Public Health England

Protecting and improving the nation's health

UK Recovery Handbooks for Radiation Incidents 2015

Inhabited Areas Handbook

Version 4

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UK Recovery Handbooks for Radiation Incidents 2015

Inhabited Areas Handbook

Version 4

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Abstract

The handbook for assisting in the management of contaminated inhabited areas following a radiation incident has been developed as a result of a series of UK and European initiatives that started in the early 1990s, involving a wide range of stakeholders. The handbook is aimed at national and local authorities, central government departments and agencies, radiation protection experts, emergency services, industry and others who may be affected.

The handbook includes management options for application in the early and medium to longer term phases of an incident. Sources of contamination considered in the handbook include nuclear accidents and radiological dispersion devices. The handbook is divided into several sections which provide supporting scientific and technical information; an analysis of the factors influencing recovery; compendia of comprehensive, state-of-the-art datasheets for 29 management options; and guidance on planning in advance. A decision-aiding framework comprising colour coded selection tables for each of the main surfaces found in an inhabited area, look-up tables to assist in the elimination of options and several worked examples are also included.

The handbook can be used as a preparatory tool, under non-crisis conditions, to engage stakeholders and to develop local and regional plans. The handbook can also be applied as part of the decision-aiding process to develop a recovery strategy following an incident. In addition, the handbook is useful for training purposes and during emergency exercises. The handbook for inhabited areas complements the other two handbooks for food production systems and drinking water.

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Quick Guide to the Inhabited Areas Handbook

For what purpose do I want to use the Inhabited Areas Handbook?

Planning

Go to Section 4 "Planning in advance"

Consider customising handbook for local conditions (eg land use) using a stakeholder engagement process

Response

Go to Section 5 "Constructing a management strategy"

Follow the 8-step process:

1. Identify surfaces that are likely to be/have been contaminated
2. Consult selection table of management options for the identified surfaces
3. Check applicability of management options for radionuclides released

ELIMINATE OPTIONS

4. Check key constraints of management options

ELIMINATE OPTIONS

5. Check effectiveness of management option

ELIMINATE OPTIONS

6. Check for incremental doses and production of waste

ELIMINATE OPTIONS

7. Go to Section 7 "Datasheets" for detailed information on the remaining options

ELIMINATE OPTIONS

8. Use selection table to select and combine options and build management strategy

Training – new user

Go to all sections

Section 1 "Introduction"
Section 2 "Management options"
Section 3 "Factors influencing implementation of management options"
Section 4 "Planning in advance"
Section 5 "Constructing a management strategy"
Section 6 "Worked examples"
Section 7 "Datasheets"
Consult appendices for supporting information if required

Training – refresher

Go to Section 6 "Worked examples"

This goes through the 8-step process for two examples: major incident at a nuclear power plant involving ^{137}Cs and a small scale incident involving ^{239}Pu

Contents

1 Introduction to the Inhabited Areas Handbook

The Inhabited Areas Handbook is a tool to support decision-makers in developing a recovery strategy following a radiation incident. The handbook is a compilation of information to help users identify the important issues and evaluate management options. It should be regarded as a living document which requires updating from time to time to remain state-of-the-art.

Contaminated inhabited areas - what's the problem?

Following a radiation incident, contamination may occur in an inhabited area. As a consequence, many types of surfaces and areas could be affected which require specific types of management options to reduce external doses and doses from inhalation of resuspended material. Clean-up may result in large volumes of contaminated material requiring disposal.

How can the Inhabited Areas Handbook help?

The Inhabited Areas Handbook provides decision makers and other stakeholders with guidance on how to manage the many facets of a radiation incident. It contains scientific and technical information on what to do during the emergency, as well as tools to assist in the selection of a recovery strategy taking into account the wide range of influencing factors. The Inhabited Areas Handbook is also helpful for contingency planning.

