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EVALUATION OF EARLY PHASE NUCLEAR ACCIDENT CLEAN-UP PROCEDURES FOR NORDIC RESIDENTIAL AREAS

Kasper G. Andersson

Risø National Laboratory
Roskilde, Denmark

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CONTENTS

EXECUTIVE SUMMARY

The work reported was carried out as a part of the EKO-5 project under the framework of the Nordic co-operative NKS programme. The project is aimed at giving guidelines relating to Nordic conditions for the reduction of external doses in the early phase of a major accidental airborne nuclear contamination (essentially with ^{137}Cs) situation in urban areas.

The material in this report describes the expected effects, in terms of immediate dose rate reduction and of reduction of the integrated doses over 70 years, of implementation of the methods which were considered to be feasible for early phase treatment of contaminated urban surfaces. Also given are estimates of the integrated doses if no action were taken.

The given estimates were based on the experience obtained through large amounts of in situ measurements on different types of surface, mainly since the Chernobyl accident in 1986.

The computer model URGENT, which is described briefly in Chapter 2, was used to apply the information on the migration of the radioactive material with time, together with the results of Monte Carlo photon transport calculations, for the time-integrated dose estimates.

Chapter 6 of the report consists of 66 data sheets, each describing the beneficial effects, costs and disadvantages of application of a feasible method for cleaning in the early phase of a specific type of surface in one of five different urban or suburban environments. This data forms the foundation for the recommendations on guidelines, which are the ultimate goal of the EKO-5 project.

The report further contains chapters on how the data sheets were made, on how to apply the data sheets in a decontamination strategy and on how to deal with the radioactive waste that would be generated by some of the suggested procedures. Estimates of the costs of waste treatment are given in the data sheets where appropriate.

A separate chapter indicates that in some cases of contamination in the absence of rain, contamination of indoor surfaces may give significant contributions to dose. The magnitude of this contribution, however, depends on the ventilation rate and the indoor deposition rate rather than for instance the material density of the building, and the contribution of the indoor surfaces to the dose has therefore little or no correlation to the dose contributions originating from outdoor contamination.

References are given to recommended supplementary reading.

1. INTRODUCTION

On the basis of Swedish legislation, a need was recognised in Sweden for a preparedness strategy for early phase clean-up in the event of a major accidental nuclear contamination of residential areas. Due to obvious common interests between the different Nordic countries it was decided to make this investigation under the responsibility of NKS.

For this purpose, a catalogue was requested, which could facilitate the local decision-making process by stating the advantages, disadvantages and requirements of each method that was considered to be feasible for cleaning of each type of contaminated surface in a few representative Nordic housing environment scenarios. The design of the data sheets was discussed in the EKO-5 work group and it was decided that only external doses were to be treated, and since it was considered that ^{137}Cs would be likely to be by far the most important isotope concerning the long-term external dose after a serious nuclear accident, it was decided to focus on this isotope.

This catalogue consists of a series of individual data sheets designed to give the essential information to evaluate early phase decontamination situations under different circumstances. The data has been derived from measurements, experimentation and modelling.

Throughout the decade that has passed since the Chernobyl accident in 1986, the impact of a contamination of different types of inhabited areas has been investigated carefully. An example of this is that the contamination levels on different surfaces in and around the town of Gävle, which received a relatively high level of contamination from the Chernobyl accident, have been followed over the years by Risø staff through seven measurement campaigns.

The URGENT model, which was developed at Risø mainly on the basis of this in situ measurement data, was one of the very first dynamic external dose models to comprise the whole urban environment in the event of an accidental contamination with radiocaesium. It was, for instance, the first extensive model to take into account the contamination on trees and vegetation, which has proved to be a potentially important factor in dry deposition scenarios. The model uses the results of Monte Carlo photon transport calculations to link the time-dependent radio-contaminant concentrations to dose rates to persons staying at different locations in different housing environments of varying population density.

The URGENT model was used together with practical experience from semi-large scale decontamination testing to evaluate the feasible remedial countermeasures when applied in the early phase. The modelled scenarios reflect what is considered to be typical situations in the Nordic countries with areas of varying population density (from small single-family houses made of wood or brick to multi-storey house blocks) and varying weather conditions at deposition.

Additional text chapters have been written to supplement and facilitate the understanding and application of the data sheets.

Chapter 2 explains how the calculations of doses and dose rates were performed and which assumptions were made, whereas Chapter 3 is aimed at giving the decision maker the ability of applying the data sheets in the decision-making process by weighting factors that need to be considered in the formation of a decontamination strategy.

Chapter 4 describes the mechanisms that are responsible for the dose contributions received from contaminated indoor surfaces. These are treated separately from the outdoor-originating dose contributions, as there is no distinct correlation between the size of the house and the parameters influencing indoor aerosol deposition.

Chapter 5 describes disposal techniques for the radioactive waste that is generated by some of the decontaminating countermeasures. A list of relevant literature for further information in this relation is given at the end of the chapter.

Chapter 6 is a listing of the methodological data sheets that form the basis for the development of emergency preparedness plans for the early phase. Two references to particularly recommendable supplementary literature are given to each data sheet. A full list of these references is given in Chapter 7.

2. CALCULATION OF EXTERNAL DOSES AND DOSE RATES IN INHABITED AREAS

This chapter describes how the doses and dose rates referred to in the data sheets of Chapter 6 were estimated.

First of all, it must be stated that only the *external* doses are considered in the following, so wherever the term 'dose' is mentioned it refers to external dose only.

The formation of the data sheets on cost-effectiveness details for application of different clean-up methods under different circumstances demanded that some dose and dose rate modelling be made. In the early phase, doses received by the public from untreated contaminated areas can be estimated on the basis of the initial dose rate which, at least for a ^{137}Cs contamination, is not likely to change considerably over a period from the first few days to the first couple of months. In order to estimate the doses potentially averted by the introduction of a countermeasure, however, it is necessary to integrate over life-long periods of time.

To accomplish these tasks it is necessary to estimate the initial levels of contamination on different surfaces and the resulting contributions to an averaged dose rate to people staying in an area. Further, the change in time of the contamination levels - and corresponding dose rate contributions - of the different surfaces must be estimated over a long period.

The experience from the Chernobyl accident has shown that a typical relationship between the contamination levels on different types of urban surface (e.g., walls, roofs, roads and grassed areas) can be expected if the deposition of the caesium contaminants occurs with rain, and another if the deposition occurs in the absence of precipitation. These relative figures are shown in Table 1 (relative to a dry deposition on very short grass where it is assumed that all the deposited material is retained on the grass and none on the soil). The relationships in Table 1 have been assumed in the calculations of dose rates and doses. Consequently, to estimate absolute contamination figures in a given accident situation, it would only be necessary to measure the contamination level on the reference surface type - short grass.

Table 1. Relative source strengths on different types of urban surface immediately after a deposition of ^{137}Cs with or without precipitation. Averages over observations in different European countries after the Chernobyl accident.

Surface type	Rel. dry deposition	Rel. wet deposition
Walls	0.1	0.01
Roofs	1.0	0.4
Grass/soil	1.0	0.8
Streets	0.4	0.5
Trees	3.0	0.1

Using the above relative figures for initial contamination levels, estimates of initial dose rates and integrated doses were made for 5 different urban or suburban environments, which have been found to adequately cover the construction practice in the Nordic countries. The conversion factors from contamination levels to population doses were based on calculations made using the Monte Carlo photon transport codes MCNP4A and SAM-CE (calculations performed by R. Meckbach, P. Jacob and H.G. Paretzke: Rad. Prot. Dos. vol. 25, no.3, pp.167-179, 1988). Essentially, only 4 different housing environments were chosen. These are shown in Figures 2.1-2.4.

Fig.2.1: Detached single-family house area

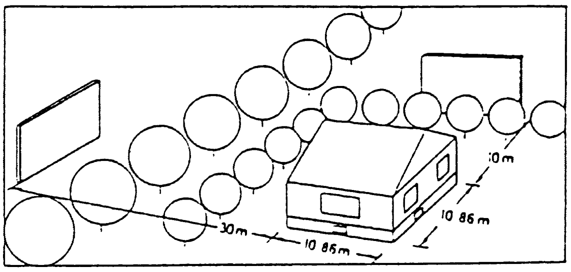


Fig.2.2: Semi-detached house area

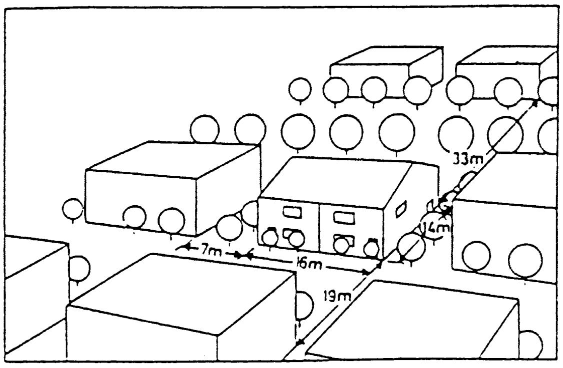


Fig.2.3: Terrace (row) house area

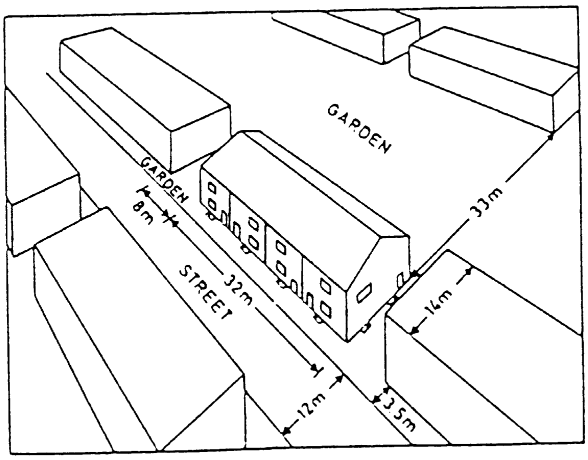
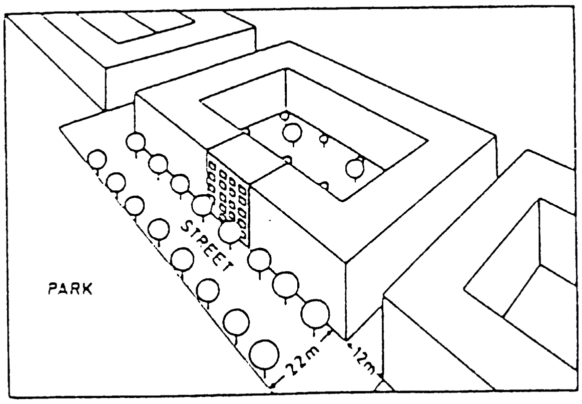


Fig.2.4: Multistorey building area



Figures 2.1-2.4. Four different housing environments, for which data sheets for decontamination have been worked out (illustrations as published by Meckbach, Jacob and Paretzke, 1988).

