but not least, the responsible preparedness organisations should identify the countermeasures that would be deemed most suitable for inclusion in local preparedness plans, given, e.g., the climate, topography, population density and availability of equipment. For each of these selected countermeasures it would be extremely useful to have identified practical plans to overcome foreseeable problems prior to any implementation. Persons and organisations that would be responsible for the practical implementation, supervision, radiological control measurements and dissemination of relevant information to operators and the public should be identified and made aware of their duties. It should be assessed that the responsible persons possess the required operator skills and sufficient knowledge of any potential health aspects to be aware of and as far as possible reduce hazards. Also, it is important to keep track of material resources, in the forms of required equipment, utilities, consumables, infrastructure, etc., to ensure that they are sufficient and can be made ready for implementation within the relevant time-frame. Also for instance demographic information databases may be highly beneficial in estimating the effect of a countermeasure for a specific area. All this requires implementation in an operational preparedness, and requires active selection of information material from this handbook and other sources *prior to* an emergency situation.

Some issues to consider in relation to social, ethical and communication factors:

- Has it been considered which direct costs the countermeasure implementation will have on society?
- Which indirect, economical, social, psychological and ethical problems could arise from countermeasure implementation, and which problems would be solved?
- How could the problems be addressed, with respect to re-establishment of societal functions and minimisation of penalties?
- Have adequate steps been made towards establishment of strategies for communication in an emergency, e.g., with the public and media?
- Have local assessments of risk perception been adequately considered in development of communication strategies?
- Do implementation plans contain sufficient level of stakeholder dialogue to avoid social disruption / problems?
- Is there risk that ethical key issues could be violated?
- Is the decision-making platform sufficiently matured to eliminate the risk of implements that could be seen as contradictory?
- Has it been ensured that affected persons are adequately informed of any additional risks that might arise and given a reasonable choice?
- Is the level of information given to operators sufficient to ensure optimal countermeasure implementation?
- Have practical methodological requirements been identified in local context, and has this knowledge been communicated out so that availability (also of technical support, e.g., for measurements) is secured prior to an emergency?

8. Application examples for countermeasure strategy development

This chapter provides a couple of worked examples, aimed at illustrating how the information written in some of the other chapters can be used to narrow down the possible choices, so as to facilitate strategical decision-making for dose reduction in the intermediate to late phase following contamination of an inhabited area. Different types of incidents can lead to very different concerns determining the choices. For instance, a major reactor accident is, as demonstrated by the Chernobyl accident, likely to give a more homogeneous and widespread contamination pattern over an area than would a 'dirty bomb' device. To cover different aspects of decision making, therefore, two different worked examples are given in this chapter. It should be stressed that these are, for the purpose of illustration, simplified examples, and that in reality the contamination level and distribution over an area, for which a given decision-maker might be in charge, could vary considerably (e.g., due to rainfall pattern), demanding different countermeasure strategies with different degrees of disruptive influences on the area. Therefore, geographical information systems and dose maps, as included in the standard European decision support systems like ARGOS and RODOS, would be valuable in selecting appropriate strategies for different parts of a contaminated region. In the case of a terror attack, such areas could be very small, depending on the characteristics of the applied dispersion device. Also, different types of environments would require different countermeasure strategies, as outlined above.

8.1. A worked example involving a reactor accident scenario

For the sake of briefly demonstrating the use of some of the information in Chapters 3-7, let us assume that a reactor accident on the 15th of July has resulted in an atmospheric release of radionuclides, and it rained while the contaminated plume passed over a city area. This has been found to lead to a contamination level of 1 MBq m^{-2} of ^{137}Cs on the grassed reference surface (for simplicity we will assume that the contributions of other radionuclides to the long term external dose are negligible). The question is: how severe is the long-term situation for the persons staying in the affected city area, and what could be done about it?

Let us assume that a given area consists mainly of terrace houses that would be adequately described by the third housing environment in section 4.2. Table 4.6 gives time-integrated doses received by inhabitants of such an environment from outdoor sources over different periods of time. As can be seen, the external dose over 70 years for the given contamination level of ^{137}Cs is estimated to 2.8 10^{-8} Sv per Bq m^{-2}. With 1 MBq m^{-2}, this becomes 28 mSv. Correspondingly, it is seen that the external dose over the first year would be estimated to 2.3 mSv. As mentioned in section 4.1, more flexible and possibly more accurate modelling incorporating also other radionuclides could be made with the model instruments that are currently under development.

As we are dealing with a predominantly wet deposition, indoor contamination levels will contribute very little to dose (see section 4.3). Doses from contamination on humans (see section 4.4) are only likely to have importance in a dry deposition scenario, as the time people would spend outdoors in the rain would be likely to be limited compared with the time it takes for the contaminated plume to pass. Doses from inhalation of contaminants during the passage of the contaminated plume would not be significant in a wet deposition situation, where near-ground air concentrations will be strongly depleted by the rain. In a densely populated city area, kitchen garden production (see Chapter 5) would be likely to have little significance.

As the contamination resulted from a reactor accident, it can be assumed that the relative distribution of the contaminants will be as indicated by Table 4.5 (wet deposition), although in reality measurements of the contamination levels on the various surfaces would probably have been made in compliance with section 2.6. By multiplication of the values in Table 4.3 for terrace houses by the contamination level on the grassed reference surface and the relative source strength factors from Table 4.5, it is seen that in this case, more than half of the dose received over the first year by an average inhabitant of the contaminated area is due to contamination on the open (grassed) areas. It is also seen that the corresponding fraction of the dose integrated over 70 years would be of the order of 90 %. As efficient countermeasures exist for reduction of dose contributions from contaminated open (grassed) areas (see Chapter 3 and Appendix A), it is clear that this is where the greatest dose saving could be made.

If we look at the countermeasure datasheets in Appendix A, there are eight different methods that could in general be considered for open (grassed) areas:

1. Lawn mowing
2. Turf harvesting
3. Top soil removal (manually)
4. Top soil removal (mechanically)
5. Triple digging of soil
6. Deep ploughing of soil
7. Skim-and-burial ploughing of soil
8. Snow removal from open areas

As indicated in the individual countermeasure descriptions, some of these methods would not be relevant for this particular case. Let us assume that we look for methods to be applied in garden areas of relatively limited areas.

Grass cutting is not relevant here, as it is a method that only has significant effect if the contamination is dry. Turf harvesting might be considered, but requires a specialised machine that may not be available. Snow removal is clearly not the solution, as we are in the month of July. Finally, the ploughing procedures could be applied in large park areas, but require much open space and would thus not be relevant for limited garden lots. This leaves us with the following three options:

1. Top soil removal (manually)
2. Top soil removal (mechanically)
3. Triple digging of soil

Which of these is the most suitable for the particular case largely depends on the total costs and benefits, but it also needs to be assessed if any of the methods would be in conflict with the local legislation and general acceptability (see Chapter 7). If we look at the detailed method descriptions in the countermeasure datasheets (Chapter 3), it is evident that the two topsoil removal methods have equal effectiveness in reducing dose. The difference lies in whether the soil is removed by hand or by machines (e.g., mini-bulldozers). If we look at the intervention costs, it is apparent that the mechanical version is the least expensive. However, it requires the use of machinery, which must be available within a reasonable time-frame. As the ^{137}Cs is very long-lived, much dose can however be saved, by implementation of this countermeasure even after several years (see Table 4.5).

Looking again at the datasheets, the main differences between digging and soil removal procedures are that by digging, the dose reduction is obtained without actually *removing* the contamination from the soil area – it is simply buried, whereby a shielding effect is obtained. This may not be acceptable to property owners and other stakeholders (this is something it could in general well be worth investigating locally in advance of a contaminating incident). Also other method-specific potential constraints and limiting factors are listed in the datasheets, which should be considered in relation to the given situation. Digging also involves rather much hard physical work, compared with a method like mechanical topsoil removal. On the other hand, contrary to topsoil removal, it would not generate waste. Management of waste would result in additional elements on the cost side. Both methods would have a significant adverse aesthetic effect on the treated garden area. This adverse effect could to some extent be described in terms of the costs of re-establishment of the gardens.

A cost-benefit analysis to 'measure' one countermeasure against another would require evaluation of the magnitude of essentially all cost and benefit aspects of the countermeasure implementation. If, for instance, we look at triple digging, the equipment is inexpensive, so that intervention costs can largely be calculated from the labour costs alone (20 euros per m^2 multiplied by the size of the treated area). The obvious benefit of the countermeasure is a reduction of the dose rate 1m above the surface by a factor of 5-10. By multiplication of the relevant value in Table 4.3 by the reference surface contamination level, the relative source strength from Table 4.5 (for soil areas: 1.0) and the dose reduction factor from the relevant datasheet, it will be possible to find how great a dose saving to an average individual living in the area this would correspond to in the particular case. The total averted dose is equal to the sum of the averted doses to individuals living in the treated area. It could be convenient to express the value of this dose saving in monetary units, as suggested in section 3.2. The value that would be assigned to a saved dose unit would be politically driven, and likely to vary between the Nordic countries. An example is that the Swedish ministries in 1998 recommended a value corresponding to 350,000 SEK per Sv (RIB, software published by the Swedish Rescue Service). Somehow, social and ethical factors also need to enter the decision matrix. Factors like reassurance, disruption, loss of productivity and loss of property value (see Chapter 7) may be highly important to consider in optimising countermeasure implementation. Such factors can be difficult to quantify in terms that are readily comparable, and it is clearly something decision-makers will need to consider carefully, as soon as possible. It is currently considered to incorporate a special user-friendly prioritising system in European decision support systems, to facilitate optimisation with respect to all important factors.

Compared with digging, soil removal procedures will have one important extra cost-element: waste management. In the individual datasheets, the amounts of all types of wastes originating from the introduction of countermeasures are estimated per m^2 area treated. By multiplying with the relevant surface area sizes in the environment, the total amounts of waste generated can be estimated. In Chapter 6, some suggested waste management options are described. If a simple, yet safe, waste repository is constructed for 500 m^3 removed soil, this will cost an additional 3000 euro. This cost should also be included in the consideration of justification and optimisation of countermeasures. If repositories can for some reason not be constructed locally in the contaminated area, extra costs for waste transport need to be added.

Similar cost-benefit considerations should be made for treatment of other types of contaminated surface in the inhabited area. If the net benefit is positive, the implementation of the countermeasure strategy is justified. In town centres, open soil areas would be small compared with those assumed in the calculations above, and so other surfaces would be comparatively more important. Even if a method does not save much dose, its implementation would still be justified, if the cost is sufficiently low. An example of this could be vacuum-sweeping of streets. The dose that can be averted by this method would often be limited, as natural weathering processes will anyhow lead to a rapid decline in contamination levels on streets. However, it is extremely easily carried out, with very small costs, and thus still attractive, although it often needs to be combined with countermeasures for other surfaces that can effectively reduce the doses to inhabitants of the area.

When countermeasures are to be carried out in practise, it is important to consider protection of workers. For instance, if short-lived radionuclides had contributed much to the dose rate in the earliest few days or weeks (as is not assumed to be the case here), countermeasure implementation could be delayed for a while, to avert unnecessary worker doses. Information on operator safety precautions in connection with the implementation of the countermeasures can be found in the individual datasheets. Sections 3.2 and 4.6 gives some generic information of relevance in this context.

Also the role of monitoring in ensuring the optimal outcome of the countermeasure strategy should be carefully considered (see Section 2.6). A countermeasure strategy implemented without careful monitoring could have disastrous effects.

Chapter 7 gives important information on items to be considered in advance of a contaminating incident, particularly in relation to non-radiological factors.

8.2. A worked example involving a ‘malicious dispersion’ scenario (terror attack)

A problem with predicting the impact on a population of a terror attack is that many very different scenarios are conceivable, and the available data on nuclear incidents relates specifically to other types of incidents, such as large accidents at nuclear installations. Moreover, existing preparedness models are currently not equipped with parameter sets that allow adequate estimation of consequences. Adequate prediction of the consequences of a ‘dirty bomb’ would require detailed consideration of for instance relevant dispersion mechanisms and their implications for contaminant aerosol characteristics, effective 'release' heights, and deposition patterns in the inhabited environment. Nevertheless, there are obvious similarities between incidents involving atmospheric dispersion of radioactivity, and much of the information in this handbook on, e.g., decision frameworks, recovery options, protection of workers and waste management has been written in a way that would apply to essentially any type of contaminating incident. Also, this handbook, probably as the first of its kind, contains guidance on estimation of doses from a ‘dirty bomb’ scenario, assuming that contamination levels on the ground are known (either measured or estimated through the use of sophisticated urban scale dispersion models).

One of the recently most discussed potential means of malicious dispersion of radioactive matter is the so-called 'dirty bomb', where a conventional bomb disperses contaminants. This would typically have greatest effect in a city area, and in dry weather. Undoubtedly, any terrorist would be aware of this, so these would be the likely conditions. There are many 'orphaned' sources in the world, which no longer serve a purpose and are not kept track of. They could thus rather easily fall into the hands of terrorist organisations. This is for instance the case in the former Soviet Union, where military sources have found their way into illegal trading after the collapse of the old regime. One example is that in the winter of 2002, three residents of Tsalenjikha in Georgia suffered severe radiation sickness and skin burns after having found a ^{90}Sr source in the forest (Falkor News, 2005). This source had in the Soviet days been in use to power a thermoelectric generator for a communication tower in a remote nature area. Such generators were also widely used in lighthouses, beacons, and other unmanned facilities (STONY, 2005). Although also other radionuclides would be suited for dispersal by a 'dirty bomb', ^{90}Sr is advantageous over most in that it is a pure beta emitter. This means that only little shielding material would be required to enable safe handling of the bomb prior to its detonation.

If a terrorist detonates a ^{90}Sr 'dirty bomb', it will generate a haze of contaminated particles, which will deposit over an area of the city. The magnitude and shape of the affected area would depend on factors such as the size of the blast, wind conditions, and 'roughness' elements of the area (buildings, vegetation, etc.). The terrorist would be likely to inform the authorities/public of the incident, at least when it has occurred, as the inherent scare effect would be desired. This means that the authorities would know that something has been dispersed by the bomb, but perhaps not exactly what.