1.1 Objectives of the Inhabited Areas Handbook

The Inhabited Areas Handbook has been developed to meet several inter-related objectives:

- to provide up-to-date information on management options for reducing the consequences of contamination in an inhabited area
- to outline the many factors that influence the implementation of these options
- to provide guidance on planning for recovery in advance of an incident
- to illustrate how to select and combine management options and hence build a recovery strategy

The Inhabited Areas Handbook also has a series of secondary aims:

- to generate awareness in emergency preparedness and recovery management options for inhabited areas
- to promote constructive dialogue between all stakeholders
- to identify under non-crisis conditions specific problems that could arise, including the setting up of working groups to find practical solutions

- to elaborate plans and/or frameworks for the management of contaminated inhabited areas at the local, national or regional level

1.2 Audience

The Inhabited Areas Handbook is specifically targeted at:

- central government departments and agencies
- experts in radiation protection
- local councils and representatives
- water and health authorities
- emergency response personnel (police force, ambulance and fire and rescue services)
- other stakeholders who may be affected/concerned, depending on the situation

1.3 Application

The Inhabited Areas Handbook can be considered solely as a reference document containing information on scientific, technical and societal aspects relevant to the management of contaminated inhabited areas. However, it is intended that it be used as part of a participatory process in order to realise its full potential. Examples of the most likely applications of the handbook are:

- in the preparation phase, under non-crisis conditions to engage stakeholders and to develop local, regional and national plans/framework/tools
- in the post-accident phases by local and national stakeholders as part of the decision-aiding process
- for training purposes
- in the preparation for and during emergency exercises

1.4 Context

The primary focus of the Inhabited Areas Handbook is radiological protection, or, in other words, reducing exposure of humans to radiation. However, experience from past contamination events, particularly the accident at the Chernobyl nuclear power plant, has shown that the consequences of widespread and long-lasting contamination are complex and multi-dimensional. Radiological protection should be considered as only one aspect of the situation. It has been recognised that, to be efficient and sustainable, the management of consequences of radioactive contamination must take into account other dimensions of living conditions, such as economic, social, cultural and ethical issues. Therefore this handbook also addresses aspects that go beyond those of radiological protection (see Section 3).

1.5 Scope

The sources of contamination considered in the Inhabited Areas Handbook are from a nuclear site or weapons' transport accident. However many of the management options described will also be relevant to other radiation incidents (eg an improvised terrorist device) even though the pattern of contamination would be different.

This handbook only covers the recovery part of the post-accident phase, with a focus on reducing doses from external exposure to radioactive contamination and from inhalation of resuspended material in air. Following a radiation emergency there will be an initial acute emergency phase where urgent measures such as sheltering or evacuation are required to protect individuals from short-term, relatively high risks. The recovery phase should be seen as starting after the incident has been contained; although there are no exact boundaries between the two phases. It continues until agreed recovery criteria have been met. While the handbook relates only to the recovery phase, it may also be used in the acute phase to provide useful information and advice on the longer-term management of the incident and to look at the implications of early urgent actions on any subsequent recovery strategy.