However, a need was recognised for data for small detached houses both with bricked and with wooden outer walls, wherefore construction data modifications were made, and the dose rate data for the detached house (Fig. 2.1) therefore exist both for 3.8 cm wooden outer walls supported with gypsum and glass wool and for 11 cm brick walls supported with 11 cm thick breeze block layers.

The semi-detached house in two stories has a similar construction to the detached brick house, but has a slightly higher window fraction. However, the garden areas are, as can be seen from Figures 2.1-2.2, much smaller here, and the house has two stories.

The terrace house area is in many ways similar to the semi-detached house area. The house-walls and window fractions are practically identical. The differences between the two environments in terms of average dose-conversion factors 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.

The 5-storey urban centre block of flats has very thick outer walls (30 cm brick). Further, the grassed areas are here smaller, the road 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.

In all calculations it was assumed that the average person spends 85 % of the time at indoor locations, equally distributed between the different residential floors and 15 % outdoors in gardens and on streets.

The exact dimensions and materials of the different environments are stated in great detail by Meckbach et al. in the reference given above.

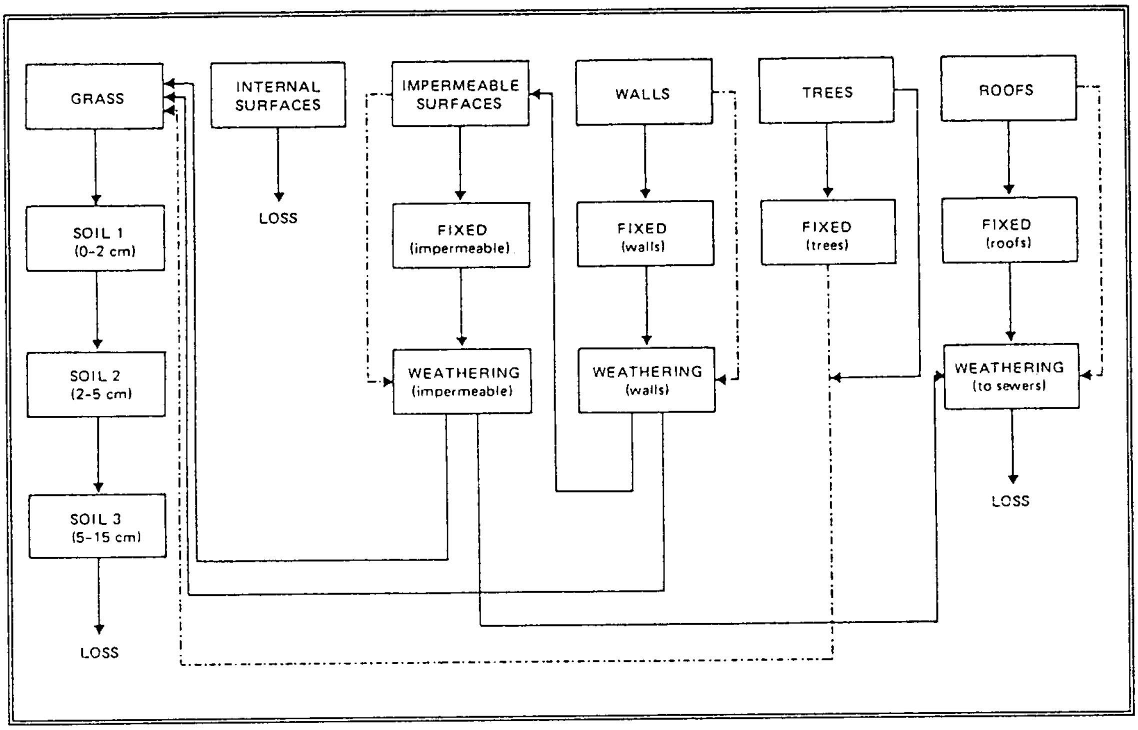
The dynamics in the contamination levels (and thereby the dose contribution time-integration) on the different surfaces due to weathering, migration and other time-dependent processes have been treated by application of the URGENT model developed at Risø. Using this model it was possible to estimate the integrated doses to the populace over 70 years, assuming that no forced decontamination is introduced.

The dynamic part of the model URGENT is mainly based on the linear compartment model theory. Thus, the transfer rate for radioactive matter following deposition on a given type of surface, m, can be written as:
in which X_m and X_n represent the radioactive matter in compartments m and n, respectively, at a time t. S_{nm} is the transfer coefficient from compartment n to m. L_m is the transfer coefficient for flow of radioactivity out of the system, etc. (for instance, loss by radioactive decay).

$$\frac{dX_m}{dt} = \sum_{n=1}^{P} S_{nm} X_n - (\sum_{n=1}^{P} S_{mn}) X_m - L_m X_m$$

The flow diagram (Figure 2.5) shows the principle of the migration model with its assumptions. The dotted lines indicate processes taking place as discrete events. The term 'impermeable surfaces' means all horizontal surfaces that are not easily penetrated by water, such as asphalt and concrete.

Figure 2.5. URGENT contamination flow chart.



The 'internal surfaces' compartment contains the amount of radioactive matter deposited on the internal surfaces of buildings and on furniture and furnishings. The internal surfaces have been dealt with separately in a special section as there is no distinct correlation between the size and shape of a house with surroundings and the parameters influencing indoor deposition of radioisotopes.

For those 'hard' surfaces on which weathering processes are likely to cause a migration of caesium contamination from one type of surface to another (paved horizontal surfaces, walls and roofs), the migration/retention is accommodated by splitting the radioactive matter into three 'pools'. These represent three different states at which radioactive substances may be found on the particular surface. The first is the mobile phase representing part of the initially dry-deposited material. The second state is the more strongly bound. Weathering processes will however mobilize the material in this state, and it is here the third state arises, representing the remobilized material.

For the contamination deposited on trees the model structure is different. Here, a slow transfer of activity from the trees to the grass due to the effects of wind and rain is taken into account in the model. A loss by leaf-fall from deciduous trees is modelled over the autumn.

The input parameters in URGENT are, where possible, based on experimental results, mainly obtained after the Chernobyl accident. A more extensive description of the models applied to calculate doses and dose rates is given in the European Commission report EUR 16604 EN, ISBN1018-5593, 1995.

All doses and dose rate contributions in the data sheets in Chapter 6 are given per 1 MBq/m^2 ^{137}Cs initially deposited on a grassed surface, so as to facilitate a scaling to the actual contamination levels.

The 'immediate averaged total dose rate reduction in the area' is the percentage reduction of the total averaged dose rate level (to which there are contributions from different types of surface) which can be achieved immediately by implementing a countermeasure shortly after the contaminant deposition. The averaging is with respect to the location of the people in the area.

The 'averaged total accumulated lifetime dose reduction over 70 years' is an estimate of the percentage reduction achievable by a countermeasure of the total accumulated dose (total of dose contributions from different surfaces) to a person who stays in the area for 70 years. This is also averaged with respect to the location of the people in the area.

The 'averaged total accumulated lifetime doses to people living in the area' are estimates of the location averaged total doses received by a person staying in the area for 70 years if no countermeasures were implemented to reduce the dose.

Other parameters given in the data sheets are almost exclusively based on knowledge obtained through experimental investigations. For each data sheet, references are given to relevant literature.

3. FORMATION OF STRATEGIES BASED ON DATA SHEETS

The data sheets in Chapter 6, which have been developed for clean-up of various types of contaminated area under different circumstances can be used for guidance through some of the decision-making aspects of an introduction of the required countermeasures to restore a radiocaesium-contaminated area to an acceptable level in terms of external dose-rate.

As indicated in the data sheets, numerous aspects will need to be considered and several different types of surface in an environment will often need to be treated by different means. Clearly, it is important not only to consider the traditional cost-effectiveness aspects of such an operation, but also to evaluate the local relevance, psychological impact and general acceptability of each suggested countermeasure.

Also the order in which different strategical decontamination procedures in an area are carried out is important to consider. Due to the risk of resuspension or translocation of contaminants, the most heavily contaminated surfaces should generally be treated first. However, also the orientation of the surfaces should be taken into account. A procedure such as water hosing of walls should for instance be carried out before treatment of the soil surfaces or pavements directly under below wall (although these may well have a much higher level of initial contamination), as such surfaces would inevitably receive some of the radioactive material, which was removed from the wall.

The strategy planner should take into account in the prioritising that the doses stated in the data sheets are estimates for adults, and that doses received by children from contamination on horizontal surfaces are higher (by a factor of ca. 1.2 on a large field and more than that in areas of limited dimensions) as the target person comes closer to the source. Further, as the children are in growth and increasing (splitting) their body cells, the impact on the body of interaction between radiation and a cell could have a much more serious outcome for a child than for an adult. Therefore, special efforts should be made to clean for instance schools, kindergartens, children's playgrounds and sandboxes particularly well. Children would also normally have a long life ahead of them to accumulate radiation doses over. Likewise, for instance elderly people in rest homes have shorter time to accumulate doses over, but as the personnel in such places are younger people, no distinct recommendation can be given to lower the priority for treatment of such places.

Also other special considerations need to be made in the specific case. Although the data sheets are grouped in sections of methodologies which are thought to be particularly suitable for a special situation, such as a radiocaesium contamination by rain over an urban centre, there is still often a choice to be made between different methods to clean a surface, which each have their advantages depending on for instance different seasons (e.g., snow removal and pruning of trees) or the amount of time which passes before remedial action is initiated (e.g., lawn mowing and pruning of trees).

A cost-effectiveness analysis is an essential step in the planning to ensure that the efforts are made in a way which has the maximum beneficial effect for the allocated economical means. Ideally, this would be carried out for each single housing environment, but naturally, due to both economical and practical limitations as well as time-constraints in carrying out the dose reducing operations, this is not possible.

Instead, guidelines (data sheets) have been provided for a limited number of housing environments, which are believed to cover most of the construction practice in the Nordic countries. Illustrations of the selected housing environments are given in the section on 'Calculation of doses and dose rates in inhabited areas'.

These five different environments could not only be regarded as five 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 5 standard environments. The main features and differences between the 5 standard environments are outlined in the section with the illustrations.

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 recent 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.

By looking at the raw data for the dose response (from Meckbach et al.'s presentation of the standard environments, Rad. Prot. Dos. vol.25, no.3, pp. 167-179, 1988), 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.

Looking through all the produced data sheets it is clear that there are certain similarities between the data for all different standard environments. The open garden areas in all cases give the largest single dose rate contribution to the local populace. It is therefore of greatest importance to treat these areas, if it can be practiced in a cost-effective manner in the particular case. An example of how the data sheets might be used in the formation of a strategy is given in the following.

Let us assume that we are dealing with a situation in the late spring where contamination has occurred by wet deposition of ^{137}Cs to a suburban area consisting mostly of detached wooden single family houses. A contamination level of 10 MBq/m^2 has been measured on a grassed surface shortly after the deposition. A rough estimate of the initial contamination levels on the other surfaces in the area can be deduced from Table 1 in the section on 'Calculation of doses and dose rates in inhabited areas'.