When a monitoring crew has been sent out, it will soon be apparent that rapid screening of large areas, in accordance with section 2.4, is exceedingly difficult, since the range in air of the beta particles emitted by ^{90}Sr is short. On the other hand, it will be very clear where the point of 'release' is, and a somewhat slow monitoring effort with handheld beta detectors can take place at increasing distance, to map the probably rather inhomogeneous distribution of contaminants on different surfaces. In this context, a local scale dispersion model working from actual meteorological data would be helpful in obtaining an overview of the situation (such a model is currently under development for the ARGOS decision support system). A rough measure of the dose rate to freely exposed skin from a given level of contamination on the ground can be obtained using the conservative conversion factor of $4\ 10^{-13}$ Sv h^{-1} per Bq m^{-2} (see section 4.2). As mentioned in section 4.2, corresponding doses to inner organs would be very much lower. As mentioned also in section 4.2, the dose rate from contamination on soil would be likely to be reduced considerably over a limited period of time, due to slight penetration of the contaminants into the soil. If the large contaminant particles were not readily soluble (solubility of strontium compounds vary widely), they would probably rather rapidly be removed from impermeable surfaces (e.g., streets) by wind and weather. If they were more readily soluble, the contamination would be likely to become incorporated in environmental surfaces/particles. The dose rate conversion factor given in section 4.2 would, due to the short range of beta particles, only apply during periods where persons would be staying unshielded, near (within about a metre of) the contaminated surface.

It would be recommended to screen persons that were present in the area during a period after the incident (section 2.6.3). Doses from contamination on human skin – even over a short period of time - can be high (see section 4.4). However, it should be considered that the size distribution of contaminant particles originating from a 'dirty bomb' incident would be likely to be very different from that after a nuclear power plant accident. A very large fraction of the particles would be likely to be in the ca. 2-20 µm size range, but most of the activity would probably be associated with larger particles in the 100 µm range, depending on the construction of the bomb and the physicochemical form of the applied radionuclides (Andersson, 2005). By far the most exposed persons are those who were outdoors during the incident (or indoors with open windows). This is because the major part of the contamination is associated with large particles, and the typical relationship between indoor and outdoor air concentrations of large particles will be extremely little. Only the smallest of the particles would be likely to be able to enter a dwelling if air ducts (doors, windows) are closed, and resultant doses to indoor persons could for this fraction of the contaminants probably adequately be estimated using the factors given in Table 4.8. Outdoors, also very large particles would deposit strongly on persons, and this could give significant doses, although such particles would not be expected to stay on the skin very long. Doses can, according to aerosolisation processes, be estimated using Tables 4.9 and 4.10. To limit doses from contamination on skin, possibly exposed persons should be instructed as early as possible to wash and scrub their body very thoroughly. However, unnecessary countermeasures in this direction would be likely to result in considerable undue anxiety and disruption.

As for external doses from indoor contamination, it should again be considered that only a limited fraction of the contaminants (the smallest particles) would be able to enter a dwelling. However, due to the generally very limited depth of penetration of contaminants into indoor surfaces, external doses received from indoor contamination of ^{90}Sr might well be of the same order of magnitude as those from outdoor contamination (Andersson, 2005).

Doses from inhalation of resuspended contaminants would be expected to be small, both since the dose conversion factors given in Table 4.13 are in general rather small, and because the largest particles carrying most of the activity would not be inhalable.

Needless to say, workers should be protected in compliance with the principles referenced in sections 3.2 and 7.1.

As for countermeasures, essentially the same methods would be available, as would be considered for, e.g., a power plant accident scenario (see Chapter 3, Appendix A and section 8.1). However, if deposited contaminant particles are very large, the efficiency of some countermeasures would be likely to be significantly higher than the current version of the datasheets describe (see, e.g., Clark & Cobbin, 1964). Also, given that a 'dirty bomb' incident would be expected to affect much smaller areas than would for instance a nuclear power plant explosion, it might be desired to further increase the dose reducing effect in the affected area, even if it requires much more expenditure per unit area. Also, the contamination pattern would be expected to be less homogeneous after a ‘dirty bomb’ than after a major nuclear accident that occurred at some distance, and assessments based on only few measurements could possibly underestimate the problems connected with a ‘dirty bomb’ detonation. This means that some relatively expensive methods that would not be considered for large scale operations, and are thus not currently in the countermeasure database, could become attractive. Here, for instance, experience from decontamination on-site in nuclear installations might be exploited. The implementation of countermeasures would still be subject to cost-benefit optimisation (see Chapter 3), but the society's willingness to pay to reduce the adverse consequences of the incident may well differ between different types of incidents (see section 7.2, also for other 'social' factors).

Conclusions

A handbook has been written with the purpose of providing extensive information and background data to decision-makers on how to establish a countermeasure strategy for remediation of inhabited areas contaminated by airborne releases of radionuclides. The contamination may originate from a large nuclear power plant accident or from the detonation of a ‘dirty bomb’ for malicious dispersion of radioactive matter. The data presented needs careful consideration and elaboration in the local context in order to establish a preparedness for inhabited areas that is operational and can select the optimal countermeasure strategies with respect to the full range of site/case specific factors. Factors that would need to be assessed locally include the value assigned to a saved unit of dose, and the extent and importance of societal impact (positive/negative) of countermeasure implementation. Communication is a key instrument in avoiding social disruption, and some advice on communication aspects is given. The handbook consists of a series of chapters addressing the various important aspects to be considered in connection with remediation of contaminated inhabited areas. These span from descriptions of the current responsibilities of the key players in the countermeasure strategy development in each Nordic country, over instruments to identify the extent of the radiological problem to be addressed, to comprehensive descriptions of potentially suitable countermeasure options and their implications, e.g., with respect to waste generation and management, implementation costs and other factors that will need to enter the decision matrix.

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Appendix A: Countermeasure datasheets for inhabited areas in general

The generic URBHAND countermeasure template format is shown below, and the descriptions for the 17 individual countermeasures that have been selected as most appropriate for Nordic contaminated inhabited areas in general are shown in the following pages of this appendix.

Name of countermeasure	
Method description	
Surface type / scale	
Relevant contaminants	
Time of implementation	
Requirements:	
• Equipment / remedies and their costs	
• Consumables and other practical requirements	
• Operator skills and costs	
• Operator safety	
• Other practical constraints	
• Factors influencing costs	
Effectiveness:	
• Countermeasure effectiveness	
• Factors influencing effectiveness and averted dose/risk	
Waste:	
• Amount and type	
• Waste management recommendations	
• Specific waste problems	
Further constraints, concerns, side-effects and other costs	
State of testing	
Key references	

Roof cleaning by pressurised hot water trolley

Method description	The cleaning is done through rotating nozzles driven by hot water (ca. 65 °C), at high pressure. Contrary to ordinary high pressure hosing, this system is closed so that contaminant spreading is minimised. The device is mounted on a trolley that can be drawn up across the roof. It is operated from the top of the roof. The loosened contamination will be washed to the roof gutter system and can be collected from the drain pipe, if desired.
Surface type / scale	Contaminated roofs. Can be applied on a large scale if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Could be postponed for several years and still have effect on, e.g., Cs, depending on roof material and removable debris/growth.
Requirements:	
• Equipment / remedies and their costs	Roof cleaning trolley (ca. 500 EURO) and high pressure hot water generator (40,000 EURO).
• Consumables and other practical requirements	30 l m^{-2} of water. Power supply. Possibly mobile lifts for operation from the roof (variable costs).
• Operator skills and costs	No particular worker skills, but some instructions needed. Estimated to ca. 10 minutes per m^2 roof for each of 2 workers. Workers could be e.g., fire brigade, professional roof workers, civil defence or possibly volunteers.
• Operator safety	Lifeline. Safety helmets. Water proof safety clothing recommended. Inhalation hazard is negligible. Should not be carried out as self help, because of risk of falling from the roof.
• Other practical constraints	Care must be taken not to block drains with moss, etc.
• Factors influencing costs	Distance to and transport options for equipment and consumables. Type of possible mobile lifts (height of building). Worker effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of Cs contamination by 50-85 %.

- Factors influencing effectiveness and averted dose/risk	Radionuclide (Cs is strongest bound to surface). Contaminant aerosol type (size, solubility). Compliance with described procedure. Roof material (lowest effect for slate, clay and concrete roofs, best effect for silicon-treated slate and aluminium/ iron). Amount of water/time used and pressure. Care taken to wash contamination to the roof gutter rather than translocating it on the roof. Increased water temperature (to e.g., 80 °C) will increase the effect. As time passes, some of the contamination will become more firmly fixed to the roof material. If a surface layer of moss/algae covers the roof at the time of the contamination, almost all the contamination may be removable. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
- Amount and type	Generates some 30 l m^{-2} of liquid waste, with ca. 0.2 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 7000 Bq m^{-3} per Bq m^{-2}). Waste may be toxic (asbestos).
- Waste management recommendations	After filtration in a simple filter the water can be disposed of. Simple repositories should be constructed. Costs related to transport and disposal must be considered.
- Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Visual improvement (nice clean roof). Clear information material for users and affected persons must be available before application of method.
State of testing	Tested on selected roofs of different types in the laboratory and in the CIS after the Chernobyl accident, on realistic scale.
Key references	K.G. Andersson, G.V. Antsipov, G.A. Astashko, M.I. Balonov, A.N. Barkovsky, O.M. Bogachev, V. Yu. Golikov, I.A. Kenik, L.N. Kovgan, S.A. Matveenko, A. Kh. Mirkhairdarov, J. Roed & P. Zombori: "Guide on decontamination of rural settlements in the late period after radioactive contamination with long-lived radionuclides", IAEA Working Document TC Project RER/9/059, IAEA, Vienna, 84 p., 2001.

Roof cleaning by high pressure water

Method description	High pressure washing with 'professional' equipment (typically at about 150 bar) can often loosen much of the contamination on a roof. A continuous water flow must be applied to ensure that the removed contaminants are washed to the roof gutter system. The waste stream can be collected from the drain pipe, if desired.
Surface type / scale	Contaminated roofs. Can be applied on a large scale if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Could be postponed for several years and still have effect on, e.g., Cs, depending on roof material and removable debris/growth.
Requirements:	
• Equipment / remedies and their costs	'Mobile' pressure washer (ca. 80 kg) with turbo nozzle and hose pipes (ca. 3,000 EURO).
• Consumables and other practical requirements	20 l m^{-2} of water. Power supply. Possibly mobile lifts or scaffolding for operation on the roof (variable costs).
• Operator skills and costs	No particular worker skills, but some instructions needed. Estimated to ca. 1-2 minutes per m^2 roof (alternatively, fire-hosing at 0.1-0.2 minutes per m^2). Workers could be e.g., fire brigade, professional roof workers, civil defence or possibly volunteers.
• Operator safety	Lifeline. Safety helmets. Water proof safety clothing and safety glasses recommended. Dust formation will be limited due to the water. Should not be carried out as self help, because of risk of falling from the roof.
• Other practical constraints	Care must be taken not to block drains with moss, etc. Frost (may require water heating).
• Factors influencing costs	Distance to and transport options for equipment and consumables. Type of possible mobile lifts or scaffolding (height of building). Worker effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of Cs contamination by 40-80 %.

- Factors influencing effectiveness and averted dose/risk	Radionuclide (Cs is strongest bound to surface). Contaminant aerosol type (size, solubility). Compliance with described procedure. Roof material (lowest effect for slate, clay and concrete roofs, best effect for silicon-treated slate and aluminium/ iron). Amount of water/time used and pressure. Care taken to wash contamination to the roof gutter rather than translocating it on the roof. Increased water temperature (to e.g., 80 °C) will increase the effect. As time passes, some of the contamination will become more firmly fixed to the roof material. If a surface layer of moss/algae covers the roof at the time of the contamination, almost all the contamination may be removable. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
- Amount and type	Generates some 20 l m^{-2} of liquid waste, with ca. 0.2 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 7000 Bq m^{-3} per Bq m^{-2}). Waste may be toxic (asbestos).
- Waste management recommendations	After filtration in a simple filter the water can be disposed of. Simple repositories should be constructed. Costs related to transport and disposal must be considered.
- Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Visual improvement (cleaner roof). Clear information material for users and affected persons must be available before application of method.
State of testing	Tested on selected roofs of different types in the laboratory and in the CIS and in Europe after the Chernobyl accident, on realistic scale.
Key references	J. Roed & K.G. Andersson: "Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout", J. Environmental Radioactivity vol.33, no.2, pp. 107-116, 1996. K.G. Andersson & J. Roed: "A Nordic Preparedness Guide for Early Clean-up in Radioactively Contaminated Residential Areas", J. Environmental Radioactivity vol. 46, no. 2, pp. 207-223, 1999.

Wall cleaning by high pressure water

Method description	High pressure washing with 'professional' equipment (typically at about 150 bar) can often loosen much of the contamination on a wall. A continuous water flow must be applied to ensure that the removed contaminants are washed off the wall and to the ground. The washing must be done in a sequence from the top down to the bottom of the wall. Alternatively, fire-hosing may be applied at (hydrant pressure), but with less effect.
Surface type / scale	Contaminated outer walls. It should be considered that water may possibly penetrate wooden walls. Can be applied on a large scale in densely populated or very strongly contaminated areas if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives.
Relevant contaminants	Cs (and other long-lived gamma or beta emitting radionuclides)
Time of implementation	Should be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Could be postponed for several years and still have effect on, e.g., Cs.
Requirements:	
• Equipment / remedies and their costs	'Mobile' pressure washer (ca. 80 kg) with turbo nozzle and hose pipes (ca. 3,000 EURO). Alternatively, fire-hosing equipment (ca. 1,000 EURO).
• Consumables and other practical requirements	20 l m^{-2} of water. Power supply. Possibly mobile lifts or scaffolds for operation on tall buildings (variable costs).
• Operator skills and costs	No particular worker skills, but some instructions needed. Estimated to ca. 1-2 minutes per m^2 roof (alternatively, fire-hosing at 0.1-0.2 minutes per m^2). Workers could be e.g., fire brigade, professional construction workers, civil defence or possibly volunteers.
• Operator safety	Water proof safety clothing and safety glasses recommended. For tall buildings: lifeline and safety helmets. Dust formation will be limited due to the water.
• Other practical constraints	If there is no drain in the ground to take up the waste water, basements may be damaged. Frost (may require water heating). The treatment may necessitate repair or plastering of the wall.