1.5.1 Topics not covered by the Inhabited Areas Handbook

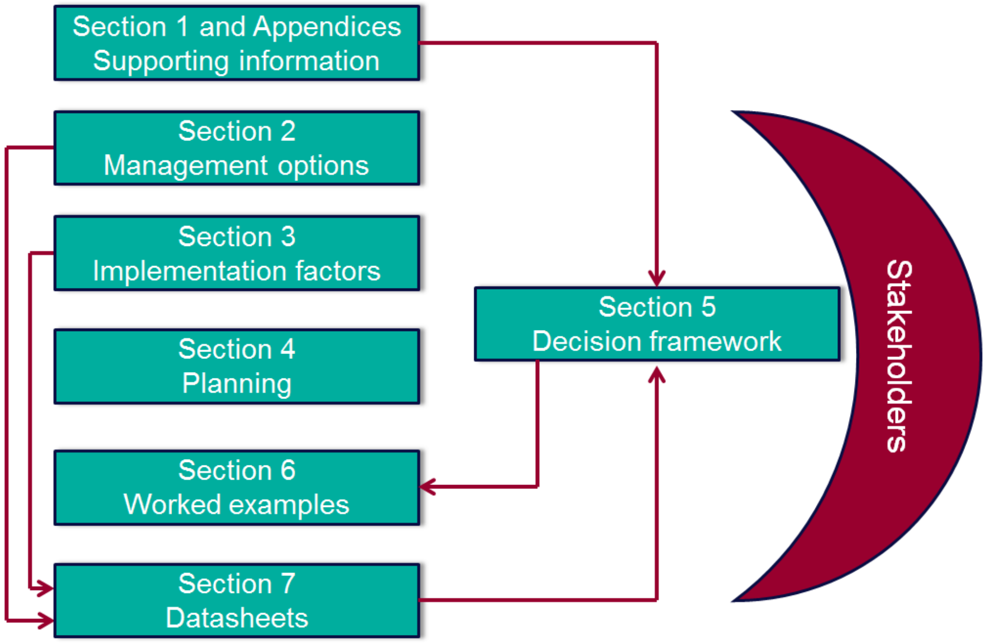
Topics that are not covered by the Inhabited Areas Handbook include:

- guidance for setting up a detailed monitoring scheme
- lists and details of contacts and contractors and the responsibilities of organisations in the event of a radiation emergency
- links between responses at different levels eg local, regional
- detailed planning for radiation emergencies including pre-drafted press releases and standard answers
- communication strategy
- wider socioeconomic issues of damage, compensation, recovery of business, personal and private losses

1.6 Structure of the Inhabited Areas Handbook

The overall structure of the Inhabited Areas Handbook is illustrated in Figure 1.1. Section 1 sets the context, scope, application and audience of the handbook describes the importance of various surfaces and hazards in inhabited areas. Section 2 provides an overview of management options for different types of inhabited area. Factors influencing the implementation of management options in contaminated areas are described in Section 3. Information on planning for recovery in advance of an incident is given in Section 4. The main decision aiding framework, two worked examples are given in Section 5 and Section 6, respectively. The datasheets for each management option are presented in Section 7. A detailed glossary can be found in Section 8 and supporting and background information can be found in the appendices.

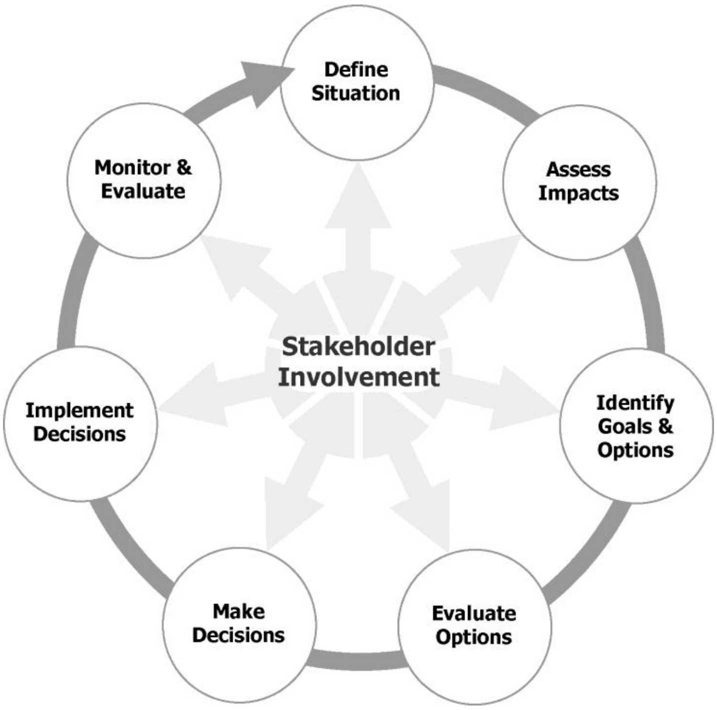
Figure 1.1 Structure of the Inhabited Areas Handbook