If we look at one of the data sheets for wet deposition in areas with detached wooden houses, it can be seen that the estimate of the averaged total accumulated lifetime dose to the local populace is about 170 mGy per 1MBq/m^2 of ^{137}Cs contamination - or in this case 1.7 Gy (corresponding to 1.7 Sv).

The intervention level ranges for introduction of relocation of the population (or cleaning of the area) as recommended by the ICRP in their publication no. 40 (1) are 50-500 mSv per year, while the CEC Article 31 Group of Experts recommends an intervention level for permanent relocation of members of the population (for life-long exposure) of 1 Sv (2). As can be seen the case is such that decontamination would be justified according to these principles. That is if it can be carried out at a cost that is reasonable and with an acceptable impact on the local population, also regarding non-radiological factors, such as possibly social disruption, psychology in general and political considerations.

The IAEA (3) recommended relocation of the population if the individual dose per month multiplied by a 'value of a man-Sv' exceeds the individual monthly costs for relocation (estimated at the time to $ 100-1000). The IAEA (4) recommended a minimum value of $ 3000 per averted man-Sv, while the ICRP (5) recommended a value of $ 20000 for most developed countries. The Nordic radiation protection authorities have, however, revised the risk factors suggested by the ICRP and recommend a value of as much as 100000 $ per Sv (2). Using such a figure, the total costs of a dose-reducing operation can be compared to the value of the dose averted.

If it is decided in the area under consideration that forced decontamination could be initiated to reduce the radiation level, the data sheets for the type of environment and deposition in question in this case give five different options, from which a clean-up strategy may be formed. Snow removal, however, is not likely to be a realistic solution in the late spring. As can be seen, the total dose reduction over 70 years of cleaning the roofs and pruning trees and bushes would normally be less than 6 %. As these procedures would be quite costly methods to obtain such a small effect, they would only be applied under special circumstances (e.g., if contaminated litter has been accumulated on a roof), while a treatment of the open (grassed) areas by either soil removal or triple digging would give a great reduction of the lifetime dose (by a factor of 4.5 to 6) at a probably affordable cost (all the necessary details to calculate the costs under the specific circumstances are given in the data sheets and can be adjusted according to the local labour costs). These two procedures are almost equally effective in reducing the dose. Which one of the two methods would be chosen for the particular case would depend on various considerations. As can be seen, for instance the soil removal procedure may in some areas greatly affect the local soil fertility and generates a large amount of waste, and the transport and storage of this waste has relatively high costs. On the other hand, triple digging may not be a publicly satisfactory solution, since a burial of the contamination by triple digging would make it very difficult to remove the contamination at a later date and further considerations should be made in accordance with the data sheets, so that the most beneficial methodological strategy can be chosen for the particular area.

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4. EVALUATION OF THE POTENTIAL DOSE CONTRIBUTION FROM INDOOR SOURCES

The accidental deposition of radionuclides to an inhabited area may evidently lead to high contamination levels on the outdoor surfaces, where in most cases particularly the open horizontal surfaces will contribute greatly to the dose to the inhabitants. These surfaces will certainly dominate in wet deposition scenarios. However, calculations have shown that in some *dry* deposition scenarios, highly significant dose contributions may be ascribed to the deposition of airborne radioactive material inside dwellings. There is no distinct correlation between the dose received from indoor deposition and the size or architectural features of the dwelling or its surroundings. However, the concentration of airborne particle contamination inside a leaky building is higher than that in a building with a small air exchange rate. Likewise, if the building interior constitutes rough surfaces, then a relatively large fraction of the aerosol will deposit.

As the calculations, which are described below, indicate, the indoor contamination level will greatly depend on factors which can be contained in three variables: the rate coefficient of ventilation (the fraction termed λ_r of air exchanged in the dwelling per unit of time), the rate coefficient of deposition (the fraction termed λ_d of aerosols in the building deposited per unit time) and the filtering factor f (the fraction of aerosols in air entering the building which are not retained in cracks and fissures of the building structure).

From the assumption of a constant aerosol concentration outside a building, and the knowledge of the rate coefficient of ventilation, the rate coefficient of deposition and the filtering factor, the relationship between the equilibrium indoor aerosol concentration (C_i) and the outdoor aerosol concentration (C_o) can be calculated as:

$$C_i / C_o = f \lambda_r / (\lambda_r + \lambda_d).$$

From the average local indoor deposition velocity V_d ($V_d = \lambda_d V/A$, where V is the indoor volume and A is the indoor surface area), and V_{dg} (the average deposition velocity on a grassed outdoor surface), a relationship can be established between the average deposited contaminant concentration on indoor surfaces (S_i) and the deposited contaminant concentration on a smooth, cut lawn (the common reference surface for outdoor contamination), here termed S_o:

$$S_i / S_o = (V_d / V_{dg}) f \lambda_r / (\lambda_r + \lambda_d).$$

Field investigations by Roed (1990) showed the caesium aerosol from Chernobyl (size of about 1µm) to have a typical deposition velocity of $4.3\ 10^{-4}$ m/s on cut grass surfaces (V_{dg}). A representative value of the relationship V/A for a furnished room is 0.5 m. Following the Chernobyl accident, a series of experiments (Roed and Cannell, 1987) were made in which the typical values of λ_r, λ_d and f were determined for the Chernobyl ^{137}Cs aerosol in a furnished Danish house. These values, which are believed to be realistic for most common houses, were used in the following calculations (Table 4.1) of the mean indoor deposition (kBq/m^2).

Table 4.1. **Calculated mean indoor deposition (kBq/m^2) of 1µm caesium aerosol under different circumstances relating to an outdoor dry deposition on grass of 1 MBq/m^2.**

f = 0.4	λ_d = 0.36 h^{-1}	λ_d = 0.60 h^{-1}	λ_d = 1 h^{-1}
λ_r = 0.3 h^{-1}	21	26	30
λ_r = 0.4 h^{-1}	24	30	37
λ_r = 0.6 h^{-1}	29	39	48

f = 0.6	λ_d = 0.36 h^{-1}	λ_d = 0.60 h^{-1}	λ_d = 1 h^{-1}
λ_r = 0.3 h^{-1}	32	39	45
λ_r = 0.4 h^{-1}	36	45	56
λ_r = 0.6 h^{-1}	44	58	72

f = 1.0	λ_d = 0.36 h^{-1}	λ_d = 0.60 h^{-1}	λ_d = 1 h^{-1}
λ_r = 0.3 h^{-1}	53	65	75
λ_r = 0.4 h^{-1}	60	75	93
λ_r = 0.6 h^{-1}	73	97	120

The corresponding dose estimates for indoor surfaces were made equivalent to a target position 1m above the ground in a room with height 3m and in the centre of a ground area of 4m by 4m. The dose contribution from scattered radiation and deposition on internal surfaces of neighbouring rooms was not included. It was stipulated in the dynamic calculations that the caesium level on the floor decreases with a half-life of 6 months due to hoovering, and that the effective half-life on walls, furniture and ceiling is 5 years, as these surfaces are usually only rarely treated.

Recent experiments carried out at the Contamination Physics Group at Risø using porous silica particles of various monodisperse size distributions ranging from 0.7 to 20 microns and labelled with neutron activatable tracers have shown that the deposition velocity to the floor approximately equals the sum of the deposition velocities to the four walls and the ceiling (Table 4.2). This distribution pattern was applied in the dose modelling.

Table 4.2. **Mean deposition velocities (10^{-4} m/s) of monodisperse 0.7 micron particles collected on hard pressed Whatman 542 filters on surfaces of different orientation in a room.**

Ceiling	Wall (N)	Wall (S)	Wall (E)	Wall (W)	Floor
0.189	0.235	0.230	0.117	0.249	1.581

Table 4.3 shows the dose estimates relating to the deposited radiocaesium concentrations given in Table 4.1.

<u>Table 4.3.</u> Estimated received doses the first year following contamination (mGy), equivalent to a target position 1m above ground in a room with height 3 m and in the centre of a 4m by 4m ground area assuming the above mean indoor concentrations and that 50 % of the total amount of caesium is deposited on the floor, while the rest is equally distributed on the walls and ceiling.

f = 0.4	$\lambda_d = 0.36\ h^{-1}$	$\lambda_d = 0.60\ h^{-1}$	$\lambda_d = 1\ h^{-1}$
$\lambda_r = 0.3\ h^{-1}$	0.19	0.23	0.27
$\lambda_r = 0.4\ h^{-1}$	0.22	0.27	0.33
$\lambda_r = 0.6\ h^{-1}$	0.26	0.35	0.4

f = 0.6	$\lambda_d = 0.36\ h^{-1}$	$\lambda_d = 0.60\ h^{-1}$	$\lambda_d = 1\ h^{-1}$
$\lambda_r = 0.3\ h^{-1}$	0.29	0.35	0.41
$\lambda_r = 0.4\ h^{-1}$	0.32	0.40	0.51
$\lambda_r = 0.6\ h^{-1}$	0.39	0.53	0.65

f = 1.0	$\lambda_d = 0.36\ h^{-1}$	$\lambda_d = 0.60\ h^{-1}$	$\lambda_d = 1\ h^{-1}$
$\lambda_r = 0.3\ h^{-1}$	0.48	0.59	0.68
$\lambda_r = 0.4\ h^{-1}$	0.54	0.68	0.84
$\lambda_r = 0.6\ h^{-1}$	0.66	0.88	1.08

For comparison it can be mentioned that the corresponding total first year dose contribution from dry deposition on all outdoor surfaces varies between 1.2 mGy (for large buildings with thick walls) and about 9 mGy (for single-family houses with very thin walls), according to calculations made with the URGENT model. As can be seen from Table 4.3, the first year doses from deposition on internal surfaces of buildings may be rather large compared with those from the outdoor surfaces. In well-shielding buildings with a high ventilation rate, a high deposition rate, and a low degree of filtration of caesium aerosols passing through the building, the first year dose contribution from indoor surfaces may be almost as much as the total from outdoor dry deposition.

As can be seen from Table 4.2, about half of the contamination is on the floor of a room. Hoovering may remove some of the deposited aerosol on carpets, but great difficulties have been encountered in attempts to remove such small particles, and a removal of the carpet, as well as the wallpaper may well be required to obtain a good result.

References

Roed, J., Deposition and Removal of Radioactive Substances in an Urban Area, Nordic Liaison Committee for Atomic Energy, 1990.

Roed, J. and Cannell, R.J., Relationship Between Indoor and Outdoor Aerosol Concentration Following the Chernobyl Accident, Rad. Prot. Dos. vol. 21, No. 1/3, pp. 107-110, 1987.

5. DISPOSAL OF RADIOACTIVE WASTE FROM CLEAN-UP OPERATIONS

This chapter makes some suggestive remarks relating to the treatment and final disposal of solid or liquid radioactive wastes generated by some of the methods described in Chapter 6.