- Factors influencing costs	Distance to and transport options for equipment and consumables. Type of possible mobile lifts or scaffolds (height of building). Worker effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	
- Countermeasure effectiveness	Reduction of Cs contamination by 40-80 %.
- Factors influencing effectiveness and averted dose/risk	Radionuclide (Cs is strongest bound to surface). Contaminant aerosol type (size, solubility). Compliance with described procedure. Wall material generally has little influence, although plastered walls may be slightly easier to clean. Amount of water/time used and pressure. Care taken to wash contamination completely off the wall. Increased water temperature (to e.g., 80 °C) will increase the effect. As time passes, some of the contamination will become more firmly fixed to the wall material. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
- Amount and type	Generates some 20 l m^{-2} of liquid waste, with ca. 0.4 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 4000 Bq m^{-3} per Bq m^{-2}). The waste is virtually impossible to collect.
- Waste management recommendations	The only way to remove the washed-off material from the area is to clean the (often much stronger contaminated) underlying surface *subsequently*.
- Specific waste problems	-
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Visual improvement (cleaner wall). Clear information material for users and affected persons must be available before application of method.
State of testing	Tested on selected walls of different types in the laboratory and in the CIS and in Europe after the Chernobyl accident, on realistic scale.
Key references	J. Roed & K.G. Andersson: "Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout", J. Environmental Radioactivity vol.33, no.2, pp. 107-116, 1996. K.G. Andersson & J. Roed: "A Nordic Preparedness Guide for Early Clean-up in Radioactively Contaminated Residential Areas", J. Environmental Radioactivity vol. 46, no. 2, pp. 207-223, 1999.

Wall cleaning by wet sandblasting

Method description	As the contamination will be confined to a very thin layer of the wall, this can be removed by sandblasting. Sandblasting should be wet to suppress dust. The sandblasting must be done in a sequence from the top down to the bottom of the wall, to avoid translocation of contaminants.
Surface type / scale	Contaminated outer walls. Can be applied on a large scale in densely populated or very strongly contaminated areas if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Could be postponed for several years and still have effect on, e.g., Cs.
Requirements:	
• Equipment / remedies and their costs	'Mobile' pressure washer (ca. 80 kg) with hose pipe and sandblasting device injecting sand into the water stream (ca. 3,000 EURO).
• Consumables and other practical requirements	50 l m^{-2} of water. 2 kg m^{-2} of sand. Power supply. Possibly mobile lifts or scaffolds for operation on tall buildings (variable costs).
• Operator skills and costs	Skills of construction/decontamination workers can be exploited. In any case, some instructions needed. Estimated to ca. 3-4 minutes per m^{2} roof. Workers could be e.g., fire brigade, professional construction workers, civil defence or possibly volunteers.
• Operator safety	Water proof safety clothing and safety glasses recommended. For tall buildings: lifeline and safety helmets. Dust formation will be limited due to the water, but respiratory protection is required.
• Other practical constraints	If there is no drain in the ground to take up the waste water, basements may be damaged. Frost (may require water heating). The treatment may necessitate repair or plastering of the wall.
• Factors influencing costs	Distance to and transport options for equipment and consumables. Type of possible mobile lifts or scaffolds (height of building). Worker effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of Cs contamination by 75-85 %.

- Factors influencing effectiveness and averted dose/risk	Radionuclide (Cs is strongest bound to surface). Contaminant aerosol type (size, solubility). Sand type (ideally quartz sand of 0.5-2 mm grains). Compliance with described procedure. Wall material generally has little influence. Amount of water/sand/time used and pressure. Care taken to wash contamination completely off the wall. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
- Amount and type	Generates some 50 l m^{-2} of liquid waste, with ca. 3 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 500 Bq m^{-3} per Bq m^{-2}). The waste is virtually impossible to collect.
- Waste management recommendations	The only way to remove the washed-off material from the area is to clean the (often much stronger contaminated) underlying surface *subsequently*.
- Specific waste problems	-
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Visual improvement (very clean wall). Clear information material for users and affected persons must be available before application of method.
State of testing	Tested on selected walls of different types in the laboratory and in the CIS and in Europe after the Chernobyl accident, on realistic scale.
Key references	J. Roed & K.G. Andersson: "Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout", J. Environmental Radioactivity vol.33, no.2, pp. 107-116, 1996.

Pruning/felling of trees and bushes

Method description	Trees and bushes in leaf at time of dry deposition can 'filter' much contamination out of the air and thus become strongly contaminated. Pruning of trees to remove leaves/needles can save much of this dose contribution, but must be initiated very early, as natural leaf-fall from deciduous trees will reduce the tree contamination by often several orders of magnitude. For conifers, needle shedding will occur over 3-5 autumns. Only a very small proportion of the contamination in the ground below will over a long time be taken up and accumulated in the tree. Pruning is generally not possible for coniferous trees, which must be felled.
Surface type / scale	Highly contaminated garden or park areas with trees and shrubs (in leaf).
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides).
Time of implementation	Should be carried out within weeks, and before first leaf-fall. Worker doses must be considered.
Requirements:	
• Equipment / remedies and their costs	Variable, e.g., chainsaws (200-1000 EURO), cutters (100 EURO), axes (100 EURO), rope (30 EURO), ladder (200 EURO). Waste transportation trucks (depending on distance to repository).
• Consumables and other practical requirements	Power supply / petrol for chainsaws and other motorised equipment.
• Operator skills and costs	Variable - strongly depends on amount and type of vegetation. Could be 10-50 h for a 'typical' 500 m^2 garden area, incl. loading to truck. The experience of professional forestry workers, tree surgeons and gardeners would be valuable, but the procedure could be carried out by unskilled workers with some instruction.
• Operator safety	Respiratory protection, covering clothing, safety helmets, lifeline (for tall trees).
• Other practical constraints	Felling of large trees in confined urban spaces may be a complicated and slow process.
• Factors influencing costs	Worker effectiveness/skills and wages, season, vegetation type, height and density, applied equipment type, degree of pruning/felling, distance to equipment and consumables. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Proportional to the degree of pruning. If all leaves are removed, the dose rate contribution is reduced by several orders of magnitude.

• Factors influencing effectiveness and averted dose/risk	Whether trees were in leaf at time of contamination. Time and amount of precipitation during/since contamination. Window areas of nearest dwellings - much radiation from trees will pass through thin windows rather than shielding walls. Contamination on vegetation that is not deciduous is most important to treat, as it will persist over years. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
• Amount and type	Highly variable, depending on season, type and height/density of vegetation and extent of pruning or felling (generally large amounts).
• Waste management recommendations	If trees are felled early, the core wood is not contaminated and can be used, e.g., for domestic firing. Leaf material must be safely disposed of.
• Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Adverse aesthetic consequences of vegetation removal. Clear information material for users and affected persons must be available before application of method. Vegetation removal may to some extent be necessary to allow subsequent garden soil decontamination.
State of testing	Tested on a small scale in Europe and CIS after the Chernobyl accident.
Key references	O. Guillitte and C. Willdrodt: "An assessment of experimental and potential countermeasures to reduce radionuclide transfers in forest ecosystems", Sci. Tot. Env. 137, pp. 273-288, 1993.

Road cleaning by vacuum sweeping

Method description	In the Nordic countries, vacuum sweepers are used by municipalities to clean roads on a routine basis. Vacuum sweeper manufacturers are represented in all the Nordic countries. The typical ride-on vacuum sweeper has 2 or 3 rotating brushes. The loosened dust is removed by a vacuum device and collected in a vessel, mostly behind the operator seat. The vessel could be shielded to reduce external dose to the operator. Water is generally applied on the road to control dust. With novel vacuuming systems it has been assessed that resuspension in air of particles in the < 10μm range can be further reduced by a factor of 20.
Surface type / scale	Contaminated roads and walkways, particularly in densely populated areas. Can be applied on a large scale if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives and the short natural weathering half-life of road contamination.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should generally be done within few weeks to be effective, but worker doses from short-lived radionuclides must be considered.
Requirements:	
• Equipment / remedies and their costs	Vacuum sweeping machine (110,000 EURO). Larger and more expensive vacuum sweepers (trucks) exist, but are not more effective. Waste transportation trucks (depending on distance to repository).
• Consumables and other practical requirements	0.1 m^3 of water per h (spraying for dust control). Typical machines have 2.5 m^3 water vessels. 5-6 l per h of petrol.
• Operator skills and costs	Ca. 10^{-4} h per treated m^2 (excl. emptying of waste and making the machine ready). Experienced operators will usually be available in municipalities where machines are available.
• Operator safety	Respiratory protection if the street contamination level is very high. Here it will also reduce the operator external dose if the dust collection vessel (typically ca. 2 m^3) contains water that can add to shielding. Metal shielding may also be inserted between operator and collection tank. Without shielding/water the operator dose over 1 hour will typically correspond to that from staying in the contaminated area for 2-4 days.

• Other practical constraints	Maximum slope of street where the machine can be applied is according to manufacturer 30 %.
• Factors influencing costs	Vacuum sweeper size. Distance to and transport options for equipment and consumables. Worker effectiveness/skills. Worker wages. If vacuum sweeping is carried out on a regular basis in the area, extra implementation costs would largely be limited to waste handling and disposal.
Effectiveness:	
• Countermeasure effectiveness	Reduction of Cs contamination by 50-70 % by early application.
• Factors influencing effectiveness and averted dose/risk	Radionuclide (Cs is strongest bound to surface). Contaminant aerosol type (size, solubility). Road surface type (dust particle size and loading). Time of operation (must be applied within weeks as contaminant binding to surface will increase, and natural weathering through traffic will rather rapidly remove street contaminants). Homogeneity of treatment. Water spraying will increase effect slightly. Road gutters must be cleaned carefully. Operator protection (see above). Compliance with described procedure. Collective averted doses depend on population density and behaviour.
Waste:	
• Amount and type	Generates some 100-200 g m^{-2}. Waste contamination level: ca. 7000 Bq m^{-3} per Bq m^{-2}.
• Waste management recommendations	Simple repositories should be constructed. Costs related to transport and disposal must be considered.
• Specific waste problems	Specific activity of waste is relatively high (needs consideration in handling). Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Cleans the street of dirt. Clear information material for users and affected persons must be available before application of method.
State of testing	Applied in the CIS after the Chernobyl accident. Small scale tests made in Denmark and USA to find, e.g., influence of street dust loading and application of water.
Key references	K.G. Andersson & J. Roed: "A Nordic Preparedness Guide for Early Clean-up in Radioactively Contaminated Residential Areas", J. Environmental Radioactivity vol. 46, no. 2, pp. 207-223, 1999. J. Roed: "Deposition and removal of radioactive substances in an urban area", Nordic Liaison Committee for Atomic Energy, NORD 1990:111, ISBN 87 7303 514 9, 1990.

Road cleaning by fire hosing

Method description	Ordinary fire hosing can, if applied early, remove much of the contamination on a road. The water can be taken from a hydrant (if available) or pumped from local water bodies (e.g., a lake).
Surface type / scale	Contaminated roads and walkways, particularly in densely populated areas. Can be applied on a large scale if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives and the short natural weathering half-life of road contamination.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should generally be done within few weeks to be effective, but worker doses from short-lived radionuclides must be considered.
Requirements:	
• Equipment / remedies and their costs	Hose pipe (complete with fittings: ca. 700 EURO). A petrol driven pump, if required, costs ca. 6000 EURO. The equipment is likely to be readily available
• Consumables and other practical requirements	5 m^3 of water per h. 10 l per h of petrol if pump is needed.
• Operator skills and costs	Ca. 0.01-0.02 h per treated m^2 (excl. handling of waste). The local fire brigade are experts, but also others can contribute after little instruction (e.g., civil defence, military, local inhabitants).
• Operator safety	Water resistant clothing recommended, particularly for heavily contaminated areas.
• Other practical constraints	Should not be applied at very low frost temperatures.
• Factors influencing costs	Distance to and transport options for equipment and consumables. Worker effectiveness. Worker wages. Need for a pump.
Effectiveness:	
• Countermeasure effectiveness	Reduction of Cs contamination by 50-75 % by early application.
• Factors influencing effectiveness and averted dose/risk	Radionuclide (Cs is strongest bound to surface). Contaminant aerosol type (size, solubility). Road surface type (dust particle size and loading). Time of operation (must be applied within weeks as contaminant binding to surface will increase, and natural weathering through traffic will rather rapidly remove street contaminants). Homogeneity of treatment. Road gutters must be cleaned carefully. Compliance with described procedure. Collective averted doses depend on population density and behaviour.
Waste:	

• Amount and type	Generates some 50 g m^{-2} waste, which is impossible to collect. Waste contamination level: ca. 30000 Bq m^{-3} per Bq m^{-2}.
• Waste management recommendations	The waste should be led to the drains with the run-off water. It is important to clean road sides carefully to avoid accumulation of waste here.
• Specific waste problems	-
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Cleans the street of dirt. Clear information material for users and affected persons must be available before application of method.
State of testing	Small scale tests made in Denmark and USA to find, e.g., influence of street dust loading and application of water.
Key references	K.G. Andersson & J. Roed: "A Nordic Preparedness Guide for Early Clean-up in Radioactively Contaminated Residential Areas", J. Environmental Radioactivity vol. 46, no. 2, pp. 207-223, 1999. L. Warming: "Weathering and decontamination of radioactivity deposited on concrete surfaces", Risø National Laboratory, RISØ-M-2473, 1984.