1.7 Recovery cycle

The recovery cycle can be depicted as an iterative process involving a series of well-defined steps all of which require the active participation of stakeholders (Figure 1.2). Unlike emergency situations where prompt response toward preserving life and critical infrastructures is the overriding consideration, more time is available in the recovery phase to develop effective schemes for involving stakeholders. Recovery is necessarily community focused and community-based and stakeholders representing local needs can provide essential input on the complex and multi-faceted issues facing the recovery programme. Stakeholders encompass a wide range of organisations and groups including local representatives of national agencies, local government, elected members, faith groups, voluntary organisations, and trade unions etc. Facilitating a meaningful integration of stakeholders into the decision making process requires effective communication methods and the ability to accommodate feedback from stakeholders in a timely fashion. Stakeholders must be fully informed of the objectives and processes of recovery and share in the outcomes.

Figure 1.2 The Recovery Cycle (NCRP, 2014)



Define situation Establishing an accurate and detailed characterisation of the contamination and presenting it in an understandable manner is an important element to defining the situation. This includes determining the radionuclide composition of the deposit, its mobility, spatial variability and location of hotspots. This process relies on extensive monitoring and surveillance of buildings, pavements, infrastructure, parks, surface waters soils, produce, livestock and commodities. Other important aspects of defining the situation include establishing land use, population size, distribution, composition, habits and activities.

Assess impacts Environmental monitoring data coupled with assessment models may be used to calculate projected doses to adults and children living in the affected area, taking into account their habits. The situation can be complex due to the involvement of multiple radionuclides, multiple surfaces and media, and multiple exposure pathways. When assessing impacts, focus should be on doses from the various exposure scenarios, not activity concentrations on (or in) various media. This is because the time and effort required for removing contamination beyond certain levels from everywhere does not automatically lead to a reduction in doses and can generate unnecessarily large amounts of waste. The assessments must be realistic and take into account prevailing environmental conditions and the potential for elevated background radiation coming, for example, from direct shine from adjacent sites or contaminated objects such as trees. Local knowledge can play a critical role in the impact assessment process.

Identify goals and options For a radiation emergency, the primary goal of the entire recovery process will be to develop an agreed strategy for returning areas affected by the emergency to a state as close as possible to that existing before the release of radioactivity and the population to a lifestyle where the accident is no longer a dominant influence. It is important that the public participate fully in establishing the goals for recovery, be they based on radiological, economic, environmental or other criteria. When setting radiological goals, it is important to establish how the level of radiological risk (dose) will be equated with measurable levels of radioactivity in the environment. Other goals of recovery may include targets for restoring businesses or for minimising waste generation.

There are many options available for managing recovery (Section 2). Options may include controlling access, modifying individual behaviours, intervening in food production systems and drinking water supplies or decontaminating the open and built environment within inhabited areas. Identification and selection of these options will depend on the goals of recovery; some options will be very effective at reducing doses but generate large volumes of waste for which no disposal route is available, other options may be less effective but provide reassurance to the population. In meeting different recovery goals it may be necessary to reconcile options to optimise the overall recovery strategy.

Evaluate options Evaluation of options involves scrutinising their key attributes to decide whether the agreed goals for recovery can be met (Section 5). This should be carried out at the local level and in conjunction with stakeholders. Key attributes include: effectiveness, feasibility, capacity, timescales of implementation, constraints (legal, societal and environmental), waste generation, and doses to implementers, costs, societal impact and acceptability to stakeholders. To assist in comparison between options and for selecting and combining options, datasheets have been produced for each recovery option to systematically record information on key attributes (Section 7).

Make decisions Decision-making is a multi-agency responsibility that is heavily reliant on the involvement of stakeholders, especially from the communities affected. The UK Nuclear Recovery Plan Template (DECC, 2013) is a living document that provides guidance on all aspects of the decision-making process, including who to involve, issues to address and a template for a recovery action plan.