5.1. Liquids

In some cases it is possible (though perhaps not desirable) to collect liquid radioactive waste, typically from wash-off procedures, instead of leading it to the sewers. In such cases, a rather simple filtering of the liquid would remove by far the largest part of a radiocaesium contamination from the liquid and concentrate it in a small solid fraction, as these ions will attach to practically any surface (in the liquid: for instance small grains of sand or small fragments of construction materials or algae loosened by an abrasive method).

For instance, the 'liquid' waste from a water hosing of a roof could be collected in the roof gutter and lead through a down pipe into a large vessel, where a filter material coating on a plastic covered metal net could filtrate the solution so that only the 'clean' liquid fraction could penetrate. On the other side of the filter, the cleaned water is then pumped to another vessel, and might be recycled for the clean-up operation. A filtering material which has been successfully applied is a commercially available polymer fibre textile called 'typar', with a pore size of 0.14 mm. The cost of this material is about 0.50 ECU/m^2. An alternative would be to filter the water through an ion exchanger, such as 'Lewotit 100 S' from Bayer, which is applied in many water cleaning plants.

Regarding disposal of very large amounts of contaminated water in the form of snow masses, which are difficult to clean, a possibility would be to dump the snow into the ocean, where the resulting radionuclide concentration increase will often be negligible.

5.2. Solids

The solid radioactive waste generated from operations such as a removal of contaminated top soil and vegetation could be very large in quantity, since large areas would often require treatment. Reduction of the waste volume would clearly be advantageous, but the methods which have been suggested so far are too expensive and do not have a large scale potential (e.g., electrokinetic migration and soil washing, as described in (1)).

The disposal of solid waste could take place in large specially constructed centralised trenches, but it would often be an advantage to choose a disposal site in the vicinity of the decontaminated area to avoid labour-intensive and costly large scale waste transportations over long distances.

Such a disposal site could be constructed by landfilling, where the radioactive waste is buried in a shallow ground repository. The current legislative directives issued by the CEC regarding landfill procedures are stated in (9). An alternative (where practicable) to this is landraising, where the waste is not placed in an excavation, but above the ground, for instance between two natural hills.

Common for these two types of disposal techniques is that it is sought to retain the radioactive waste ideally permanently (which is impracticable in reality), or as long as possible, within the disposal trench, and slow down the further dispersion to the environment so as to allow the waste to decay radioactively and keep any ground water leaching to an acceptable level.

Probably the most problematic gamma emitting isotopes from a nuclear facility accident are the radiocaesium isotopes, as these have relatively long half-lives, which are comparable to the duration of a human life and emit both gamma and beta radiation. Luckily, the migration rate of caesium in practically all soils is exceedingly slow. This is due to the strong, selective fixation of caesium ions at so-called frayed edges by the interlayer spacing of most common 3-layer soil micas. This fixation mechanism retains the caesium ions, even in the presence of excessive amounts of similar, competing cations, such as potassium and ammonium.

For containment of other, more easily migrating ions in the radioactive waste, stabilisation and cement solidification processes for the radioactive soil have been envisaged (10).

Clearly, a landfilling for permanent storage of radioactive waste requires careful consideration in the construction phase. A detailed practical example of how it might be carried out is given in (1), where radioactive soil waste from a removal of a contaminated layer of top soil was buried in a specially constructed disposal trench with ditches on the sides so as to collect run-off water from the arched trench-top and avoid groundwater contamination.

Examples of landfilling and landraising operations are also treated with illustration in (2).

5.3. Suggested reading on waste treatment and disposal of radioactive waste after reclamation of inhabited areas

1) Jukka Lehto (editor): Clean-up of Large Radioactive-Contaminated Areas and Disposal of Generated Waste, Final report of the KAN-2 project, Nordic Council of Ministers, TemaNord 1994:567, ISBN 92 9120 488 9, 1994.

2) R.H. Little, C. Torres, D. Charles, H.A. Grogan, I. Simon, G.M. Smith, T.J. Summerling and B.M. Watkins: Post-disposal safety assessment of toxic and radioactive waste: waste types, disposal practices, disposal criteria, assessment methods and post-disposal impacts, CEC Report EUR 14627 EN, ISBN 92-826-5610-1, 1993.

3) T. Brasser, J.J. Heijdra, U. Mühlenweg, A. Van Dalen, J. van der Gaag and L.H. Vons: Disposal of radioactive waste and toxic waste in underground repositories: Comparative examination of the objectives, requirements and techniques, CEC Report EUR 16603 DE/EN, ISBN 92-827-5064-7, 1995.

4) S. Orlowski and K.H. Schaller (editors): Objectives, standards and criteria for radioactive waste disposal in the European Community, CEC Report EUR-12570, ISBN 92-826-0994-4, 1989.

5) K. Andersson, R. Boge, U. Niederer, S. Norrby, J.O. Snihs and A. Zurkinden: Regulatory guidance for radioactive waste disposal - an advisory document, SKI Technical Report 90:15, 1990.

6) W. Krischer and R. Simon (editors): Testing, evaluation and shallow land burial of low and medium radioactive waste forms, proceedings of a seminar organised by CEC at Geel, Belgium 28-29 September 1983, Harwood Academic Publishers, EUR 8979, ISBN 3-7186-0206-7, 1984.

7) J. Roed, C. Lange, K.G. Andersson, H. Prip, S. Olsen, V.P. Ramzaev, A.V. Ponomarjov, A.N. Barkovsky, A.S. Mishine, B.F. Vorobiev, A.V. Chesnokov, V.N. Potapov and S.B. Shcherbak: Decontamination in a Russian Settlement, Risø R-870(EN), ISBN 87-550-2152-2, 1996.

8) K. Brodersen and K. Nilsson: Mechanisms and interaction phenomena influencing releases in low- and medium level waste disposal systems: Final report 1986-90, Risø M-2908, Risø National Laboratory, ISBN 87-550-1694-4, 1990.

9) CEC: Proposal for a council directive on the landfill of waste. COM (91) 102 Final, SYN335, Brussels, 22 May, 1991.

10) K. Brodersen: Cement solidification of soil and interactions between cement and radioactive contaminated soil, Risø-I-721(EN), Risø National Laboratory, Denmark, August 1993.

6. METODOLOGICAL DATA SHEETS

This chapter presents 66 data sheets, in which the dose and dose-rate estimates are the results of calculations as described in Chapter 2. A number of supplementary informations have been added to each sheet, describing some of the other aspects that need to be considered in an evaluation of the feasibility of each method for treatment of a specific contamination scenario. In Chapter 3, a description is given of how the data sheets may be applied in the formation of a decontamination strategy, while further information on the treatment of radioactive waste generated by some of the decontamination procedures is given in Chapter 5.

The data sheets are given in order according to the following main categories:

1. Dry deposition in detached wooden house area
2. Wet deposition in detached wooden house area
3. Dry deposition in detached brick house area
4. Wet deposition in detached brick house area
5. Dry deposition in semi-detached house area
6. Wet deposition in semi-detached house area
7. Dry deposition in terrace house area
8. Wet deposition in terrace house area
9. Dry deposition in multistorey block area
10. Wet deposition in multistorey block area

For each of these main categories a number of relevant countermeasures for different types of surface are treated.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by some 40 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by a factor of ca. 63-69 %. The open (grassed) areas contribute about 47 % of the dose rate in the early phase - or in other terms: 26 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 186 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Dry
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a dry deposition contaminating a garden area, some grassed areas could in the very early phase be decontaminated by cutting grass. In areas where vegetation is thin or areas of bare soil, however, a *removal* of the contamination, requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by about 38 %. Averaged total accumulated lifetime dose reduction over 70 years by 60-67 %. The open (grassed) areas contribute about 47 % of the dose rate in the early phase - or in other terms: 26 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 186 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Dry deposition to snow cover
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 46 %. Averaged total accumulated lifetime dose reduction over 70 years by 66-71 %. The open (grassed) areas contribute about 47 % of the dose rate in the early phase - or in other terms: 26 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 186 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Lawn mowing (Literature 5, 6)

In a dry deposition case, lawn mowing is an efficient decontamination procedure in the early phase. If the grass is not extremely short at the time of deposition, the radiocaesium aerosol deposition to a grassed area will be significantly higher than that to an area of bare soil (in some cases more than 6 times as much). The transfer process of deposited radiocaesium from the grass to the underlying soil has a half-life of 7 days (at 11mm rain/week) to 15 days (dry weather), so it is important to get started immediately. Naturally, the cut-off grass must be removed from the lawn.

Expected effect: Immediate averaged total dose rate reduction in the area by about 35-40 %, if carried out within the first few days following deposition. Averaged total accumulated lifetime dose reduction over 70 years by ca. 60 %. The open (grassed) areas contribute about 47 % of the dose rate in the early phase - or in other terms: 26 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 186 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local inhabitants. It is assumed that the procedure could be carried out at a speed of ca. $2 \bullet 10^{-4}$ man-days per treated m^2 - plus an additional 0.003 man-days/m^2 to remove the grass by rake. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The ordinary household lawn mower (estimated price: 600 ECU (petrol operated) or 150 (manually operated)) will normally be readily available for the task Consumables for the motorized version would amount to ca. 2 l/h of petrol.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount will depend on the length and density of the removed grass (on average about 600 l/ha). The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 400 ECU/ha.

Further remarks: It is important to cut the grass as short as possible, and that practically all cut-off grass is removed.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Dry
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

Although it would be a relatively demanding procedure in terms of man-power, pruning of vegetation, if in leaf at the time of deposition, would in the early phase have a great effect on the dose contribution from trees, hedges or bushes, as radioactive material can accumulate to high levels on leaves or needles during dry deposition. The procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous should be felled, as the contamination on these could contribute to the dose over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 27 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 9 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 34 % of the dose rate in the early phase - or in other terms: 18 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 186 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: If vegetation is not in leaf the contaminant deposition is likely to be very small.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Dry
Surface type: House walls (incl. windows)

Clean-up action: Fire hosing (Literature 1, 3)

In the early phase, where the contaminant migration has often not progressed too deep into a wall (certainly not if it is made of brick), a reductive effect by some 60 % on the contamination level of the wall can easily be achieved by fire hosing. Once the contamination is strongly bound in a clay or concrete brick (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result. Deposition on windows is small, weakly bound and easily removed.

Expected effect: Immediate averaged total dose rate reduction in the area by some 6 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 8 %. The wall areas contribute about 8 % of the dose rate in the early phase - or in other terms: 5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 186 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.001 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required for tall buildings. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). It is impossible to collect the waste from the operation. Therefore the surface immediately below the wall should be treated *afterwards*.