Lawn mowing

Method description	If contaminants in grassed areas are to a great extent deposited on grass rather than the underlying soil (notably in case of dry deposition), rapid cutting and removal of the grass can greatly reduce dose rate and prevent soil contamination which would be a considerably greater problem. The grass should be cut as close to the soil surface as possible.
Surface type / scale	Contaminated grass covered areas, such as gardens and parks. Can be applied on a large scale if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives and the short natural weathering half-life of road contamination.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	As the natural transfer process of contamination from grass to soil has a half-life of only few weeks (greatly dependant on rainfall), the method should be implemented as early as possible to be effective (certainly before first heavy rain). However, worker doses from short-lived radionuclides must be considered.
Requirements:	
• Equipment / remedies and their costs	Lawn mower with clippings collector (ca. 1000 EURO). Waste transportation trucks (depending on distance to repository).
• Consumables and other practical requirements	Ca. 25 l per ha of petrol.
• Operator skills and costs	Can be carried out by any available personnel. Could be applied as ‘self-help’ after instruction from authorities. Typically 15 h per treated ha (plus 20-40 h per ha if grass must be collected manually by rakes).
• Operator safety	Protective clothes. Respiratory protection if the contamination level is very high and the area is dry.
• Other practical constraints	-
• Factors influencing costs	Mower type (ideally motorised and with collector). Distance to and transport options for equipment and consumables. Worker effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by 50-90 % by early application in case of dry contamination. Generally low effect for wet contamination.

- Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Time of operation (must be applied within weeks to have any effect). Grass length and growth density. Cutting height. Evenness of ground surface. Extent of removal of the cut grass. Homogeneity of treatment. Compliance with described procedure (incl. operator safety recommendations). Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
- Amount and type	Highly variable, depending on length and density of grass cover and cutting height. Typically some 1-2 m^3 per ha. This gives a waste contamination level of ca. 5-10000 Bq m^{-3} per Bq m^{-2}.
- Waste management recommendations	Simple repositories should be constructed. Costs related to transport and disposal must be considered.
- Specific waste problems	Specific activity of waste is relatively high (needs consideration in handling). Without shielding the dose to the driver of a waste transport truck over 1 hour will typically correspond to that from staying in the contaminated area for 1-2 days. Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Clear information material for users and affected persons must be available before application of method.
State of testing	Tested in Europe on a small scale.
Key references	K.G. Andersson & J. Roed: "A Nordic Preparedness Guide for Early Clean-up in Radioactively Contaminated Residential Areas", J. Environmental Radioactivity vol. 46, no. 2, pp. 207-223, 1999. H. Maubert, I. Vovk, J. Roed, G. Arapis & A. Jouve: "Reduction of soil-plant transfer factors: mechanical aspects", Sci. Tot. Env. 137, pp. 163-168, 1993.

Turf harvesting

Method description	In the early phase after an emergency practically all contamination deposited on soil will be in the upper few centimetres. Later on, a downward migration will set in, depending on, e.g., contaminant and soil characteristics. The contaminated upper soil layer can be removed by a turf harvester (standard equipment in grass nurseries), that cuts off thin turf rolls or slabs.
Surface type / scale	Contaminated grass covered areas, such as gardens and parks. Can be applied on a large scale if equipment can be made available within a reasonable timeframe considering important radionuclide half-lives and the short natural weathering half-life of road contamination.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose from ^{137}Cs contamination.
Requirements:	
• Equipment / remedies and their costs	Turf harvester (ca. 10,000 EURO). Many different designs are available. Some also require the use of a tractor. Waste transportation trucks (depending on distance to repository).
• Consumables and other practical requirements	Ca. 20 l per ha of petrol.
• Operator skills and costs	Grass nursery workers or agricultural workers, who are familiar with soil treatment machines and could operate the turf harvester after a few hours of instruction/practice. Care must be taken to remove soil to the optimal depth. Ca. 70 h per ha including loading to waste transport truck.
• Operator safety	Protective clothes. Respiratory protection if the contamination level is very high and the area is dry.
• Other practical constraints	-
• Factors influencing costs	Harvester type and size. Layer depth. Vegetation that requires prior removal. Distance to and transport options for equipment and consumables. Worker skills/effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by 70-90 % if applied optimally and in time.

• Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Uniformity of contamination depth. Time of operation. Cutting depth - must be optimised relative to thorough measurements of vertical soil profile of most important contaminant(s). Evenness of ground surface. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
• Amount and type	Depends on cutting depth. If a 2 cm thick layer is removed: ca. 30 kg m^{-2}. Waste contamination level: ca. 50 Bq m^{-3} per Bq m^{-2}.
• Waste management recommendations	Simple repositories should be constructed. Costs related to transport and disposal must be considered.
• Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further limitations, concerns, side-effects and other costs	Influences public reassurance. Clear information material for users and affected persons must be available before application of method. May increase soil erosion risk and significantly reduce fertility. Adverse aesthetic effect on the area.
State of testing	Tested on relatively large areas of virgin land in the CIS.
Key references	K.G. Andersson, A. Rantavaara, J. Roed, K. Rosén, B. Salbu and L. Skipperud: "A guide to countermeasures for implementation in the event of a nuclear accident affecting Nordic food-producing areas", NKS/BOK1.4 project report NKS-16, ISBN 87-7893-066-9, 76 p., 2000. P. Hubert, L. Annisomova, G. Antsipov, V. Ramsaev, V. Sobotovitch (eds.): "Strategies of decontamination", European Commission, ISBN 92-827-5195-3, Luxembourg, 1996.

Top soil removal (manually)	
Method description	In the early phase after an emergency practically all contamination deposited on soil will be in the upper few centimetres. Later on, a downward migration will set in, depending on, e.g., contaminant and soil characteristics. The contaminated upper soil layer can be removed manually with a spade after careful assessment of the contamination depth.
Surface type / scale	Contaminated open (soil) areas, such as gardens and parks. Can be applied on a large scale if it can be carried out within a reasonable timeframe considering important radionuclide half-lives and the short natural weathering half-life of road contamination.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose from ^{137}Cs contamination.
Requirements:	
• Equipment / remedies and their costs	Spade (ca. 20 EURO). Waste transportation trucks (depending on distance to repository).
• Consumables and other practical requirements	-
• Operator skills and costs	Any available personnel. Could be applied as ‘self-help’ after instruction from authorities. Care must be taken to remove soil to the optimal depth. Ca. 0.1 h per m^2 including loading to waste transport truck.
• Operator safety	Protective clothes. Respiratory protection if the contamination level is very high and the area is dry.
• Other practical constraints	-
• Factors influencing costs	Layer depth. Vegetation that requires prior removal. Worker effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by 90-95 % if applied optimally and in time.

• Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Uniformity of contamination depth. Time of operation. Soil characteristics (dry or sandy soil layers will be more difficult to remove fully, and clay content will limit downward migration). Cutting depth - must be optimised relative to thorough measurements of vertical soil profile of most important contaminant(s). Evenness of ground surface. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
• Amount and type	A removal of a 5 cm topsoil layer will produce about 70 kg m^{-2} waste. Waste contamination level: ca. 20 Bq m^{-3} per Bq m^{-2}.
• Waste management recommendations	Simple repositories should be constructed. Costs related to transport and disposal must be considered.
• Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further constraints, concerns, side-effects and other costs	Influences public reassurance. Clear information material for users and affected persons must be available before application of method. May increase soil erosion risk and significantly reduce fertility. Adverse aesthetic effect on the area.
State of testing	Tested on relatively large areas in the CIS. Carried out by CIS authorities after Chernobyl, but with little effect, since it was not optimised in relation to contamination depth, and not consistently applied over a large area.
Key references	C.L. Fogh, K.G. Andersson, A.N. Barkovsky, A.S. Mishine, A.V. Ponamarjov, V.P. Ramzaev & J. Roed: "Decontamination in a Russian Settlement", Health Physics 76(4), pp. 421-430, 1999.

Top soil removal (mechanically)	
Method description	In the early phase after an emergency practically all contamination deposited on soil will be in the upper few centimetres. Later on, a downward migration will set in, depending on, e.g., contaminant and soil characteristics. The contaminated upper soil layer can be removed with 'Bobcat' mini-bulldozers, which require rather little space in, e.g., a garden (or similar equipment), after careful assessment of the contamination depth.
Surface type / scale	Contaminated open (soil) areas, such as gardens and parks. Can be applied on a large scale if it can be carried out within a reasonable timeframe considering important radionuclide half-lives and the short natural weathering half-life of road contamination.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose from ^{137}Cs contamination.
Requirements:	
• Equipment / remedies and their costs	'Bobcat' mini-bulldozer or similar (40,000 EURO). Waste transportation trucks (depending on distance to repository).
• Consumables and other practical requirements	Ca. 50 l ha^{-1} of petrol.
• Operator skills and costs	Contractors or municipal workers who know how to operate the machinery. Others could be instructed within a day. Care must be taken to remove soil to the optimal depth and not 'smear' the treated soil with contamination. Ca. 100 h per ha including loading to waste transport truck.
• Operator safety	Protective clothes. Respiratory protection if the contamination level is very high and the area is dry.
• Other practical constraints	-
• Factors influencing costs	Layer depth. Vegetation that requires prior removal. Size and type of machine. Distance to and transport options for equipment and consumables. Worker effectiveness/skills. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by 90-95 % if applied optimally and in time.

- Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Uniformity of contamination depth. Time of operation. Soil characteristics (dry or sandy soil layers will be more difficult to remove fully, and clay content will limit downward migration). Cutting depth - must be optimised relative to thorough measurements of vertical soil profile of most important contaminant(s). Evenness of ground surface. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
- Amount and type	A removal of a 5 cm topsoil layer will produce about 70 kg m^{-2} waste. Waste contamination level: ca. 20 Bq m^{-3} per Bq m^{-2}.
- Waste management recommendations	Simple repositories should be constructed. Costs related to transport and disposal must be considered.
- Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further constraints, concerns, side-effects and other costs	Influences public reassurance. Clear information material for users and affected persons must be available before application of method. May increase soil erosion risk and significantly reduce fertility. Adverse aesthetic effect on the area.
State of testing	Tested on relatively large areas in the CIS.
Key references	C.L. Fogh, K.G. Andersson, A.N. Barkovsky, A.S. Mishine, A.V. Ponamarjov, V.P. Ramzaev & J. Roed: "Decontamination in a Russian Settlement", Health Physics 76(4), pp. 421-430, 1999. J. Roed, K.G. Andersson, A.N. Barkovsky, C.L. Fogh, A.S. Mishine, S.K. Olsen, A.V. Ponomarjov, H. Prip, V.P. Ramzaev, B.F. Vorobiev.: "Mechanical Decontamination Tests in Areas Affected by the Chernobyl Accident", Risø-R-1029, ISBN 87-550-2361-4, 101 p., 1998.

Triple digging of soil	
Method description	In the early phase after an emergency, practically all contamination deposited on soil will be in the upper few centimetres. Later on, a downward migration will set in, depending on, e.g., contaminant and soil characteristics. Triple digging is a manual digging method, by which the top (contaminated) layer (ca. 5 cm) is buried at a depth of ca. 45 cm, with the upper surface facing down. The bottom ca. 20 cm layer is placed on top of this, with the intermediate ca. 20 cm layer at the very top (not inverted). Thereby, the contaminated soil is buried deep and shielded well against, and the adverse impact on fertility is minimised (compared with ordinary digging). The contamination depth must first be carefully assessed through measurements.
Surface type / scale	Contaminated open (soil) areas, such as gardens and parks. Can be applied on a large scale if it can be carried out within a reasonable timeframe considering important radionuclide half-lives and the short natural weathering half-life of road contamination.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose from ^{137}Cs contamination.
Requirements:	
• Equipment / remedies and their costs	Spade (ca. 20 EURO).
• Consumables and other practical requirements	-
• Operator skills and costs	Any available personnel. Could be applied as ‘self-help’ after instruction from authorities. Care must be taken to optimise thickness of the 3 soil layers. Ca. 0.4 h per m^2.
• Operator safety	Protective clothes. Respiratory protection if the contamination level is very high and the area is dry.
• Other practical constraints	-
• Factors influencing costs	Layer depth. Soil type, moisture and season influence how easy it is to dig. Vegetation that requires prior removal. Worker effectiveness. Worker wages. Area size influences costs per unit area.
Effectiveness:	

• Countermeasure effectiveness	Reduction of dose rate contribution 1m above the surface from ^{137}Cs (and most other relevant contaminants) by 80-90 % if applied optimally. If edible crops are grown in the soil the method may reduce consumption dose, depending on crop root system.
• Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Uniformity of contamination depth. Time of operation. Soil characteristics (dry or sandy soil layers will be more difficult to exchange, and clay content will limit downward migration). Top layer digging depth - must be optimised relative to thorough measurements of vertical soil profile of most important contaminant(s). Evenness of ground surface. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
• Amount and type	-
• Waste management recommendations	-
• Specific waste problems	-
Further constraints, concerns, side-effects and other costs	Influences public reassurance. It must be accepted that the contamination is not *removed* from the area. In fact it will be very complicated to remove after triple digging. Clear information material for users and affected persons must be available before application of method. May increase soil erosion risk and possibly reduce fertility, although the latter effect will be minimal by optimised application. The area must not subsequently be deep-tilled, due to risk of bringing contaminants back to the surface. Since Cs is strongly bound in soil, it is no problem to bring it closer to the groundwater level, but with other more mobile contaminants there may be a problem that should be considered. Adverse aesthetic effect on the area.
State of testing	Tested on relatively large areas in the CIS.
Key references	J. Roed, K.G. Andersson, C.L. Fogh, A.N. Barkovski, B.F. Vorobiev, V.N. Potapov, A.V. Chesnokov: "Triple Digging - a Simple Method for Restoration of Radioactively Contaminated Urban Soil Areas", J. Environmental Radioactivity vol.45, no.2, pp. 173-183, 1999.

Deep ploughing of soil

Method description	In the early phase after an emergency, practically all contamination deposited on soil will be in the upper few centimetres. Later on, a downward migration will set in, depending on, e.g., contaminant and soil characteristics. By deep ploughing to ca. 45 cm with an ordinary mouldboard plough, the contaminated soil layer is buried deep. This provides good shielding against radiation from the contaminated soil area. The contamination is also placed out of reach of some types of plants.
Surface type / scale	Large contaminated open (soil) areas, such as parks. Can be applied on a large scale.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides).
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose from ^{137}Cs contamination.
Requirements:	
• Equipment / remedies and their costs	Plough (ca. 2,000 EURO). Powerful tractor (ca. 50,000 EURO).
• Consumables and other practical requirements	Ca. 15 l ha^{-1} petrol.
• Operator skills and costs	Agricultural workers, who are used to ploughing. Must be instructed about the specific objective. Ca. 1.5 h per ha^{-1}.
• Operator safety	Protective clothes and respiratory protection – particularly if the contamination level is very high and the area is dry.
• Other practical constraints	-
• Factors influencing costs	Soil type, moisture and season influence work rate. Worker effectiveness/skills. Worker wages. Area size influences costs per unit area.
Effectiveness:	
• Countermeasure effectiveness	Reduction of dose rate contribution 1m above the surface from ^{137}Cs (and most other relevant contaminants) by 80-90 % if applied optimally. If edible crops are grown in the soil the method may reduce consumption dose, depending on crop root system.

• Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Uniformity of contamination depth. Time of operation. Soil characteristics (dry or sandy soil layers will be more difficult to exchange, and clay content will limit downward migration). Evenness of ground surface. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure. Collective averted doses depend on population density and behaviour. Resuspension of contaminants may in the very early phase influence the countermeasure effectiveness.
Waste:	
• Amount and type	-
• Waste management recommendations	-
• Specific waste problems	-
Further constraints, concerns, side-effects and other costs	Influences public reassurance. It must be accepted that the contamination is not *removed* from the area. In fact it will be very complicated to remove after deep ploughing. Clear information material for users and affected persons must be available before application of method. May increase soil erosion risk and significantly reduce fertility. The area must not subsequently be deep-tilled, due to risk of bringing contaminants back to the surface. Since Cs is strongly bound in soil, it is no problem to bring it closer to the groundwater level, but with other more mobile contaminants there may be a problem that should be considered. Adverse aesthetic effect on the area.
State of testing	Tested on large areas in the CIS and on somewhat smaller areas in Denmark.
Key references	Vovk, IF, Blagoyev, VV, Lyashenko, AN & Kovalev, IS: "Technical approaches to decontamination of terrestrial environments in the CIS", Sci. Tot. Env. 137, 49-64, 1993.

Skim-and-burial ploughing of soil

Method description	In the early phase after an emergency, practically all contamination deposited on soil will be in the upper few centimetres. Later on, a downward migration will set in, depending on, e.g., contaminant and soil characteristics. By skim-and-burial ploughing, the thin contaminated topsoil layer is buried deep in the soil profile. This provides good shielding against radiation from the contaminated soil area. The contamination is also placed out of reach of some types of plants. This special plough has two plough shares: one that skims off the top layer (typically 5 cm; must be optimised according to measurements of the contaminant depth) and places it at a depth of ca. 45 cm, and another that lifts a subsoil layer (ca. 50 cm deep) above the 'topsoil', without inverting it. Thereby the adverse effect on soil fertility is minimised.
Surface type / scale	Large contaminated open (soil) areas, such as parks. Can be applied on a large scale, although the ploughs are not readily available. They can be constructed over a period that is short compared with the time that the relevant doses would be received over.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides).
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose from ^{137}Cs contamination.
Requirements:	
• Equipment / remedies and their costs	Skim-and-burial plough (ca. 4,000 EURO). Powerful tractor (ca. 50,000 EURO).
• Consumables and other practical requirements	Ca. 15 l ha^{-1} petrol.
• Operator skills and costs	Agricultural workers, who are used to ploughing. Must be instructed about the specific objective. Ca. 3 h per ha^{-1}.
• Operator safety	Protective clothes and respiratory protection – particularly if the contamination level is very high and the area is dry.
• Other practical constraints	-
• Factors influencing costs	Soil type, moisture and season influence work rate. Worker effectiveness/skills. Worker wages. Area size influences costs per unit area.
Effectiveness:	

- Countermeasure effectiveness	Reduction of dose rate contribution 1m above the surface from ^{137}Cs (and most other relevant contaminants) by 82-92 % if applied optimally. If edible crops are grown in the soil the method may reduce consumption dose, depending on crop root system.
- Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Uniformity of contamination depth. Time of operation. Soil characteristics (dry or sandy soil layers will be more difficult to exchange, and clay content will limit downward migration). Evenness of ground surface. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure. Collective averted doses depend on population density and behaviour. Resuspension of contaminants may in the very early phase influence the countermeasure effectiveness.
Waste:	
- Amount and type	-
- Waste management recommendations	-
- Specific waste problems	-
Further constraints, concerns, side-effects and other costs	Influences public reassurance. It must be accepted that the contamination is not *removed* from the area. In fact it will be very complicated to remove after deep ploughing. Clear information material for users and affected persons must be available before application of method. May reduce fertility, although this adverse effect is minimised. The area must not subsequently be deep-tilled, due to risk of bringing contaminants back to the surface. Since Cs is strongly bound in soil, it is no problem to bring it closer to the groundwater level, but with other more mobile contaminants there may be a problem that should be considered. Adverse aesthetic effect on the area.
State of testing	Tested in areas up to 1 ha in the CIS and in Denmark.
Key references	Roed, J, Andersson, KG & Prip, H: "The Skim and Burial Plough: a New Implement for Reclamation of Radioactively Contaminated Land", J. Environmental Radioactivity vol.33, no.2, pp. 117-128, 1996.

Snow removal

Method description	Some Nordic areas will over a large part of the year be covered by snow. If a thick snow cover is contaminated (either through dry deposition or deposition in snowfall), the top layer of the snow (ca. 5 cm) can be removed together with virtually all the contamination. Thereby the contaminants would never reach the underlying surface (where the problem would be much more severe). The method requires early application, certainly before the first thaw. It can be accomplished with, e.g., 'Bobcat' mini-bulldozers, front-loaders or tractors with scrapers on open areas. Alternatively, the snow can, with much greater effort, be removed with hand tools (manual scrapers, shovels). This would be required if contaminated snow were to be removed from a roof.
Surface type / scale	Contaminated open areas - particularly gardens, parks and other soil areas, but also paved areas and roofs of buildings. Can be applied on a large scale if it can be carried out within a reasonable timeframe considering important radionuclide half-lives and the time-frame determining the method effectiveness.
Relevant contaminants	Cs (and other long-lived gamma emitting radionuclides)
Time of implementation	Should generally be carried out as early as possible (before first thaw), when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose from ^{137}Cs contamination.
Requirements:	
• Equipment / remedies and their costs	Open areas: 'Bobcat' mini-bulldozer or similar (40,000 EURO). (possible alternatives: front-loader (80,000 EURO), tractor with scraper (50,000 EURO)). Roofs: manual scrapers, shovels. Waste transportation trucks (depending on distance to dumping site).
• Consumables and other practical requirements	Ca. 50 l ha^{-1} of petrol for 'Bobcat'.

- Operator skills and costs	Contractors or municipal workers who know how to operate the machinery or work on a roof. Others could be instructed within a day. Care must be taken to remove snow to the optimal depth and not 'smear' the underlying surface with contamination. Open areas: ca. 40 h per ha including loading to waste transport truck. Roofs: ca. 10 minutes per m^2 roof.
- Operator safety	Protective clothes, boots and gloves. In dry frost and storm also respiratory protection.
- Other practical constraints	-
- Factors influencing costs	Layer depth. Vegetation that requires prior removal. Size and type of machine. Distance to and transport options for equipment and consumables. Worker effectiveness/skills. Worker wages. Area size influences costs per unit area.
Effectiveness:	
- Countermeasure effectiveness	Reduction of contamination by 90-98 % (both on open areas and roofs) if applied optimally and in time (influences uptake to subsequently grown crops in open areas accordingly).
- Factors influencing effectiveness and averted dose/risk	Contaminant aerosol type (size, solubility). Uniformity of contamination depth. Time of operation. Cutting depth. Evenness of ground surface. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure. Contamination in neighbouring areas influences avertable individual doses. Collective averted doses depend on population density and behaviour.
Waste:	
- Amount and type	A removal of a 5 cm top snow layer will produce about 50 kg m^{-2} waste. Waste contamination level: ca. 20 Bq m^{-3} per Bq m^{-2}.
- Waste management recommendations	May be disposed of in the sea or in other water bodies where the environmental impact is negligible (must be considered carefully as e.g., some lakes are reservoirs for drinking water). Costs related to transport and disposal must be considered.
- Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further constraints, concerns, side-effects and other costs	Influences public reassurance. Clear information material for users and affected persons must be available before application of method.
State of testing	Tested in realistic scale in Norway.
Key references	C. Qvenild & U. Tveten: "Decontamination and winter conditions", Institute for Energy Technology, Kjeller, Norway, ISBN 82-7017-067-4, 1984.

Indoor floor and wall decontamination

Method description	Airborne contaminants can penetrate into buildings and give rise to considerable indoor contamination (depending on physico-chemical characteristics of contaminants and indoor surfaces as well as dwelling type and deposition mode). This can give high dose contributions from floor/indoor walls, particularly over the first year. Over longer periods of time outdoor contaminants may also be tracked in by humans. Thorough vacuum cleaning of door mats and washing of uncovered floors on a regular basis can reduce this dose, and also washing of indoor walls (or removal of wall paper) can in strongly contaminated areas be recommended.
Surface type / scale	Contaminated walls and floors of dwellings. Particularly floors, as most of the airborne contamination from an outdoor incident, and virtually all tracked-in contamination will deposit here. Can be applied on a large scale.
Relevant contaminants	Cs (and other long-lived gamma or beta emitting radionuclides)
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. In strongly contaminated areas, careful regular floor cleaning would be recommended over years.
Requirements:	
• Equipment / remedies and their costs	Ordinary household vacuum cleaner (ca. 200 EURO). Cloth/ washing sponge (ca. 1 EURO).
• Consumables and other practical requirements	About four vacuum cleaner filter bags per 100 m^2 per year, and variable costs for water and cleaning detergent.
• Operator skills and costs	Could be applied as ‘self-help’ after instruction from authorities. Vacuuming takes about 0.5 minute per m^2, washing typically 2-4 minutes per m^2, depending on orientation of surface.
• Operator safety	Respiratory protection recommended in strongly contaminated areas. Water-proof plastic gloves recommended for washing.
• Other practical constraints	-
• Factors influencing costs	Worker effectiveness. Vacuum cleaner type. Strategy for walls (cleaning or wallpaper removal).
Effectiveness:	

• Countermeasure effectiveness	Within short time (few days), particles smaller than ca. 3 µm will become attached to or clustered in larger particles. These can (contrary to the smaller particles) effectively be removed by vacuum cleaning (removal efficiency: more than 90 %). Tracked-in soil particles are large and easily removed. Washing of floors and walls will typically remove 30-60 % of the contamination. Removal of wallpaper can remove virtually all contamination from a wall.
• Factors influencing effectiveness and averted dose/risk	Surface type. Time of operation. Dust loading at the time of deposition. Vacuum cleaner type (preferably equipped with efficient outlet filter). Cleaning detergents. Care taken to carefully clean the whole surface. Contaminant aerosol type (size, solubility). Cleaning frequency. Human (or animal) activities in dwelling affect amounts and types of house dust to which contaminants may attach. Collective averted doses depend on population density and behaviour.
Waste:	
• Amount and type	Contaminated vacuum cleaner filters (variable, but generally high specific activity). Perhaps some 40 g m^{-2} per year. Contaminated cloths or sponges. Contaminated washing water can be led to the drains.
• Waste management recommendations	Simple repositories should be constructed. Costs related to transport and disposal must be considered.
• Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further constraints, concerns, side-effects and other costs	Influences public reassurance. Clear information material for users and affected persons must be available before application of method.
State of testing	Small-scale tests have been made both before and after the Chernobyl accident.
Key references	Allott, R.W., Kelly, M. & Hewitt, C.N.: "A model of environmental behaviour of contaminated dust and its application to determining dust fluxes and residence times", Atmospheric Environment 28(4), pp. 679-687, 1994. Roed, J.: "Relationships in indoor/outdoor air pollution", Risø Natinal Laboratory, Risø-M-2476, 1985.

Indoor furniture decontamination	
Method description	Airborne contaminants can penetrate into buildings and give rise to considerable indoor contamination (depending on physico-chemical characteristics of contaminants and indoor surfaces as well as dwelling type and deposition mode). This can give high dose contributions from contaminated furniture, e.g. regularly used sleep sofas, which come into very close contact with persons. Early vacuum cleaning of soft (upholstered) furniture can reduce this dose, but if (part of) the contamination has penetrated into the upholstering, it may be recommendable to get rid of the furniture. Dusting of hard furniture (e.g., tables and cupboards) can also reduce dose.
Surface type / scale	Contaminated furniture in dwellings. Can be applied on a large scale.
Relevant contaminants	Cs (and other long-lived gamma or beta emitting radionuclides)
Time of implementation	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered.
Requirements:	
• Equipment / remedies and their costs	Ordinary household vacuum cleaner (ca. 200 EURO). Cloth (ca. 1 EURO). Waste transportation trucks (depending on distance to repository).
• Consumables and other practical requirements	Vacuum cleaner filter bags (since it would also be recommended to vacuum clean the floor regularly and over a long time period, the extra amount of dust from cleaning furniture once would probably add little to the cost).
• Operator skills and costs	Could be applied as ‘self-help’ after instruction from authorities. Vacuuming takes about 1 minute per m^2 furniture surface. Dusting (with cloth) can be done in half that time.
• Operator safety	Respiratory protection recommended in strongly contaminated areas.
• Other practical constraints	-
• Factors influencing costs	Worker effectiveness. Vacuum cleaner type.
Effectiveness:	

• Countermeasure effectiveness	Within short time (few days), particles smaller than ca. 3 µm will become attached to or clustered in larger surface particles (unless they have penetrated upholstering). These large contaminant particles on furniture surfaces can (contrary to the smaller particles) effectively be removed by vacuum cleaning (removal efficiency: more than 90 %). Tracked-in or blown-in soil particles are large and easily removed. Dusting of hard surfaces can remove 20-95 % of the contamination, depending on particle characteristics.
• Factors influencing effectiveness and averted dose/risk	Surface type. Time of operation. Dust loading at the time of deposition. Vacuum cleaner type (preferably equipped with efficient outlet filter). Care taken to carefully clean the whole surface. Contaminant aerosol type (size, solubility). Human (or animal) activities in dwelling affect amounts and types of house dust to which contaminants may attach. Collective averted doses depend on population density and behaviour.
Waste:	
• Amount and type	Contaminated vacuum cleaner filters (variable, but generally high specific activity). Only a few g m^{-2}. Contaminated cloths. If upholstered furniture is disposed of (only in very strongly contaminated areas), this would add much waste.
• Waste management recommendations	Simple repositories should be constructed. Costs related to transport and disposal must be considered.
• Specific waste problems	Public acceptability and legal feasibility of waste treatment and storage route should be assessed.
Further constraints, concerns, side-effects and other costs	Influences public reassurance. Clear information material for users and affected persons must be available before application of method.
State of testing	Small-scale tests have been made before and after the Chernobyl accident.
Key references	Allott, R.W., Kelly, M. & Hewitt, C.N.: "A model of environmental behaviour of contaminated dust and its application to determining dust fluxes and residence times", Atmospheric Environment 28(4), pp. 679-687, 1994. Roed, J.: "Relationships in indoor/outdoor air pollution", Risø National Laboratory, Risø-M-2476, 1985.