Implement strategy Once decisions have been reached regarding the recovery strategy, implementation must be accompanied by documentation on the basis and rationale for the decisions (including prioritisation for recovery options) and there must be communication of the decision to stakeholders, including the programme of implementation, the technologies that will be used and criteria by which their success will be evaluated and the relevant timescales. The entire decision-making process and resulting recovery plan must maintain transparency throughout. It is important that the recovery plan is sufficiently flexible to allow adjustments and improvements to be made during implementation. Sometimes technologies are new or under development and have to be trialled on a small scale before consideration and approval given for their wider application.

Monitor and evaluate A long-term monitoring program is a key element to evaluating the success of the recovery strategy. It is recommended that various measurable milestones for recovery are established and agreed with input from the community; these may include short to medium-term projected radiation dose targets; restoration of utilities, transport infrastructure, local businesses, agricultural production and tourism; or the transfer of waste to safe storage for managed disposal. These targets provide a means of monitoring and evaluating progress, and may assist in deciding when specific recovery activities can be scaled down. In addition to long-term monitoring of residual contamination in the environment other public health objectives (eg referrals), economic indicators (eg employment statistics, numbers of hotel rooms filled) or environmental targets (volumes of waste) may be evaluated.

1.8 Types of contaminants, hazards and exposure pathways

Following a radiation incident, health hazards to humans depend on the characteristics of the radionuclides involved and the period of exposure, as well as the distance of the location where people live from the contamination and the presence of any shielding material. Further information on radiation hazards can be found in Appendix A.

Figure 1.3 shows the most important processes of radionuclide transfer in an inhabited area, the different hazards posed and the exposure pathways for humans. The exposure pathways which contribute most significantly to the exposure of humans in an inhabited area are external exposure from contamination on surfaces and inhalation of resuspended contaminated material. In certain cases, other exposure pathways, for example inadvertent ingestion of contaminated material, may warrant investigation. This pathway has been considered for people working with contaminated waste, but it is not considered in detail in the handbook. The ingestion of contaminated food, although not discussed in this handbook is also an important exposure pathway. The Food Production Systems Handbook should be consulted for further information on this pathway and how radionuclide transfer may be reduced.

The radionuclides considered in the handbook have been grouped according to both their radioactive half-lives and whether their hazard arises mainly from emission of gamma, beta or alpha radiation. Half-lives and types of radiation emitted by radionuclides included in the handbook are given in Table 1.1.

In general, it is expected that a mix of radionuclides would be released into the environment following a radiation incident. As shown in Table 1.1, often a radionuclide emits predominantly a single type of radiation and, as a result, one exposure pathway normally dominates for a single radionuclide. However, for some radionuclides and depending on the circumstances of the incident, people's habits and whether they are members of the public or recovery workers, there may be cases where other exposure pathways should be considered.

Figure 1.3 Primary exposure pathways of relevance to the recovery phase of a radiological incident