Further remarks: The top part of the wall should be cleaned first and the bottom part should be cleaned particularly carefully, as this is the part that is closest to a human being standing outside the building.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Dry
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 8 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 3 %. The roof areas contribute about 11 % of the dose rate in the early phase - or in other terms: 6 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 186 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would facilitate the procedure. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Wet
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by some 75-79 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by about 81-88 %. The open (grassed) areas contribute about 87 % of the dose rate in the early phase - or in other terms: 21 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 170 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Wet
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a wet deposition contaminating a garden area, little or no effect is achievable by merely cutting grass. A *removal* of the contamination from this type of area therefore requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 75 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 80-84 %. The open (grassed) areas contribute about 87 % of the dose rate in the early phase - or in other terms: 21 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 170 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Wet (scavenging with snow)
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 85 %. Averaged total accumulated lifetime dose reduction over 70 years by 88-90 %. The open (grassed) areas contribute about 87 % of the dose rate in the early phase - or in other terms: 21 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 170 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Wet
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

The contamination on vegetation has little influence on the total dose in this sort of wet deposition scenarios. If remedial action is desired to reduce the dose contribution from vegetation, the procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous could be felled, as the contamination level on these would be fairly constant over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 3 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 1 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 3 % of the dose rate in the early phase - or in other terms: 0.6 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 170 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: This method should only be considered in scenarios of extremely high contamination levels, or where vegetation removal could facilitate treatment of soil areas.

Region: Suburban or urban
House type: Detached wooden
Weather conditions at deposition: Wet
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 7 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 3 %. The roof areas contribute about 10 % of the dose rate in the early phase - or in other terms: 2.5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 170 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would facilitate the procedure. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 38-41 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 62-68 %. The open (grassed) areas contribute about 46 % of the dose rate in the early phase - or in other terms: 17 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 121 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Dry
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a dry deposition contaminating a garden area, some grassed areas could in the very early phase be decontaminated by cutting grass. In areas where vegetation is thin or areas of bare soil, however, a *removal* of the contamination requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 38 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 58-66 %. The open (grassed) areas contribute about 46 % of the dose rate in the early phase - or in other terms: 17 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 121 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5{\cdot}10^{-4}$ - $1{\cdot}10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Dry deposition to snow cover
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 45 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 64-70 %. The open (grassed) areas contribute about 46 % of the dose rate in the early phase - or in other terms: 17 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 121 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.

Region: Suburban or Urban
House type: Detached brick
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Lawn mowing (Literature 5, 6)

In a dry deposition case, lawn mowing is an efficient decontamination procedure in the early phase. If the grass is not extremely short at the time of deposition, the radiocaesium aerosol deposition to a grassed area will be significantly higher than that to an area of bare soil (in some cases more than 6 times as much). The transfer process of deposited radiocaesium from the grass to the underlying soil has a half-life of 7 days (at 11mm rain/week) to 15 days (dry weather), so it is important to get started immediately. Naturally, the cut-off grass must be removed from the lawn.

Expected effect: Immediate averaged total dose rate reduction in the area by about 35-40 %, if carried out within the first few days following deposition. Averaged total accumulated lifetime dose reduction over 70 years by ca. 55 %. The open (grassed) areas contribute about 46 % of the dose rate in the early phase - or in other terms: 17 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 121 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local inhabitants. It is assumed that the procedure could be carried out at a speed of ca. $2 \bullet 10^{-4}$ man-days per treated m^2 - plus an additional 0.003 man-days/m^2 to remove the grass by rake. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The ordinary household lawn mower (estimated price: 600 ECU (petrol operated) or 150 ECU (manually operated)) will normally be readily available for the task Consumables for the motorized version would amount to ca. 2 l/h of petrol.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount will depend on the length and density of the removed grass (on average about 600 l/ha). The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 400 ECU/ha.

Further remarks: It is important to cut the grass as short as possible, and that practically all cut-off grass is removed.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Dry
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

Although it would be a relatively demanding procedure in terms of man-power, pruning of vegetation, if in leaf at the time of deposition, would in the early phase have a great effect on the dose contribution from trees, hedges or bushes, as radioactive material can accumulate to high levels on leaves or needles during dry deposition. The procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous should be felled, as the contamination on these could contribute to the dose over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 27 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 10 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 33 % of the dose rate in the early phase - or in other terms: 12 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 121 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: If vegetation is not in leaf the contaminant deposition is likely to be very small.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Dry
Surface type: House walls (incl. windows)

Clean-up action: Fire hosing (Literature 1, 3)

In the early phase, where the contaminant migration has often not progressed too deep into a wall (certainly not if it is made of brick), a reductive effect by some 60 % on the contamination level of the wall can easily be achieved by fire hosing. Once the contamination is strongly bound in a clay or concrete brick (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result. Deposition on windows is small, weakly bound and easily removed.

Expected effect: Immediate averaged total dose rate reduction in the area by some 3-4 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 4 %. The wall areas contribute about 5 % of the dose rate in the early phase - or in other terms: 2 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 121 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.001 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required for tall buildings. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). It is impossible to collect the waste from the operation. Therefore the surface immediately below the wall should be treated *afterwards*.

Further remarks: The top part of the wall should be cleaned first and the bottom part should be cleaned particularly carefully, as this is the part that is closest to a human being standing outside the building.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Dry
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 12 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 5 %. The roof areas contribute about 16 % of the dose rate in the early phase - or in other terms: 6 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 121 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would facilitate the procedure. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Wet
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 71-75 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 78-84 %. The open (grassed) areas contribute about 83 % of the dose rate in the early phase - or in other terms: 13 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 111 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Wet
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a wet deposition contaminating a garden area, little or no effect is achievable by merely cutting grass. A *removal* of the contamination from this type of area therefore requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 71 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 77-81 %. The open (grassed) areas contribute about 83 % of the dose rate in the early phase - or in other terms: 13 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 111 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Wet (scavenging with snow)
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 81 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 81-86 %. The open (grassed) areas contribute about 83 % of the dose rate in the early phase - or in other terms: 13 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 111 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Wet
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

The contamination on vegetation has little influence on the total dose in this sort of wet deposition scenarios. If remedial action is desired to reduce the dose contribution from vegetation, the procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous could be felled, as the contamination level on these would be fairly constant over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 3 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 1 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 3 % of the dose rate in the early phase - or in other terms: 0.4 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 111 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: This method should only be considered in scenarios of extremely high contamination levels, or where vegetation removal could facilitate treatment of soil areas.

Region: Suburban or urban
House type: Detached brick
Weather conditions at deposition: Wet
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 10 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 5 %. The roof areas contribute about 14 % of the dose rate in the early phase - or in other terms: 2.2 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 111 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would facilitate the procedure. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 44 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 75-78 %. The open (grassed) areas contribute about 53 % of the dose rate in the early phase - or in other terms: 9 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 70 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Dry
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a dry deposition contaminating a garden area, some grassed areas could in the very early phase be decontaminated by cutting grass. In areas where vegetation is thin or areas of bare soil, however, a *removal* of the contamination requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 43 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 73-76 %. The open (grassed) areas contribute about 53 % of the dose rate in the early phase - or in other terms: 9 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 70 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Dry deposition to snow cover
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 52 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 80 %. The open (grassed) areas contribute about 53 % of the dose rate in the early phase - or in other terms: 9 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 70 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Lawn mowing (Literature 5, 6)

In a dry deposition case, lawn mowing is an efficient decontamination procedure in the early phase. If the grass is not extremely short at the time of deposition, the radiocaesium aerosol deposition to a grassed area will be significantly higher than that to an area of bare soil (in some cases more than 6 times as much). The transfer process of deposited radiocaesium from the grass to the underlying soil has a half-life of 7 days (at 11mm rain/week) to 15 days (dry weather), so it is important to get started immediately. Naturally, the cut-off grass must be removed from the lawn.

Expected effect: Immediate averaged total dose rate reduction in the area by about 40 %, if carried out within the first few days following deposition. Averaged total accumulated lifetime dose reduction over 70 years by ca. 68 %. The open (grassed) areas contribute about 53 % of the dose rate in the early phase - or in other terms: 9 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 70 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local inhabitants. It is assumed that the procedure could be carried out at a speed of ca. $2 \bullet 10^{-4}$ man-days per treated m^2 - plus an additional 0.003 man-days/m^2 to remove the grass by rake. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The ordinary household lawn mower (estimated price: 600 ECU (petrol operated) or 150 ECU (manually operated)) will normally be readily available for the task. Consumables for the motorized version would amount to ca. 2 l/h of petrol.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount will depend on the length and density of the removed grass (on average about 600 l/ha). The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 400 ECU/ha.

Further remarks: It is important to cut the grass as short as possible, and that practically all cut-off grass is removed.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Dry
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

Although it would be a relatively demanding procedure in terms of man-power, pruning of vegetation, if in leaf at the time of deposition, would in the early phase have a great effect on the dose contribution from trees, hedges or bushes, as radioactive material can accumulate to high levels on leaves or needles during dry deposition. The procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous should be felled, as the contamination on these could contribute to the dose over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 21 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 7 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 26 % of the dose rate in the early phase - or in other terms: 5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 70 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: If vegetation is not in leaf the contaminant deposition is likely to be very small.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Dry
Surface type: House walls (incl. windows)

Clean-up action: Fire hosing (Literature 1, 3)

In the early phase, where the contaminant migration has often not progressed too deep into a wall (certainly not if it is made of brick), a reductive effect by some 60 % on the contamination level of the wall can easily be achieved by fire hosing. Once the contamination is strongly bound in a clay or concrete brick (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result. Deposition on windows is small, weakly bound and easily removed.

Expected effect: Immediate averaged total dose rate reduction in the area by some 1.5 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 1-2 %. The wall areas contribute about 2 % of the dose rate in the early phase - or in other terms: 0.3 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 70 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.001 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required for tall buildings. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). It is impossible to collect the waste from the operation. Therefore the surface immediately below the wall should be treated *afterwards*.

Further remarks: The top part of the wall should be cleaned first and the bottom part should be cleaned particularly carefully, as this is the part that is closest to a human being standing outside the building.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Dry
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 14 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 6 %. The roof areas contribute about 19 % of the dose rate in the early phase - or in other terms: 3 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 70 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Wet
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 70-75 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 78-83 %. The open (grassed) areas contribute about 83 % of the dose rate in the early phase - or in other terms: 7.5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 64 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Wet
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a wet deposition contaminating a garden area, little or no effect is achievable by merely cutting grass. A *removal* of the contamination from this type of area therefore requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by about 71 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 80 %. The open (grassed) areas contribute about 83 % of the dose rate in the early phase - or in other terms: 7.5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 64 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Wet (scavenging with snow)
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 81 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 88 %. The open (grassed) areas contribute about 83 % of the dose rate in the early phase - or in other terms: 7.5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 64 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Wet
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

The contamination on vegetation has little influence on the total dose in this sort of wet deposition scenarios. If remedial action is desired to reduce the dose contribution from vegetation, the procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous could be felled, as the contamination level on these would be fairly constant over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 1.6 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 0.7 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 2 % of the dose rate in the early phase - or in other terms: 0.2 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 64 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: This method should only be considered in scenarios of extremely high contamination levels, or where vegetation removal could facilitate treatment of soil areas.