Appendix B: Countermeasure datasheets for kitchen gardens

In addition to some of those countermeasures described in Appendix A, which may, as stated in section 6, be useful in reducing both external doses and doses from consumption of food grown in an inhabited area, a selection of four countermeasures specifically aimed at reducing doses from consumption of food produced in kitchen garden lots in inhabited areas are described in the following pages. The information is based on a previous Nordic review (Andersson et al., 2000).

Liming of soil

Method description	Strontium behaves in soil like the macro nutrient Ca. Liming increases pH and reduces root uptake of ^{90}Sr. Effect of liming depends on actual pH or base saturation and on CEC of the soil. Liming releases K^+ to the soil solution and slightly reduces root uptake of ^{137}Cs.
Surface type / scale	Kitchen gardens from which contamination enters the food chain by uptake to crops. Can be practised on a large scale.
Relevant contaminants	Radiostrontium
Time of implementation	Liming can be made at any time when it is possible to mix the lime material with soil by harrowing or turning soil.
Requirements:	
• Equipment / remedies and their costs	Spreading device (dependent on size of area), spade (20 Euro) for turning soil.
• Consumables and other practical requirements	Lime (1-8 tonnes CaO per ha).
• Operator skills and costs	1 operator ca. 0.02 man-days m^{-2} (incl. digging) plus loading and transport of lime. No specific skills needed. Could be applied as 'self-help' after instruction from authorities.
• Operator safety	Protective clothes. Respiratory protection if the contamination level is very high and the area is dry.
• Other practical constraints	Liming may induce manganese deficiency (oats).
• Factors influencing costs	Soil type, moisture and season influencing how easy it is to turn the soil. Vegetation that requires prior removal. Worker effectiveness. Worker wages. Area size influences costs per unit area. Fertiliser transportation costs.
Effectiveness:	
• Countermeasure effectiveness	*Impact on ^{90}Sr:* Liming from pH 5 to pH 7 may decrease plant uptake of ^{90}Sr by a factor 2 on sandy soils, 3 on loamy soils and 4 on clay soils, from pH 4 to pH 6 by a factor 6 on organic soils. Liming in excess of pH 7/6 has no effect. *Impact on ^{137}Cs.* Liming may also decrease uptake of ^{137}Cs by a factor 1.3-1.6 (max. ca. 3). Corrective liming lasts for at least 5 years. Maintenance liming every 5 years, to pH 7 on mineral soils and to pH 6 on organic soils, is recommended (0.5-2 tonnes CaO ha^{-1}).
• Factors influencing effectiveness and averted dose/risk	Soil characteristics - effective on acid soils (see also above comments on soil pH). Contaminant aerosol type. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure.
Waste:	
• Amount and type	-
• Waste management recommendations	-
• Specific waste problems	-

Further constraints, concerns, side-effects and other costs	Crop yield may be increased by solving acidity problems. Liming prevents some diseases that attack crops. K- and Mg-fertilisation may be required to maintain optimal ionic equilibrium in soil and plant.
State of testing	Applied on a large scale in the former Soviet Union after the Chernobyl accident. Routine soil management technique.
Key references	Rapport FOA 4 C-4395-28, Stockholm, 1969. Report 31, Radiobiology, Uppsala, ISBN 91-, 1975. Technical report series No363, ISBN 92-0-100-894-5, 1994.

Potassium fertilisation

Method description	Caesium behaves in the soil solution like the macro nutrient K. Binding of ^{137}Cs in soil is very complex. Fixation of carrier free fallout ^{137}Cs increases with content of clay and decreases with content of organic matter. K-fertilisation decreases plant uptake of ^{137}Cs.
Surface type / scale	Kitchen gardens from which contamination enters the food chain by uptake to crops. Can be practised on a large scale.
Relevant contaminants	Radiocaesium
Time of implementation	K-fertilisation is mandatory and should be made as soon as possible after fallout both on grass land and arable soils; on arable soils together with soil management operations (turning of soil).
Requirements:	
• Equipment / remedies and their costs	Spreading device (dependent on size of area). Spade (20 Euro) for turning soil.
• Consumables and other practical requirements	Potassium fertiliser (100-200 kg K ha^{-1}). Repeated treatment may be necessary.
• Operator skills and costs	1 operator ca. 0.02 man-days m^{-2} (incl. digging) plus loading and transport of lime. No specific skills needed. Could be applied as 'self-help' after instruction from authorities.
• Operator safety	Protective clothes. Respiratory protection if the contamination level is very high and the area is dry.
• Other practical constraints	K-fertilisation during growth season can usually only be made after removal of existing crop stand.
• Factors influencing costs	Soil type, moisture and season influencing how easy it is to turn the soil. Vegetation that requires prior removal. Worker effectiveness. Worker wages. Area size influences costs per unit area. Fertiliser transportation costs.
Effectiveness:	
• Countermeasure effectiveness	*Impact on ^{137}Cs and ^{134}Cs:* Effect of K-fertilisation on ^{137}Cs uptake by crops is highly dependent on the actual K-status in soil. In potassium deficient soils the uptake reduction may be by a factor of up to 5. It may be required to repeat the treatment in following years.
• Factors influencing effectiveness and averted dose/risk	Soil characteristics (K status, soil type). Contaminant aerosol type. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure.
Waste:	
• Amount and type	-
• Waste management recommendations	-
• Specific waste problems	-
Further constraints, concerns, side-effects and other costs	Mg-fertilisation and liming may be required to maintain optimal ionic equilibrium in soil and plant. Fertiliser must not contain ammonium. Crop yield increases on soils with originally low potassium status.

State of testing	Applied on a large scale in the former Soviet Union after the Chernobyl accident. Routine soil management technique.
Key references	Rapport FOA 4 C-4557-A3, Stockholm, 1973. Technical report series No363, ISBN 92-0-100-894-5, 1994. SLU-REK-78, ISBN91-576-5134-5, 1996.

Supplement fodder with micas or zeolites

Method description	Give micas and/or zeolites as a supplement to fodder to reduce uptake of Cs in the animal by reducing absorption.
Surface type / scale	Meat and milk of animals kept in small land areas in inhabited environments. Can be practised on a large scale when supplements are available.
Relevant contaminants	Radiocaesium
Time of implementation	Medium and long term after deposition. Unlimited period.
Requirements:	
• Equipment / remedies and their costs	-
• Consumables and other practical requirements	Micas and/or zeolites.
• Operator skills and costs	Personnel to collect the herd and to feed and monitor the animals. (8 hours for 30 days – 2500 to 6500 Euro). Could be applied as 'self-help' after instruction from authorities.
• Operator safety	
• Other practical constraints	Clay minerals cannot be fed directly in semi-natural ecosystems and are not sufficiently effective to be used in salt licks or boli.
• Factors influencing costs	Costs of producing fodder with supplements.
Effectiveness:	
• Countermeasure effectiveness	A reduction of 50 – 80% in the transfer of radiocesium to milk and meat of cows, sheep and reindeer can be achieved at daily doses of about 500 mg – 2 g.
• Factors influencing effectiveness and averted dose/risk	Contamination level/ need for supplements (feeding high levels of clays or zeolites may be problematic for the animal in terms of appetite and loss of weight. Different minerals have different binding efficiencies. Homogeneity of treatment. Worker protection (see above). Compliance with described procedure.
Waste:	
• Amount and type	-
• Waste management recommendations	-
• Specific waste problems	-
Further constraints, concerns, side-effects and other costs	Inappropriate for use as a countermeasure for freely grazing ruminants. Can be used during decontamination feeding.
State of testing	Has been applied for some time in Nordic countries after the Chernobyl accident, but was here not deemed to be highly cost-effective.
Key references	Hove, K., (1993) The Science of the Total Environment, 137, 235-248, Andersson, I. (1989) Swedish J. Agr. Res. 19: pp. 85-92, Andersson, I. (1990) Swedish J. Agr. Res. 20: pp. 35-42.

Parboiling mushrooms

Method description	Parboiling fresh mushrooms in excess of water (about fourfold volume of water compared to mushrooms). Boiling time at least 3 minutes, discarding the water and rinsing mushrooms with plenty of cold water. Major part, about 90% of radiocaesium will be removed from Lactarius type mushrooms. All species can be parboiled to remove caesium.
Surface type / scale	Edible mushrooms to be parboiled or not after the normal instructions of consumer guidance. Can be practised on a large scale.
Relevant contaminants	Particularly radiocaesium, but also effective for other radionuclides present in mushrooms.
Time of implementation	Unlimited period, as long as additional reduction of ingestion dose from mushrooms is needed.
Requirements:	
• Equipment / remedies and their costs	Kettle with sufficient volume.
• Consumables and other practical requirements	Cost for electricity and water.
• Operator skills and costs	Working time for the treatment of mushrooms increases, if species not parboiled normally are treated. Could be applied as 'self-help' after instruction from authorities.
• Operator safety	-
• Other practical constraints	The volume ratio of water and mushrooms should be at least 4 to get the expected result. Mushroom species with thick and hard surface cover may need longer treatment than 3 minutes.
• Factors influencing costs	Boiling time required.
Effectiveness:	
• Countermeasure effectiveness	Internal DRF: The fraction of initial activity remaining in edible part of mushrooms is about 10 %. Specific for Cs, but all radionuclides will be removed to some degree.
• Factors influencing effectiveness and averted dose/risk	With a repeated treatment the remaining activity fraction becomes 5% or less.
Waste:	
• Amount and type	Boiling water (not highly active)
• Waste management recommendations	Can be led through ordinary drain system.
• Specific waste problems	-
Further constraints, concerns, side-effects and other costs	The taste of mushrooms does not disappear, as the best aromatic constituents are not water soluble. Consumption of mushrooms can continue after rather heavy fallout, if parboiling is used for most types of mushrooms.
State of testing	Applied widely in domestic households after the Chernobyl accident. Routine food preparation method.

Key references	Rantavaara A. Proceedings of the Seminar on radioactivity transfer during cooking and culinary preparation, Cadarache 1989. Report XI-3508/90, CEC, DG XI, 1990, p. 69 - 94.

Appendix C: Organisational structure of Nordic emergency management regarding remediation of radioactively contaminated inhabited areas

This appendix describes the organisations that are involved in the remediation of radioactively contaminated inhabited areas in the different Nordic countries. The descriptions are from the year 2005. The national descriptions are compared in order to outline differences and similarities.

C.1 Introduction

Recovering from the disaster of a radioactively contaminated living environment is a process that involves many authorities at governmental, provincial, and municipality level. This appendix describes the organisational structures in the Nordic countries in this respect.

Such descriptions are valuable for each country to have as they tell or remind the national stakeholders – residents, authorities, business representatives – who is in charge of what. Whereas such descriptions have been available for the co-operation, information exchange and assistance between Nordic authorities (The Nordic Manual, 2006), for the early emergency management (NKS Internet database, 2001) and for agricultural countermeasures (Brink & Lauritzen, 2001), a description was missing for the remediation of contaminated inhabited areas. One purpose of the present description is to fill this gap and to provide those that are concerned or otherwise interested with relevant information.

Another purpose is to foster mutual understanding within the Nordic countries by outlining organisational differences and similarities. Differences might be found, for example, in the political level (national, regional, local) at which certain activities are performed or in the degree of centralisation (or inversely de-centralisation) of organisational structures. Other distinctive features are whether there are permanently staffed crisis centres as opposed to organisations that reduce their regular agenda in order to free resources for the crisis management. In addition, the former have often a much broader agenda and deal not merely with radiation accidents.

The focus is on the organisational structure of emergency management, which is understood to comprise all activities related to the management of the situation. Organisational structures and activities related to the improvement of the process of emergency management, like training and exercise, development of the legal framework, guidance or support tools, which are essential parts of emergency preparedness, are – although occasionally mentioned in the national descriptions – not further considered.

It is recognised that a radioactively contaminated living environment and clean-up actions in settlements pose severe social problems in addition to being of radiological concern. The report strives to address the issue holistically. However, the author and contributors cannot deny their belonging to the radiation protection community.

The central part of this appendix is formed by the different national descriptions, which tabulate the involved organisations and their tasks or responsibilities in the crisis management. It follows a discussion section, in which the Nordic emergency management is looked at from different angles. The first view is guided by generic activities of the recovery process, like coordination and supervision, technical support and advice, decision making, implementation of actions and feedback, and information and communication. Another view focuses on the different aspects that need consideration and organisations involved.

C.2 Organisations and their responsibilities during remediation in different Nordic countries

This section presents – in a separate table for Denmark, Finland, Norway and Sweden – the organisations and institutions involved in the remediation process and the responsibilities they have in that process. These organisations can be anything from committees that convene for a particular purpose, over constantly operating crisis centres to institutions that provide their normal expertise without having any emergency mode of operation. The information was provided by radiation protection practitioners of each country, and reflects the situation of the year 2005.

As the actual response organisation typically depends on the extent, phase and type of disaster, a minimum amount of context was provided in form of a scenario that outlined a severe nuclear accident at a domestic or foreign NPP that let – in conjunction with unfavourable weather conditions – to a considerable contamination of inhabited areas within the own territory. Urgent rescue operations, relocation, or access restrictions were not deemed necessary, but otherwise the highest activation level of the response organisation was envisaged. The scenario tried to make it possible to concentrate on the organisational structure pertaining to clean-up actions without interference from rescue operations, which might follow a different command line.