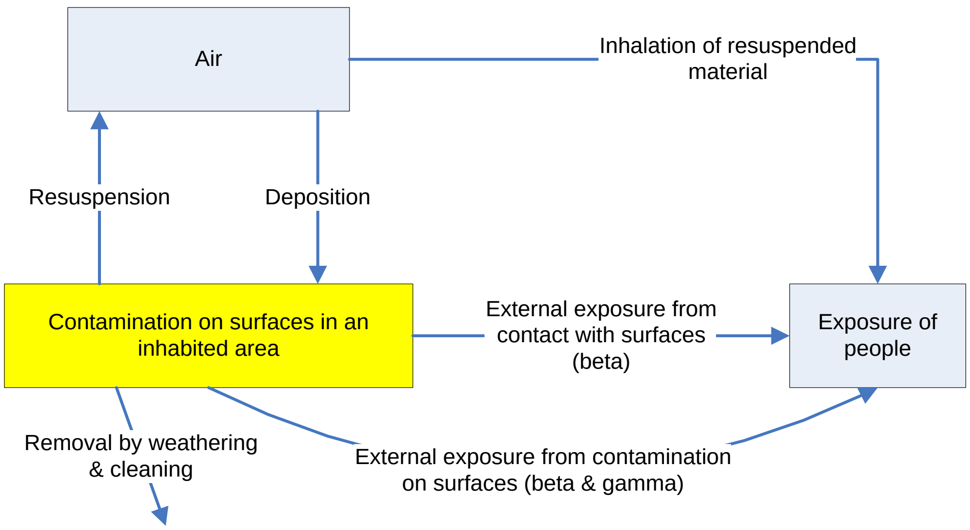


Table 1.1 Predominant emissions and half-life for each radionuclide considered in the Inhabited Areas Handbook

Radionuclide		Alpha (MeV)	Beta (MeV)	Gamma (keV)	Dominant radiation type	Radioactive half-life
Symbol	**Name**					
^{60}Co	Cobalt-60	-	1.48 (0.1%) 0.31 (99%+)	1173 (100%) 1332 (100%)	Gamma	5.27 y
^{75}Se	Selenium-75	-	-	265 (60%) 136 (57%)	Gamma	119.8 d
^{90}Sr + ^{90}Y	Strontium-90 + Yttrium-90	-	0.546 2.27	-	Beta	29.12 y
^{95}Zr	Zirconium-95	-	0.89 (2%) 0.396	724 (49%) 756 (49%)	Gamma	63.98 d
^{99}Mo + ^{99m}Tc	Molybdenum-99 + Technetium-99m	-	1.23	740 (12%) 81 (7%)	Gamma	66 h
^{103}Ru	Ruthenium-103	-	0.70 (3%) 0.21	497 (88%) 610 (6%)	Gamma	39.28 d
^{106}Ru + ^{106}Rh	Ruthenium-106 + Rhodium-106	-	3.54	512 (21%) 622 (11%)	Gamma	368.2 d
^{131}I	Iodine-131	-	0.606	364 (82%) 637 (6.8%)	Gamma	8.04 d
^{132}Te	Tellurium-132	-	0.22	53 (17%) 230 (90%)	Gamma	78.2 d
^{134}Cs	Caesium-134	-	0.662	796 (99%) 605 (98%)	Gamma	2.062 y
^{136}Cs	Caesium-136	-	0.341 0.657	819 (100%) 1048 (80%)	Gamma	13.1 d
^{137}Cs + ^{137m}Ba	Caesium-137 + Barium-137m		1.176 (7%) 0.514	662 (85%)	Gamma	30 y
^{140}Ba	Barium-140	-	1.02	438 (5%) 537 (34%)	Gamma	12.74 d
^{144}Ce	Cerium-144	-	0.318 0.238	133.5 (100%)	Gamma	284.3 d
^{169}Yb	Ytterbium-169	-	-	63(45%) 198 (35%)	Gamma	32.01 d
^{192}Ir	Iridium-192	-	0.67	317 (81%) 468 (49%)	Gamma	74.02 d
^{226}Ra	Radium-226	4.78 (95%) 4.60 (6%)	3.3	186 (4%) 260 (0.007%)	Alpha	$1.6\ 10^{3}$ y
^{235}U	Uranium-235	4.40 (57%) 4.37 (18%)	0.3	185 (54%) 143 (11%)	Alpha/ gamma*	$7.04\ 10^{8}$ y
^{238}Pu	Plutonium-238	5.50 (72%) 5.46 (28%)	-	99 (0.008%) 150 (0.001%)	Alpha	87.74 y
^{239}Pu	Plutonium-239	5.16 (88%) 5.11 (11%)	-	52 (0.02%) 129 (0.005%)	Alpha	$2.4\ 10^{4}$ y
^{241}Am	Americium-241	5.49 (85%) 5.44 (13%)	-	60 (36%) 101 (0.04%)	Alpha/ gamma*	432.2 y

*: For these radionuclides inhalation doses from resuspended material are mainly due to the alpha radiation emitted, but if the contamination is fixed to surfaces and not available for resuspension, only external exposure to gamma radiation contributes to the dose

1.9 Inhabited areas

What is an 'inhabited area'?