Region: Suburban or urban
House type: Semi-detached
Weather conditions at deposition: Wet
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 11 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 5 %. The roof areas contribute about 15 % of the dose rate in the early phase - or in other terms: 1.3 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 64 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 41-44 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 74-76 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 5.6 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Dry
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a dry deposition contaminating a garden area, some grassed areas could in the very early phase be decontaminated by cutting grass. In areas where vegetation is thin or areas of bare soil, however, a *removal* of the contamination requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 40-42 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 71-74 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 5.6 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Dry deposition to snow cover
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 49 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 81 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 5.6 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.
The procedure could also be used to remove contamination from roads.

Region: Suburban or urban
House type: Terrace-house
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Lawn mowing (Literature 5, 6)

In a dry deposition case, lawn mowing is an efficient decontamination procedure in the early phase. If the grass is not extremely short at the time of deposition, the radiocaesium aerosol deposition to a grassed area will be significantly higher than that to an area of bare soil (in some cases more than 6 times as much). The transfer process of deposited radiocaesium from the grass to the underlying soil has a half-life of 7 days (at 11mm rain/week) to 15 days (dry weather), so it is important to get started immediately. Naturally, the cut-off grass must be removed from the lawn.

Expected effect: Immediate averaged total dose rate reduction in the area by about 38 %, if carried out within the first few days following deposition. Averaged total accumulated lifetime dose reduction over 70 years by ca. 65 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 5.6 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local inhabitants. It is assumed that the procedure could be carried out at a speed of ca. $2 \bullet 10^{-4}$ man-days per treated m^2 - plus an additional 0.003 man-days/m^2 to remove the grass by rake. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The ordinary household lawn mower (estimated price: 600 ECU (petrol operated) or 150 ECU (manually operated)) will normally be readily available for the task. Consumables for the motorized version would amount to ca. 2 l/h of petrol.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount will depend on the length and density of the removed grass (on average about 600 l/ha). The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 400 ECU/ha.

Further remarks: It is important to cut the grass as short as possible, and that practically all cut-off grass is removed.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Dry
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

Although it would be a relatively demanding procedure in terms of man-power, pruning of vegetation, if in leaf at the time of deposition, would in the early phase have a great effect on the dose contribution from trees, hedges or bushes, as radioactive material can accumulate to high levels on leaves or needles during dry deposition. The procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous should be felled, as the contamination on these could contribute to the dose over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 21 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 6 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 26 % of the dose rate in the early phase - or in other terms: 2.9 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: If vegetation is not in leaf the contaminant deposition is likely to be very small.

Region: Suburban or urban
House type: Terrace-house
Weather conditions at deposition: Dry
Surface type: House walls (incl. windows)

Clean-up action: Fire hosing (Literature 1, 3)

In the early phase, where the contaminant migration has often not progressed too deep into a wall (certainly not if it is made of brick), a reductive effect by some 60 % on the contamination level of the wall can easily be achieved by fire hosing. Once the contamination is strongly bound in a clay or concrete brick (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result. Deposition on windows is small, weakly bound and easily removed.

Expected effect: Immediate averaged total dose rate reduction in the area by some 2 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 2 %. The wall areas contribute about 3 % of the dose rate in the early phase - or in other terms: 0.3 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.001 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required for tall buildings. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). It is impossible to collect the waste from the operation. Therefore the surface immediately below the wall should be treated *afterwards*.

Further remarks: The top part of the wall should be cleaned first and the bottom part should be cleaned particularly carefully, as this is the part that is closest to a human being standing outside the building.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Dry
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 7-8 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 3-4 %. The roof areas contribute about 10 % of the dose rate in the early phase - or in other terms: 1.2 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Terrace-house
Weather conditions at deposition: Dry
Surface type: Roads and pavements

Clean-up action: Vacuum sweeping (Literature 1, 4)

Municipal vacuum sweepers are currently being used in most urban and suburban areas in the Nordic countries for routine street cleaning. Similar devices were used by the authorities in Kiev to clean the streets after the Chernobyl accident. The seated vacuum sweeper has a water nozzle which sprays a fine mist of water (for dust control) onto the road before typically 3 rotating brushes sweep the road. Finally, a vacuum attachment collects the loosened dust in a vessel behind the operator.

Expected effect: Immediate averaged total dose rate reduction in the area by some 7 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 2 %. The road paving areas in the scenario contribute about 11 % of the dose rate in the early phase - or in other terms: 1.3 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure should be carried out by the local municipal road sweepers who know the equipment. The inhalation hazard to the workers would be very low due to the water application. It is estimated that the procedure could be carried out at a speed as high as ca. $4 \cdot 10^{-5}$ man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a vacuum sweeping street cleaning machine (price: ca. 90000 ECU). The equipment would often locally be readily available within the Nordic countries. Further, about 0.1 m^3 water per hour would be used, plus 5-6 l of petrol per hour.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: Wastes (amount normally in the order of 100-200 g/m^2 with a concentration in the order of 5000 Bq/m^3 per Bq/m^2) are collected in the vehicle's vessel, which is later emptied into a waste transport truck. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 30 ECU/ha.

Further remarks: Special care should be taken to clean road gutters properly, as washed-off material from the rest of the road may accumulate here. Further, if radiation levels are high the radioactive material collected in the waste vessel of the vacuum sweeping vehicle may give a significant dose to the operator.

Region: Urban or suburban
House type: Terrace house
Weather conditions at deposition: Dry
Surface type: Roads and pavements

Clean-up action: Fire hosing (Literature 1, 3)

Immediately after deposition, the radioactive matter is not very firmly fixed to a road surface, and a good effect could be obtained by water hosing at ordinary hydrant pressure. Already over the first months, the contamination fixation to the road will become significantly stronger. Investigations on freshly contaminated road pavings have shown that the radiocaesium contamination level could be reduced by a factor of 3 (on asphalt) to 5 (on concrete) by this method.

Expected effect: Immediate averaged total dose rate reduction in the area by some 7 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 2 %. The road paving areas in the scenario contribute about 11 % of the dose rate in the early phase - or in other terms: 1.3 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 42 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of 0.001 - 0.002 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, about 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: 50-200 g/m^2 solid and ca. 0.25 m^3/m^2 liquid low level. Wastes are impossible to collect and are led with the run off water to the road drains.

Further remarks: Special care should be taken to clean road gutters properly, as washed off material from the rest of the road may accumulate here.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Wet
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 61-64 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 81 %. The open (grassed) areas contribute about 72 % of the dose rate in the early phase - or in other terms: 4.5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 37 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Wet
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a wet deposition contaminating a garden area, little or no effect is achievable by merely cutting grass. A *removal* of the contamination from this type of area therefore requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 62 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 81 %. The open (grassed) areas contribute about 72 % of the dose rate in the early phase - or in other terms: 4.5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 37 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Wet (scavenging with snow)
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 70 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 87 %. The open (grassed) areas contribute about 72 % of the dose rate in the early phase - or in other terms: 4.5 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 37 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.
The procedure could also be used to remove contamination from roads.

Region: Suburban or urban
House type: Terrace house
Weather conditions at deposition: Wet
Surface type: House roofs

Clean-up action: Fire hosing (Literature 1, 2)

In the early phase, where the contaminant migration has not progressed too deep into the roof paving, a significant reductive effect (by more than 60 %) on the contamination level of the roof can be achieved by fire hosing. Once the contamination is strongly bound in the roof tile (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result.

Expected effect: Immediate averaged total dose rate reduction in the area by some 4-5 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 2 %. The roof areas contribute about 6 % of the dose rate in the early phase - or in other terms: 0.35 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 37 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. In some cases, where roofs are covered by moss, algae and/or litter at the time of deposition of the contamination, the relative dose contribution from the roofs may be more than twice as high.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.004 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). The waste can be collected and filtered (see ref. 3) to be significantly reduced in amount, but would normally be led through down-pipes to the sewer.

Further remarks: An effort should be made to clean roof gutters properly. Otherwise, contamination may accumulate here.

Region: Suburban or urban
House type: Terrace-house
Weather conditions at deposition: Wet
Surface type: Roads and pavements

Clean-up action: Vacuum sweeping (Literature 1, 4)

Municipal vacuum sweepers are currently being used in most urban and suburban areas in the Nordic countries for routine street cleaning. Similar devices were used by the authorities in Kiev to clean the streets after the Chernobyl accident. The seated vacuum sweeper has a water nozzle which sprays a fine mist of water (for dust control) onto the road before typically 3 rotating brushes sweep the road. Finally, a vacuum attachment collects the loosened dust in a vessel behind the operator.

Expected effect: Immediate averaged total dose rate reduction in the area by some 14 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 1.5-2.5 %. The road paving areas in the scenario contribute about 21 % of the dose rate in the early phase - or in other terms: 1.3 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 37 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure should be carried out by the local municipal road sweepers who know the equipment. The inhalation hazard to the workers would be very low due to the water application. It is estimated that the procedure could be carried out at a speed as high as ca. $4 \cdot 10^{-5}$ man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a vacuum sweeping street cleaning machine (price: ca. 90000 ECU). The equipment would often locally be readily available within the Nordic countries. Further, about 0.1 m^3 water per hour would be used, plus 5-6 l of petrol per hour.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: Wastes (amount normally in the order of 100-200 g/m^2 with a concentration in the order of 5000 Bq/m^3 per Bq/m^2) are collected in the vehicle's vessel, which is later emptied into a waste transport truck. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 30 ECU/ha.

Further remarks: Special care should be taken to clean road gutters properly, as washed-off material from the rest of the road may accumulate here. Further, if radiation levels are high the radioactive material collected in the waste vessel of the vacuum sweeping vehicle may give a significant dose to the operator.

Region: Urban or suburban
House type: Terrace house
Weather conditions at deposition: Wet
Surface type: Roads and pavements

Clean-up action: Fire hosing (Literature 1, 3)

Immediately after deposition, the radioactive matter is not very firmly fixed to a road surface, and a good effect could be obtained by water hosing at ordinary hydrant pressure. Already over the first months, the contamination fixation to the road will become significantly stronger. Investigations on freshly contaminated road pavings have shown that the radiocaesium contamination level could be reduced by a factor of 3 (on asphalt) to 5 (on concrete) by this method.

Expected effect: Immediate averaged total dose rate reduction in the area by some 14 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 1.5-2.5 %. The road paving areas in the scenario contribute about 21 % of the dose rate in the early phase - or in other terms: 1.3 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 37 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of 0.001 - 0.002 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, about 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: 50-200 g/m^2 solid and ca. 0.25 m^3/m^2 liquid low level. Wastes are impossible to collect and are led with the run off water to the road drains.

Further remarks: Special care should be taken to clean road gutters properly, as washed off material from the rest of the road may accumulate here.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 41-44 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 76-80 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 4 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a dry deposition contaminating a garden area, some grassed areas could in the very early phase be decontaminated by cutting grass. In areas where vegetation is thin or areas of bare soil, however, a *removal* of the contamination requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 40-42 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 74-78 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 4 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5 \cdot 10^{-4}$ - $1 \cdot 10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry deposition to snow cover
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 49 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 83 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 4 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition.
The procedure could also be used to remove contamination from roads.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: Grassed garden areas

Clean-up action: Lawn mowing (Literature 5, 6)

In a dry deposition case, lawn mowing is an efficient decontamination procedure in the early phase. If the grass is not extremely short at the time of deposition, the radiocaesium aerosol deposition to a grassed area will be significantly higher than that to an area of bare soil (in some cases more than 6 times as much). The transfer process of deposited radiocaesium from the grass to the underlying soil has a half-life of 7 days (at 11mm rain/week) to 15 days (dry weather), so it is important to get started immediately. Naturally, the cut-off grass must be removed from the lawn.