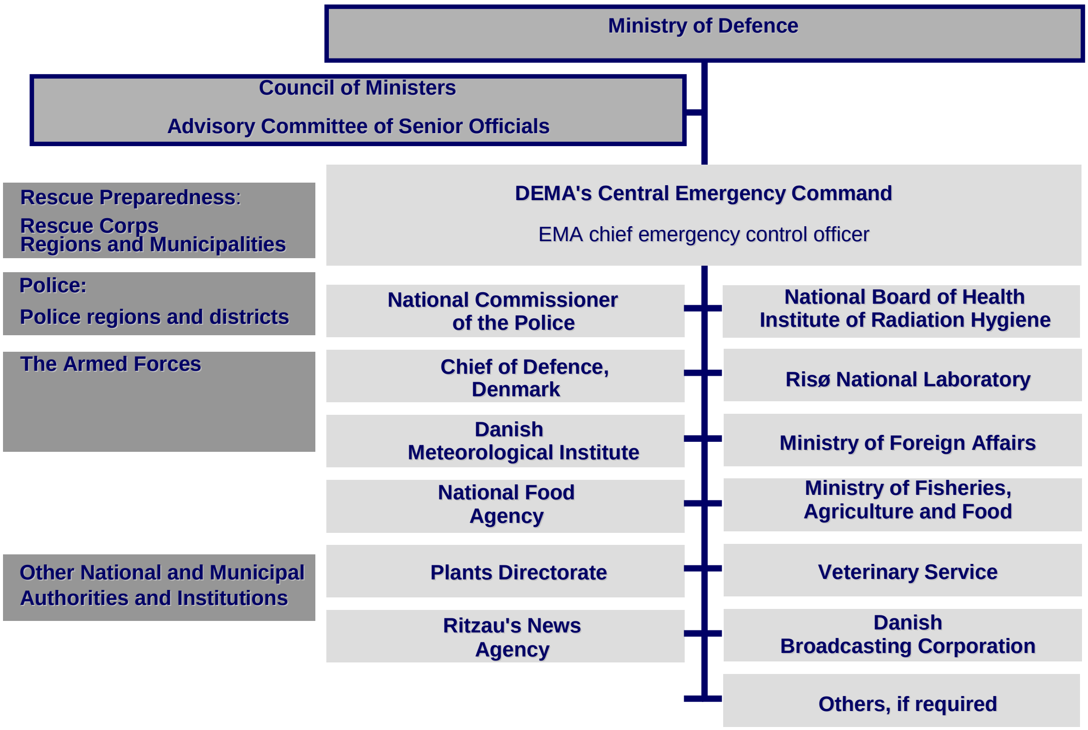
The author highlighted keywords of the given national descriptions in order to facilitate comparison in the Discussion section; and he greyed out responsibilities that do not directly concern remediation of contaminated areas as described in the scenario.

Table C.1. Organisations that are involved in remediation in Denmark and their respective responsibilities (situation of 2005)

Organisations	Responsibilities
Danish Emergency Management Agency (DEMA/ Beredskabsstyrelsen), Nuclear Division (NCA, National Competent Authority)	• Primary responsibility for preparedness and response to nuclear emergencies, including the national operations centre • Its duty officer initiates appropriate emergency response action • coordinates all responses to nuclear emergencies, assisted by experts from the other authorities involved • coordinates all countermeasures in cooperation with the Ministry of Interior and Health, the National Institute of Radiation Hygiene and the Ministry of Agriculture • responsible for decision support systems for predicting and presenting predicted as well as measured radiation levels • responsible for all nuclear 24/7 monitoring systems • directs measurement teams (airborne and car borne automatic measurement systems with isotope identification and with hand held metering devices) • responsible for training of measurement teams in the use of measurement equipment • establishes questions-and-answers centres to enable the authorities to respond to a large number of enquiries from the public • Internet information servers are used to keep the public informed
Ministry of Defence	• a liaison officer will be present at the national operations centre in case of a nuclear emergency • helicopters will be used for airborne measurements • military forces may be used to assist rescue services
National Institute of Radiation Hygiene	• supplies expertise in radiation protection
Ministry of Interior and Health	• Health services and hospitals
Risø National Laboratory	• Supplies expertise in nuclear engineering, measurement techniques, prognostication and clean-up operations • Checks radiation levels in food and fodders
Ministry of Family and Consumer Affairs	• supplies expertise in limiting the levels of radioactivity in food • suggests measures to ensure that food is “safe”
International Contact Point (at national police headquarters)	• National warning point • Alerts DEMA duty officer in case of an emergency outside Denmark • Assists in initiating emergency response
Danish Meteorological Institute (DMI)	• Expert assistance to the national command post in case of a nuclear emergency • Supplies data for prognostication of nuclear contamination
First responders from DEMA’s rescue service Local rescue services Volunteer services	• mobile measurement teams with hand held measuring devices • decontamination units • are trained to take appropriate action to minimize the consequences of a nuclear or radiological emergency
Police	• a liaison officer will be present at the national operations centre in case of a nuclear emergency • assists in issuing warnings to the public and other normal police matters
National broadcasting corporation (DR) and press service (Ritzau)	• Are by law bound to promulgate messages to the public in case of an emergency • Representatives are present at the national command post in case of a nuclear emergency

The emergency planning and response preparedness of Denmark follows IAEA requirements (IAEA Safety Standards Series No. GS-R-2). Primary responsibility rests in Denmark with the Danish Emergency Management Agency (DEMA) under the Ministry of Defence. While no specific plans exist for the longer term recovery operations, institutional arrangements are in hand which would allow for a coordinated and controlled transition from emergency response to recovery operations.

The relations between the Danish authorities (situation of 2005) are shown in this figure:



The organisation of the National Operations centre (situation of 2005) is shown below:

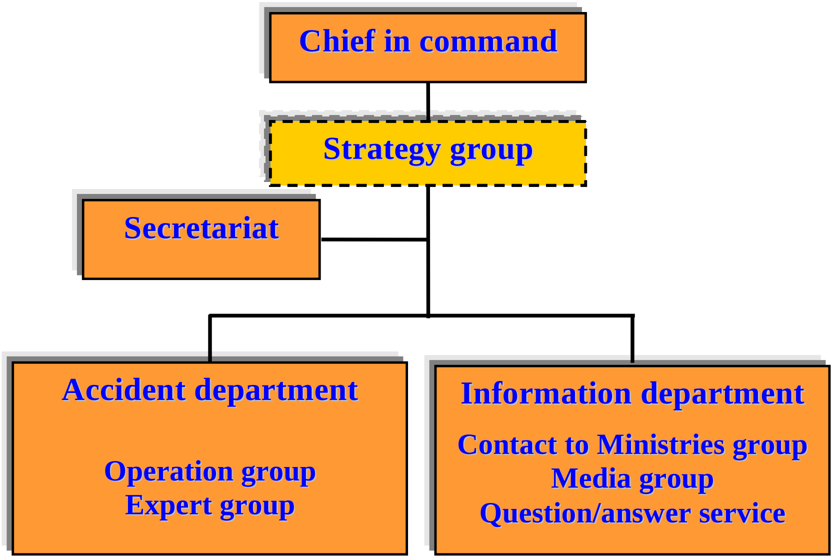


Table C.2. Organisations that are involved in remediation in Finland and their respective responsibilities (situation of 2005)

Organisations	Responsibilities
Council of State (Government), and Ministries • Ministry of Social Affairs and Health • Ministry of the Environment • Ministry of Transport and Communications • Ministry of the Interior • Ministry of Trade and Industry • National Food Agency • Ministry of Agriculture and Forestry	• Political decisions on clean-up actions and compensation issues are made by the Council of State especially when large areas are contaminated and high costs would incur. Otherwise, decisions on clean-up actions are made by the relevant administrative sectors (depending on the extent of contamination) on the governmental, provincial or municipal level. • The Information Unit of the Council of State and the Ministries disseminate information to media[1]
Radiation and Nuclear Safety Authority (STUK)	• monitor contamination, e.g. car-borne deposition survey, laboratories for foodstuffs and environmental samples, etc. • assess health consequences for public and clean-up workers • evaluate different clean-up options • evaluate long term effects of remediation • give recommendations for protective measures and clean-up actions • disseminate information to media concerning radiation protection issues[1] • advise industry, trade, transport on radiation issues • give advice for waste disposal
State Provincial Offices	• supervise and coordinate between governmental level and municipalities • allocate resources, e.g. direct activities of subordinate authorities
Social and health authorities • Ministry of Social Affairs and Health, and its regional sections	• responsible for general safety of public health and social security • disseminate information to media about issues concerning public health and social security[1]
Environmental authorities • Ministry of the Environment • Regional environmental centres	• make strategic plans at national level and sets targets for environmental protection • ensure that waste management obeys environmental legislation
Rescue authorities • Ministry of the Interior • Regional rescue services • Municipal and voluntary fire brigades	• provide logistic services and executive assistance, e.g. equipment and personnel
Defence Forces	• provide logistic services and executive assistance: clean-up equipment, personnel, personal protection material, dosimeters • perform airborne deposition mapping
General management of the municipalities, comprising • municipal manager • environmental authority • social and health authority • construction authority • waste management authority	• implement on actually performed clean-up actions (where, when, how, who) based on decision of Council of State and Ministries • request resources from State Provincial Office • hire services and equipment needed, e.g. transport services, front loader • advise residents • organise waste disposal
Local laboratories (40 municipal laboratories)	• monitor foodstuffs and environmental samples
Nuclear insurance pool	• liability questions[2]

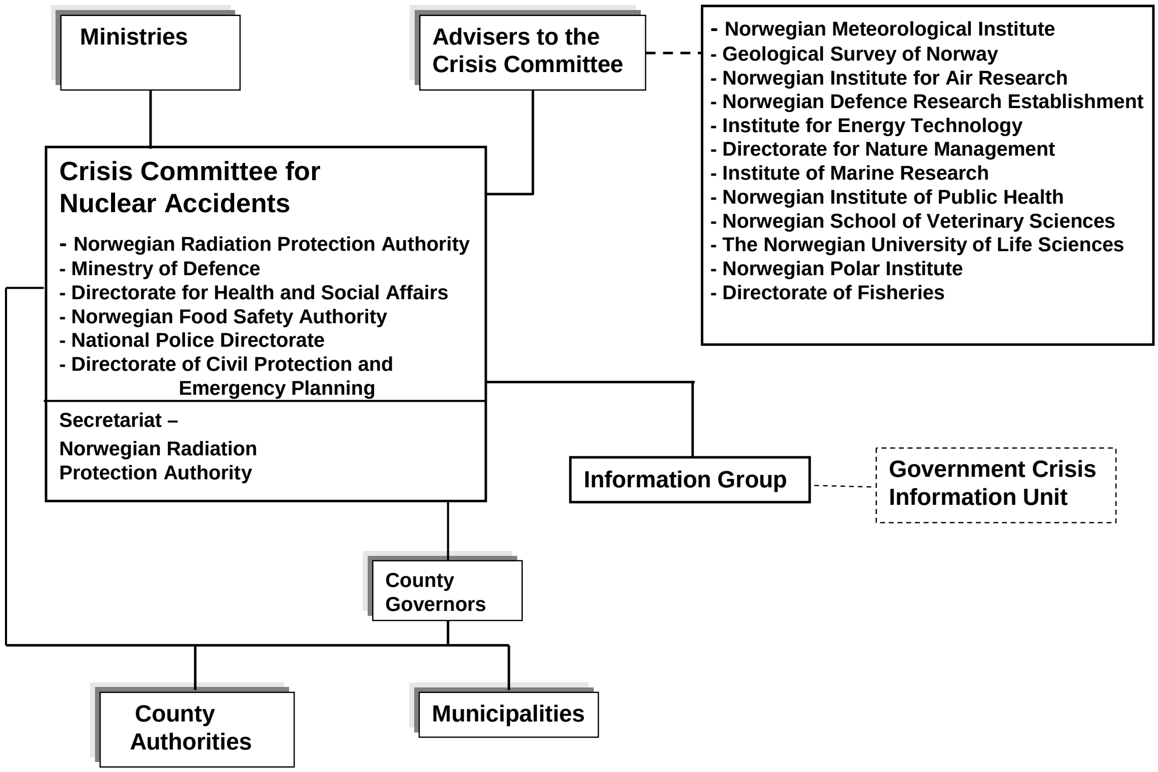
[1] In Finland it is generally practice that authorities at governmental, provincial, and municipality level inform the media on issues that belong to their responsibility.

[2] Nuclear liabilities are regulated in Finland by the Nuclear Liability Act (484/1972). Finland is a contracting party to the Paris and Brussels Conventions on Nuclear Liability. According to the internationally agreed principles manifested in these Conventions, the liability for damage lies with the operator of the nuclear installation. The principles ensure that a person entitled to compensation can receive the compensation for a suffered damage according to the nuclear liability regulations. The liability of the operator, however, is limited to a prescribed maximum amount. If the damage as a consequence of the accident exceeds this amount, the country in which the damaged nuclear facility is located, covers the additional costs to a certain limit. The last instance paying compensations to those suffered will finally be – but also to a limited extent – the community of all contractors to the above mentioned Conventions. At the end of 2005 the Finnish Nuclear Liability Act has been amended, but not yet set into force, to include the principle of unlimited liability of the licensee and also to increase the amount of available resources to pay compensation for the suffered damages. The setting into force of the amendment is waiting for the ratification of the recently amended Paris and Brussels Conventions.