Expected effect: Immediate averaged total dose rate reduction in the area by about 38 %, if carried out within the first few days following deposition. Averaged total accumulated lifetime dose reduction over 70 years by ca. 69 %. The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 4 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the personnel that usually cut the grass in the open urban areas in question. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} man-days per treated m^2, provided that the cut-off grass is automatically collected (usually in a ca. 300 l vessel) - if not, it must be collected by rake (ca. 0.003 man-days/m^2). Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The large lawn mower (estimated price: 15000 ECU) must be readily available for the task (otherwise, available equipment will do - although perhaps at lower speed). Consumables would amount to ca. 6 l/h of petrol.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount will depend on the length and density of the removed grass (on average about 600 l/ha). The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 400 ECU/ha.

Further remarks: It is important to cut the grass as short as possible, and that practically all cut-off grass is removed.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: Trees and bushes in garden

Clean-up action: Pruning (Literature 5, 8)

Although it would be a relatively demanding procedure in terms of man-power, pruning of vegetation, if in leaf at the time of deposition, would in the early phase have a great effect on the dose contribution from trees, hedges or bushes, as radioactive material can accumulate to high levels on leaves or needles during dry deposition. The procedure would be to either cut off branches of deciduous trees or wait for the natural leaf-fall and accept a dose over a limited period. Further, bushes and trees, which are not deciduous should be felled, as the contamination on these could contribute to the dose over many years. It is known that if the contamination is left on trees for years, radiocontaminants such as caesium will migrate into the wood tissue and become homogeneously distributed over the entire wood mass.

Expected effect: Immediate averaged total dose rate reduction in the area by about 19 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 4 %. In areas with much vegetation this figure could be more than twice as high. The trees and bushes contribute about 24 % of the dose rate in the early phase - or in other terms: 2 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: Pruning of trees and bushes could to some degree be carried out by local inhabitants, while the more demanding actions such as felling of trees and pruning at great heights could be carried out by professionals. As such, the actions do not require high level skills or much instruction. Depending on the exact required actions for the particular area and seasonality, it is estimated that the procedure could be carried out in an ordinary garden of 500 m^2 at a speed of ca. 1 to 8 man-days. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: Much of the equipment, such as chain-saws (ca. 200-1000 ECU), cutters (ca. 100 ECU) and ladders would be readily available in most inhabited areas. A scaffold or platform would be of great value for high level pruning.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: The amount is difficult to estimate on a general basis, as it depends on the amount and type of vegetation. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 10 ECU/m^3.

Further remarks: If vegetation is not in leaf the contaminant deposition is likely to be very small.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: House walls (incl. windows)

Clean-up action: Fire hosing (Literature 1, 3)

In the early phase, where the contaminant migration has often not progressed too deep into a wall (certainly not if it is made of brick), a reductive effect by some 60 % on the contamination level of the wall can easily be achieved by fire hosing. Once the contamination is strongly bound in a clay or concrete brick (typically after a couple of months), it would be necessary to apply the water at higher pressure to achieve the same result. Deposition on windows is small, weakly bound and easily removed.

Expected effect: Immediate averaged total dose rate reduction in the area by some 2 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 3 %. The wall areas contribute about 3 % of the dose rate in the early phase - or in other terms: 0.3 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of ca. 0.001 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, a scaffold would be required for tall buildings. About 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out in areas of high contamination levels.

Waste - amounts and costs: The procedure generates about 20 l/m^2 of liquid waste and ca. 0.4 kg/m^2 of solid waste containing practically all the contamination (ca. 2000 Bq/m^3 per Bq/m^2). It is impossible to collect the waste from the operation. Therefore the surface immediately below the wall should be treated *afterwards*.

Further remarks: The top part of the wall should be cleaned first and the bottom part should be cleaned particularly carefully, as this is the part that is closest to a human being standing outside the building.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: Roads and pavements

Clean-up action: Vacuum sweeping (Literature 1, 4)

Municipal vacuum sweepers are currently being used in most urban and suburban areas in the Nordic countries for routine street cleaning. Similar devices were used by the authorities in Kiev to clean the streets after the Chernobyl accident. The seated vacuum sweeper has a water nozzle which sprays a fine mist of water (for dust control) onto the road before typically 3 rotating brushes sweep the road. Finally, a vacuum attachment collects the loosened dust in a vessel behind the operator.

Expected effect: Immediate averaged total dose rate reduction in the area by some 14 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 2-3 %. The road paving areas in the scenario contribute about 22 % of the dose rate in the early phase - or in other terms: 1.8 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure should be carried out by the local municipal road sweepers who know the equipment. The inhalation hazard to the workers would be very low due to the water application. It is estimated that the procedure could be carried out at a speed as high as ca. $4 \cdot 10^{-5}$ man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a vacuum sweeping street cleaning machine (price: ca. 90000 ECU). The equipment would often locally be readily available within the Nordic countries. Further, about 0.1 m^3 water per hour would be used, plus 5-6 l of petrol per hour.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: Wastes (amount normally in the order of 100-200 g/m^2 with a concentration in the order of 5000 Bq/m^3 per Bq/m^2) are collected in the vehicle's vessel, which is later emptied into a waste transport truck. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 30 ECU/ha.

Further remarks: Special care should be taken to clean road gutters properly, as washed-off material from the rest of the road may accumulate here. Further, if radiation levels are high the radioactive material collected in the waste vessel of the vacuum sweeping vehicle may give a significant dose to the operator.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: Roads and pavements

Clean-up action: Fire hosing (Literature 1, 3)

Immediately after deposition, the radioactive matter is not very firmly fixed to a road surface, and a good effect could be obtained by water hosing at ordinary hydrant pressure. Already over the first months, the contamination fixation to the road will become significantly stronger. Investigations on freshly contaminated road pavings have shown that the radiocaesium contamination level could be reduced by a factor of 3 (on asphalt) to 5 (on concrete) by this method.

Expected effect: Immediate averaged total dose rate reduction in the area by some 14 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 2-3 %. The road paving areas in the scenario contribute about 22 % of the dose rate in the early phase - or in other terms: 1.8 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of 0.001 - 0.002 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, about 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: 50-200 g/m^2 solid and ca. 0.25 m^3/m^2 liquid low level. Wastes are impossible to collect and are led with the run off water to the road drains.

Further remarks: Special care should be taken to clean road gutters properly, as washed off material from the rest of the road may accumulate here.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Dry
Surface type: Grassed areas and areas of soil

Clean-up action: Ploughing (Literature 7, 1)

In large open areas such as city parks and other green areas, a considerable reduction of the dose-rate contribution from these surfaces (typically by a factor of 6-10) measured 1 m above a large soil area, with no other dose-contributing surfaces) could be achieved by ploughing. With an ordinary plough it is possible to plough as deep as ca. 45 cm, whereby a considerable shielding effect from the radioactive matter is obtained. If the radioactive matter is placed sufficiently deep it will not be redistributed by a subsequent ordinary cultivation to a depth of max. 25 cm.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 44-47 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by as much as 77-81 % (in soils suitable for the method). The open (grassed) areas contribute about 50 % of the dose rate in the early phase - or in other terms: 4 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 33 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure should be carried out by local farming workers who are experienced with ploughing. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. $2{\cdot}10^{-5}$ man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: A plough (ca. 2000 ECU) and a tractor (ca. 50000 ECU) are required, but since this is ordinary farming equipment, it is readily available in many areas.

Practicability: The procedure could be carried in some selected large open areas inside towns as an alternative to triple digging. It would further have wide applicability for farm land, where a considerable reduction in crop root radiocaesium uptake is a further advantage.

Waste - amounts and costs: No wastes produced.

Further remarks: It should be ensured that the procedure does not bring the contamination too close to the ground water level. Further, the procedure severely complicates any subsequent removal of the contamination.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Wet
Surface type: Grassed garden areas

Clean-up action: Triple digging (Literature 1, 2)

By this procedure, the order of three vertical layers of soil is changed (initially: the top ca. 5 cm, the middle ca. 15 cm and the bottom ca. 15 cm), whereby a shielding against the radioactive matter is achieved. The top soil layer, which in the early phase contains all the radioactive caesium, is placed in the bottom of the vertical profile, with the turf facing down. Soil from the bottom is placed immediately on top of this, while the intermediate layer, which must not be inverted, is placed at the top. This ensures the optimal effect with the least impact on the fertility of the area.

Expected effect: Immediate averaged total dose rate reduction in the area by 49-52 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years correspondingly by 80-84 %. The open (grassed) areas contribute about 58 % of the dose rate in the early phase - or in other terms: 3.2 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 29 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by unskilled local inhabitants, with only few instructions. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. 0.07 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The only requirement is a spade (ca. 12 ECU), which is mostly available.

Practicability: The procedure could be carried out at large scale in inhabited areas.

Waste - amounts and costs: No wastes produced.

Further remarks: The procedure severely complicates removal of the contamination. Further, in areas of very loose soil or sand a shovel may be required, as the digging would partly be accomplished from the side of the trench.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Wet
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of top soil (Literature 1, 2)

In case of a wet deposition contaminating a garden area, little or no effect is achievable by merely cutting grass. A *removal* of the contamination from this type of area therefore requires a removal of the top soil layer. Since radiocaesium is very effectively captured and retained (at least for some months) in the top ca. 2 cm soil layer, only a thin layer needs to be removed. However, testing has shown that it is difficult in practice to remove less than a 10 cm deep horizon by scraping with a bobcat, front loader and/or bulldozer.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 50 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 79-83 %. The open (grassed) areas contribute about 58 % of the dose rate in the early phase - or in other terms: 3.2 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 29 mGy per $1MBq/m^2$ initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal construction workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. $5{\cdot}10^{-4}$ - $1{\cdot}10^{-3}$ man-days per treated m^2 provided that the soil is removed by machinery such as a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU) or bobcat (estimated price: 40000 ECU) and waste transport truck must be available for the task. Since the procedure would have almost equally great impact on the dose rate in the area after one week and after two years, one set of machinery could be used to clean a large area. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery can be made available.

Waste - amounts and costs: Amounts in the order of 70 kg/m^2 of ca. 20 Bq/m^3 per Bq/m^2. The costs for transportation and final storage of waste (5-10 cm layer of soil) at a repository at a distance of less than 20 km are estimated to be in the order of 2000 ECU/ha.