Table C.3. Organisations that are involved in remediation in Norway and their respective responsibilities (situation of 2005)

Organisations	Responsibilities
Ministries: Ministries of Health, Justice and Police, Defence, Foreign Affairs, the Environment, Agriculture, Fisheries, Trade and Industry, Education and Research, Ministry of Labour and Government Administration, and the Ministry of Transport and Communications	• emergency preparedness in their area of competence • in order to deal effectively with the early phase of a nuclear accident, the Ministries have transferred responsibility for remedial actions to the Crisis Committee for Nuclear Accidents
Ministerial Coordination Committee	• ensuring cooperation and coordination between the different Ministries • Ministry of Health head the Committee
Crisis Committee (CC)	• deciding and implementing remedial actions in case of a nuclear incident or an impending nuclear accident representing a potential threat to Norway • organise the evacuation of the population if the situation represents a direct threat to health and life • provide shelter • administer stable iodine • block and secure contaminated areas • in the short term restrict production and distribution of foodstuffs • give advise on dairy products • advice industry, trade, transport • national coordination
Norwegian Radiation Protection Authority (NRPA)	• functions as national warning point (NWP) and national competent authority (NCA) • functions as secretary and leader of the Crises Committee • alerting the Nuclear Emergency Organisation • organise a 24-hrs Officer on Duty Service • give advice/recommendations for clean-up actions
CC Information Group	• compose information strategies • propose and implement information actions on behalf of CC in the different stages of an accident • assist CC mediating coordinated information to the public and the media
Advisors to the CC	• submit and make available all information, data and measurements of relevance to the emergency situations • make forecasts for radioactive dispersion, fallout and radiation doses to the public • advise on preventing or reducing the radiological and economic consequences of a nuclear accident in Norway
County Governors	• coordinate regional and local preparedness • planning and initiating countermeasures according to local needs and demands • continuously liaise with the Crisis Committee (link between governmental level and municipalities)
County Authorities (State Provincial Offices, ex. Civil defence)	• established under the direction of the County Governors
Municipalities	• advise residents • implement clean-up actions

Norwegian Nuclear Emergency Response Organisation



The Norwegian Radiation Protection Authority heads the Crisis Committee for Nuclear Accidents. Wherever possible, the Committee must consult its decisions with the Ministries before acting on such decisions. The Committee is operating with two levels of emergencies. These apply both for domestic and foreign accidents. No countermeasures are automatically implemented on the basis of declaration of level of emergency. The countermeasures will be implemented on an ad hoc basis depending on the assessments of the situation.

The Advisors to the Crisis Committee for Nuclear Accidents is made up of representatives of organisations and institutions with expertise and responsibility required for an emergency organisation, both as regards the management of nuclear accident situations and for further development and maintenance of emergency preparedness.

During accident situations, the tasks of the Advisors are to:

- submit and make available all information, data and measurements of relevance to the emergency situations and make forecasts for radioactive dispersion, fallout and radiation doses to the public;
- advise on preventing or reducing the radiological and economic consequences of a nuclear accident in Norway.

The Secretariat for the Crisis Committee (the Norwegian Radiation Protection Authority) is responsible, inter alia, for alerting the Nuclear Emergency Organisation. The Secretariat organise a 24-hrs Officer on Duty Service.

The Regional Emergency Organisations are established under the direction of the County Governors. They coordinate regional and local preparedness. They are responsible for planning and initiating countermeasures according to local needs and demands, and shall continuously liase with the Crisis Committee.

Table C.4. Organisations that are involved in remediation in Sweden and their respective responsibilities (situation of 2005)

Organisations	Responsibilities
County Administrative Boards	• Responsible for planning and implementation of remediation • Make decisions on performed clean-up actions (where, when, how, who) • Implement clean-up actions • Request advice from NESA • Request personnel and material resources from municipalities and state authorities • Hire services and equipment needed e.g. transport, lawnmowers • Organise waste disposal • Inform and advice residents • Radiation protection and education of the clean-up workers according to valid legislation • Perform measurements on recommendation from SSI
Swedish Radiation Protection Authority (SSI)	• Assess health consequences • Coordinate the national monitoring of contamination e.g. car- and air-borne deposition survey, environmental and food stuffs measurements • Information concerning radiation protection • Administratively responsible for NESA • Evaluate long term effect of remediation
National group of experts on remediation (NESA): consists of representatives from the Swedish Radiation Protection Authority, Swedish Board of Agriculture, National Food Administration, Swedish University of Agricultural Sciences, Swedish Defense Research Agency, Swedish Nuclear Power Inspectorate, Federation of Swedish Farmers, Swedish Rescue Services Agency	• Give recommendation on clean-up actions
Municipalities	• Perform gamma dose rate measurements on request from the County Administrative Board • Provide the County Administrative Board with personal and material resources on request • Inform the residents
Geological Survey of Sweden (SGU)	• Perform air-borne deposition survey on request from SSI
Laboratories at research centres	• Perform nuclide specific measurements on environmental, pasture and food stuffs samples on request from SSI
Voluntary organisations	• Collect samples on request from SSI
Nordic Nuclear Insurance Pool	• Liability questions

C.3 Discussion

The national contributions listed the involved organisations and the responsibilities they have in the crisis management concerned with the restoration of contaminated inhabited areas. Such a list of organisations and their respective mandate is valuable as a source of reference both for national stakeholders as well as for foreign observers.

Another valuable source of reference is The Nordic Manual (2006). This biannually updated document describes practical arrangements and co-operations to fulfil obligations stated in bilateral agreements between Nordic states. These obligations concern mostly early notification and exchange of information. The Nordic Manual recognizes that in “cases of serious accidents or situations with any kind of possible transboundary impact it is important that different states deal with the situation in co-operation with the neighbouring states” and that the “responsible authorities need not only be able to communicate and explain the decisions on protective measures to the state’s own citizens, they must also be able to explain the possible deviating decisions made by authorities in other states involved”. National Warning Points (NWP) have been established therefore to receive and relay initial notifications. It is also possible for each Nordic state to send liaison officers to a Nordic accident state in order to increase the understanding of the situation and assist in communication and transmission of emergency information and data to home base.

To foster mutual understanding within Nordic countries similarities and differences are outlined in the following. In order to be able to make a meaningful comparison, the disparate national descriptions must be brought into a common format. One way of doing this is to look at the activities that are reported to be performed in the crisis management. Looking at the descriptions it is somewhat easy to discern generic activities that the organisations are involved in. Following Carter and French (2004) and with regard to IAEA (2003) the following grouping is proposed:

- Coordination and supervision
- Technical support: monitoring, conduction of field studies, logistic services, etc.
- Development of a remediation program: assessment of situation, evaluation of different clean-up options
- Approval of the remediation program (formal decision making)
- Implementation of remediation program: operational aspects like waste management, radiation protection of workers, request for resources, feedback
- Information and communication: information to the public, media management and international communication

Table C.5 shows basically a pivoted view of the information given in the tables of the previous section. Whereas the latter showed what all is done by whom (i.e. the grouping was made in terms of involved organisations), Table C.5 shows who all is doing what (i.e. the grouping is made in terms of the generic activities). Looking at the table, the following observations might be made:

In Denmark, DEMA is the pivotal organisation for emergency management, a role that in Norway is held by the Crisis Committee and in Sweden by the County Administrative Boards. In Finland there is no such centralized decision making. Depending on the extent of the hazard decisions will be made by the relevant governmental, provincial, or municipal administrations. When large areas are contaminated and clean-up actions and compensation claims incur high costs, a political decision is needed by the Council of State. In the early phase the main responsibility is – depending again on the extent of the situation – with the rescue authorities on national, regional, or local scale.

Finnish and Swedish arrangements for the recovery phase rely mostly on organisations with a ‘peacetime’ agenda, i.e. ministries, State Provincial Offices or County Administrative Boards, municipalities, radiation protection authorities, and no dedicated crisis centres like DEMA of Denmark or Crisis Committee of Norway are operated.

In summary, the following portray might be given of the way that the emergency management is organized in the different Nordic countries: Denmark is characterised by a national emergency centre (DEMA), which is permanently staffed and operated during a wide range of crisis situations. In Norway a dedicated national crisis committee convenes during nuclear emergencies. In Finland, there is no such dedicated emergency management organisation and the decision making process (development of a remediation program, formal approval, and implementation related issues) involves, unless in case of urgency, normal administrative organisations. In addition, the process is not always promoted to a national level. The major characteristic of the Swedish arrangements is that, similar to Finland, there is no dedicated crisis centre, but unlike to Finland, the decision making process never rises to a nation level, because it is the counties’ administrative boards that are responsible.

Coordination and supervision are somewhat ambiguous concepts as such activities are done to various degrees by almost all players. What was intended in Table C.5, however, is to list the major responsibilities for coordination and supervision, which lies at a national level in Denmark, at a national and provincial/county level in Finland and Norway, and at a county level in Sweden. Apart from Finland, responsibilities in this respect go hand in hand with responsibilities for the formal approval of the remediation programme.

The description so far needs a clarification of the role of authorities in relation to private house holds, on the one hand, and commerce and industry, on the other, as decision making and implementation of actions is not necessarily (or entirely) with authorities. In cases like decontamination of private property authorities give merely advice and recommendations, but cannot enforce any decision. These are made by the property owners, who also implement them to a large extent (e.g. snow or grass removal, protection of kitchen gardens).

It is characteristic for the organisational structures in all considered countries that technical support is provided from many organisations. Differences can be seen how their involvement is organised. In Denmark, Norway, and Sweden they are associated with DEMA, Crisis Committee for Nuclear Accidents, and NESA, respectively. The relationships in Finland are more intertwined and not so easily depicted.

Table C.5. Generic activities of remediation and organisations that are mainly involved

Activity	Denmark	Finland	Norway	Sweden
Coordination and supervision	Central emergency command and organisation	Ministries, State Provincial Offices	Ministerial Coordination Committee, County Governors	County Administrative Boards
Technical support	Ministry of Defence, Armed Forces, Ministry of Interior and Health, National Institute of Radiation Hygiene, RISO, DMI, Rescue services, Police	Defence Forces, STUK	Advisors to the Crisis Committee	SSI, NESA, Municipalities, SGU, Research centres, Voluntary organisations
Remediation program	DEMA	STUK, Ministries and State Provincial Offices	Crisis Committee, County Governors	County Administrative Boards
Decision making	Central emergency command	Council of State	Crisis Committee and County Governors	County Administrative Boards
Implementation	Central emergency command and organisations; Municipalities	Municipality	Crisis Committee, County Governors, Municipalities	County Administrative Boards
Information	DEMA, Danish Broadcasting corporation, Ritzau's News Agency	Information Unit of the Council of State, STUK, others as well	Information Group of the Crisis Committee	County Administrative Boards, SSI, Municipalities

Another distinctive element is media management: Denmark and Norway seem to have a centralized and concerted information policy whereas in Finland it is generally practice that authorities at all political levels inform the media on issues within their sphere of competence.

Information encompasses also international communication. For example in the Danish emergency preparedness plan "it is assumed that a high degree of international coordination will be required so as to ensure that the cessation of the emergency phase in one country coincides, as far as possible, with that in the neighbouring countries." Therefore, information units of the Nordic nuclear and radiation safety authorities keep regular contact with each other.

The descriptions must be checked for completeness, which can be done by tabulating the aspects that need consideration in the process versus the organisations that address the issues (Table C.6). Typically support organisations provide expertise on the various aspects, and ministries and/or liaison bodies (CC in Norway, NESA in Sweden, DEMA in Denmark) gather the input.

Table C.6. Aspects of remediation that need consideration and organisations involved in their consideration

	Denmark	Finland	Norway	Sweden
Waste	Central emergency command	Ministry of Environment; Regional environmental centres; Municipalities[1]	CC or advisors to the CC	NESA
Cost and liability	Central emergency command	Nuclear insurance pool; Council of State		Nordic Nuclear Insurance Pool
Radiation protection of workers	National Institute of Radiation Hygiene	Authorities in charge of the operation; STUK gives recommendations	CC or advisors to the CC	SSI
Health and psycho-social	Ministry of Interior and Health	Ministry of Social Affairs and Health; STUK	CC or advisors to the CC	NESA
Resources	Central emergency command	Ministry of the Interior; Defence Forces; State Provincial Offices; Regional rescue services; Fire brigades	CC or advisors to the CC	NESA
Environment	Central emergency command	Ministry of the Environment; Regional environmental centres	CC or advisors to the CC	NESA
Economic	Central emergency command; ministries	relevant ministries and interest groups	CC or advisors to the CC	NESA

Regarding waste, IAEA (2003) requires that an “appropriate waste management strategy and its associated legal framework shall be established that are capable of dealing with the waste arising from the remediation of contaminated areas. This shall include the assignment of any additional responsibilities for the funding, conduct and regulatory control of waste management activities”. A comparison of the waste management strategies adopted in the various countries was outside the scope the present description but would be worthwhile doing.

The actual response organisation might depend on various factors, like the scale of contamination, or the causation (i.e. foreign or domestic nuclear accident, transport accident, terrorist attack). Only the highest activation level was investigated and reference was made to an accident at a nuclear power plant. The focus was on activities related to the remediation of radioactively contaminated inhabited areas. However, it remained slightly unclear to what extent the various national descriptions honoured this prescribed scope. It might well be that the descriptions (if not existing

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[1] In Finland environmental authorities ensure that environmental legislation is observed when deciding on clean-up actions and waste management. Regarding radioactive waste STUK is the authority to ensure radiation safety by providing instructions on collections, handling, storage, and final disposal of waste.

arrangements) are still somewhat geared towards the acute emergency phase and that the transition to later phase issues is a rather new development and not yet totally reflected in the various descriptions. The requirements for such a transition are stated by IAEA (2002) as follows: “Arrangements shall be established for the transition from emergency phase operations to routine term recovery operations. This process shall include: the definition of the roles and functions of organisations; methods of transferring information; methods of assessing radiological and non-radiological consequences; and methods of modifying the actions taken to mitigate the radiological and non-radiological consequences of the nuclear or radiological emergency.”

C.4 References to Appendix C

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Abstract

The handbook is aimed at providing Nordic decision-makers and their expert advisors with required background material for the development of an optimised, operational preparedness for situations where airborne radioactive matter has contaminated a Nordic inhabited area. The focus is on the mitigation of long-term problems. It should be stressed that the information given in the handbook is comprehensive, and many details require careful consideration well in time before implementation of countermeasures in a specific area. Training sessions are therefore recommended. The handbook describes the current relevant Nordic preparedness (dissemination routes) in detail, and suggests methods for measurement of contamination and prognoses of resultant doses, and data for evaluation of countermeasures and associated waste management options. A number of non-technical aspects of contamination in inhabited areas, and of countermeasures for its mitigation, are discussed, and a series of recommendations on the application of all the handbook data in a holistic countermeasure strategy are given. A part of the handbook development has been a dialogue with end-user representatives in each of the Nordic countries, to focus the work of the specific needs of the users.

Key words

Radiation dose, radiocaesium, urban, inhabited areas, preparedness, decontamination, countermeasures, nuclear emergency, cost-benefit analysis, nuclear power plant, accident, dirty bomb, decision-making, waste management, kitchen garden

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