Further remarks: The procedure has the disadvantageous side-effect that it could remove the entire fertile soil layer.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Wet (scavenging with snow)
Surface type: Grassed or bare soil garden areas

Clean-up action: Removal of snow (Literature 9, 10)

When contamination occurs in a wintry, thick snow-covered landscape, it has the advantage that if action is taken in the early phase to remove the contaminated snow, significant soil contamination may be averted, since the contaminated snow layer will be at the very top of the vertical profile. Very good results of snow scraping by tractor at -3 to -10°C have been reported (removal of about 99 % of the contamination). When the snow melts, however, the contaminants will rapidly reach the ground. In such situations about 30 % of the radiocaesium contamination has been found to run off from the ground surface with the melt water.

Expected effect: Immediate averaged total dose rate reduction in the area by about 57 %. Averaged total accumulated lifetime dose reduction over 70 years by ca. 89 %. The open (grassed) areas contribute about 58 % of the dose rate in the early phase - or in other terms: 3.2 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 29 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure could be carried out by local entrepreneurs and municipal workers, who have the machinery available and the routine to use it. It is assumed that the procedure could be carried out at a speed of ca. 10^{-4} - 10^{-3} man-days per treated m^2 depending on whether the snow is removed by a tractor with a mounted shovel or by a bobcat/bulldozer. The objective could also be achieved by spade by locals - but at a much slower rate. Overheads are estimated to 150 % of the manpower costs.

Equipment / other requirements and costs: The bulldozer (estimated price: 90000 ECU), bobcat (estimated price: 40000 ECU) or tractor (estimated price: 50000 ECU) and a waste transport truck must be available for the task. Consumables would amount to ca. 0.04 l/m^2 of petrol (excluding waste transport).

Practicability: The procedure could be carried out at large scale in inhabited areas, where the machinery is available.

Waste - amounts and costs: The amount depends on snow layer thickness. The costs for transportation to the sea, where it could be dumped without raising the local contamination level significantly, depend on the distance but would mostly be in the order of 2-5 ECU/m^3.

Further remarks: The procedure must be carried out before the first thaw following deposition. The procedure could also be used to remove contamination from roads.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Wet
Surface type: Roads and pavements

Clean-up action: Vacuum sweeping (Literature 1, 4)

Municipal vacuum sweepers are currently being used in most urban and suburban areas in the Nordic countries for routine street cleaning. Similar devices were used by the authorities in Kiev to clean the streets after the Chernobyl accident. The seated vacuum sweeper has a water nozzle which sprays a fine mist of water (for dust control) onto the road before typically 3 rotating brushes sweep the road. Finally, a vacuum attachment collects the loosened dust in a vessel behind the operator.

Expected effect: Immediate averaged total dose rate reduction in the area by some 27 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 5-6 %. The road paving areas in the scenario contribute about 41 % of the dose rate in the early phase - or in other terms: 2.3 μGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 29 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure should be carried out by the local municipal road sweepers who know the equipment. The inhalation hazard to the workers would be very low due to the water application. It is estimated that the procedure could be carried out at a speed as high as ca. $4 \cdot 10^{-5}$ man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a vacuum sweeping street cleaning machine (price: ca. 90000 ECU). The equipment would often locally be readily available within the Nordic countries. Further, about 0.1 m^3 water per hour would be used, plus 5-6 l of petrol per hour.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: Wastes (amount normally in the order of 100-200 g/m^2 with a concentration in the order of 5000 Bq/m^3 per Bq/m^2) are collected in the vehicle's vessel, which is later emptied into a waste transport truck. The costs for transportation and final storage of waste at a repository at a distance of less than 20 km are estimated to be in the order of 30 ECU/ha.

Further remarks: Special care should be taken to clean road gutters properly, as washed-off material from the rest of the road may accumulate here. Further, if radiation levels are high the radioactive material collected in the waste vessel of the vacuum sweeping vehicle may give a significant dose to the operator.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Wet
Surface type: Roads and pavements

Clean-up action: Fire hosing (Literature 1, 3)

Immediately after deposition, the radioactive matter is not very firmly fixed to a road surface, and a good effect could be obtained by water hosing at ordinary hydrant pressure. Already over the first months, the contamination fixation to the road will become significantly stronger. Investigations on freshly contaminated road pavings have shown that the radiocaesium contamination level could be reduced by a factor of 3 (on asphalt) to 5 (on concrete) by this method.

Expected effect: Immediate averaged total dose rate reduction in the area by some 27 % by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by 5-6 %. The road paving areas in the scenario contribute about 41 % of the dose rate in the early phase - or in other terms: 2.3 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 29 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken. The relative dose contribution from pavings to people who spend much time on the paved areas could be up to 4 times higher.

Personnel requirements and costs: The procedure could be carried out by the local fire brigade, but could also be carried out by less skilled workers, given only few instructions. The inhalation hazard to the workers would be negligible. It is assumed that the procedure could be carried out at a speed of 0.001 - 0.002 man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: The required equipment is a hosepipe, and, where no hydrant is available, a pump. The equipment would often locally be readily available; otherwise an investment in the order of 1000 ECUs per set may be called for. Further, about 20 m^3 water per hour would be used, plus 10 l of petrol per hour if a pump is required. Water might be pumped from a nearby lake.

Practicability: The procedure could be carried out at large scale in many inhabited areas.

Waste - amounts and costs: 50-200 g/m^2 solid and ca. 0.25 m^3/m^2 liquid low level. Wastes are impossible to collect and are led with the run off water to the road drains.

Further remarks: Special care should be taken to clean road gutters properly, as washed off material from the rest of the road may accumulate here.

Region: Urban
House type: Multi-storey block
Weather conditions at deposition: Wet
Surface type: Grassed areas and areas of soil

Clean-up action: Ploughing (Literature 7, 1)

In large open areas such as city parks and other green areas, a considerable reduction of the dose-rate contribution from these surfaces (typically by a factor of 6-10) measured 1 m above a large soil area, with no other dose-contributing surfaces) could be achieved by ploughing. With an ordinary plough it is possible to plough as deep as ca. 45 cm, whereby a considerable shielding effect from the radioactive matter is obtained. If the radioactive matter is placed sufficiently deep it will not be redistributed by a subsequent ordinary cultivation to a depth of max. 25 cm.

Expected effect: Immediate averaged total dose rate reduction in the area by ca. 52-55 % (for typical soils) by application in the early phase. Averaged total accumulated lifetime dose reduction over 70 years by as much as 84-87 % (in soils suitable for the method). The open (grassed) areas contribute about 58 % of the dose rate in the early phase - or in other terms: 3.2 µGy/d per 1 MBq/m^2 of ^{137}Cs deposited to a lawn. The averaged total accumulated lifetime dose to people living in the area would amount to ca. 29 mGy per 1MBq/m^2 initially deposited to a lawn if no action were taken.

Personnel requirements and costs: The procedure should be carried out by local farming workers who are experienced with ploughing. In particularly dry areas prevention against inhalation of resuspended dust should be considered. It is assumed that the procedure could be carried out at a speed of ca. $2 \cdot 10^{-5}$ man-days per treated m^2. Overheads are estimated to 100 % of the manpower costs.

Equipment / other requirements and costs: A plough (ca. 2000 ECU) and a tractor (ca. 50000 ECU) are required, but since this is ordinary farming equipment, it is readily available in many areas.

Practicability: The procedure could be carried in some selected large open areas inside towns as an alternative to triple digging. It would further have wide applicability for farm land, where a considerable reduction in crop root radiocaesium uptake is a further advantage.

Waste - amounts and costs: No wastes produced.

Further remarks: It should be ensured that the procedure does not bring the contamination too close to the ground water level. Further, the procedure severely complicates any subsequent removal of the contamination.

7. LIST OF SUGGESTED SUPPLEMENTARY READING, AS NUMBERED IN THE INDIVIDUAL DATA SHEETS:

1. J. Roed, K.G. Andersson and H. Prip (eds.): Practical Means for Decontamination 9 Years After a Nuclear Accident, Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, December 1995.

2. J. Roed, C. Lange, K.G. Andersson, H. Prip, S. Olsen, V.P. Ramzaev, A.V. Ponomarjov, A.N. Barkovsky, A.S. Mishine, B.F. Vorobiev, A.V. Chesnokov, V.N. Potapov, S.B. Shcherbak: Decontamination in a Russian Settlement, Risø-R-870(EN), ISBN 87-550-2152-2, ISSN 0106-2840, March 1996.

3. J. Roed and K.G. Andersson: Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout, J. Environ. Radioactivity vol.33, no.2, pp. 107-116, 1996.

4. J. Sinnaeve and M. Olast (eds.): Improvement of Practical Countermeasures: the Urban Environment, Commission of the European Communities, EUR 12555 EN, 1991.

5. J. Roed: Deposition and Removal of Radioactive Substances in an Urban Area, Final report of the NKA project AKTU-245, ISBN 87 7303 514 9, October 1990.

6. J. Roed: Dry Deposition in Rural and in Urban Areas in Denmark, Rad. Prot. Dos. vol. 21, No.1/3, pp. 33-36, 1987.

7. J. Roed, K.G. Andersson and H. Prip: The Skim and Burial Plough: A New Implement for Reclamation of Radioactively Contaminated Land, J. Environ. Radioactivity vol. 33, no. 2, pp. 117-128, 1996.

8. J. Lehto (editor): Cleanup of Large Radioactive-Contaminated Areas and Disposal of Generated Waste, Final Report of the KAN2 project, TemaNord 1994:567, ISBN 92 9120 488 9, February 1994.

9. C. Qvenild and U. Tveten: Decontamination and Winter Conditions, Report on work carried out under the NKA program 'Safety Research in Energy Production', Institute for Energy Technology, Kjeller, Norway, ISBN 82-7017-067-4, December 1984.

10. L. Warming: Weathering and Decontamination of Radioactivity Deposited on Asphalt Surfaces, Risø-M-2273, ISBN 87-550-0903-4, December 1982.

8. CONCLUSIONS

A series of data sheets has been made, each presenting the likely beneficial effects and costs of a feasible method for early phase dose-reducing treatment of a contaminated surface in a particular type of environment, where contamination has occurred either in the presence or absence of precipitation.

The chosen house-types are aimed at representing some of the most typical housing environments of the Nordic countries. From the five standard environments modifications and adjustments can be made to reflect specific environments in greater detail, as explained in Chapter 3.

The data sheets show that under normal conditions and with the stipulated dimensions and locations of the individual surfaces in the standard environments, the open (grassed) areas will give the largest contribution to both the dose-rate immediately after deposition and the integrated dose over 70 years. However, in reality, some urban areas have considerably smaller open areas, and in such cases the importance of these needs to be reconsidered as described in Chapter 3.

The data sheets show that if action is taken in the early phase, it is possible by relatively simple means to reduce the accumulated life-time external dose to the local inhabitants by more than a factor of 10.

Also contaminated indoor surfaces may in some cases contribute significantly to the dose. This influence of indoor deposition is treated in a separate chapter.

Suggestions on how to dispose of the radioactive waste arising from some of the described methods are also given in a separate chapter.

The reported data is used in the final phase of the EKO-5 project, as the background material for guidelines for the local authorities in the different Nordic countries on how to clean radioactively contaminated urban surfaces.