Inhabited areas are places where people spend their time. They can be divided into a number of sub-areas such as residential, industrial and recreational. These sub-areas contain a variety of surfaces such as buildings, vehicles, roads, soils and vegetation.

The sub-areas and surfaces found in inhabited areas are described in Table 1.2 and Table 1.3 respectively. Figure 1.4 shows the types of surface which can be found in each sub-area.

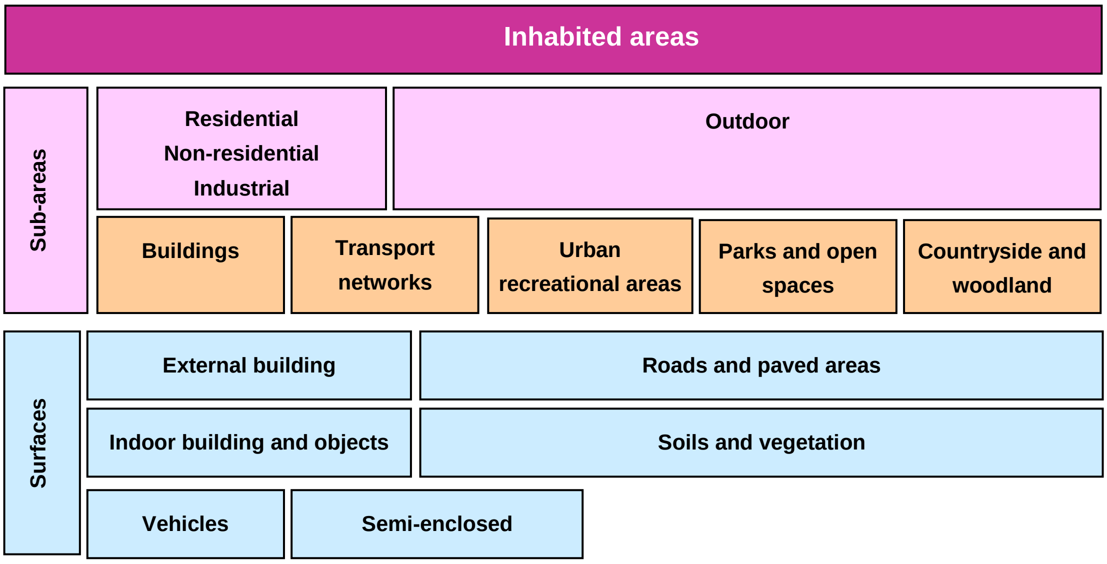
Table 1.2 Types of sub-areas in inhabited areas

Sub-area	Description
Residential	Areas used for residential purposes (eg houses, small settlements, housing estates, block of flats), including vehicles.
Non-residential	Areas accessed by the public for services and employment (eg commercial districts, shopping centres, supermarkets, town and city centres).
Industrial	Non-residential areas where production and/or commercial activities are undertaken (eg industrial estates, factories).
Outdoor	The non-built environment
The sub-areas may comprise:	
Buildings	Buildings used for residential, public, commercial and industrial purposes. Also includes buildings key to the provision of infrastructure in an area, such as railway stations and water treatment plants.
Urban recreational areas	Areas with private access from residential dwellings (eg playing areas, driveways, patios, gardens) and areas with public access (eg roads, pavements, car parks, gardens, playing fields, playgrounds).
Transport networks	Roads and rail
Parks and open spaces	All gardens, parks, children's play areas and sports fields with public access. Size of these areas is typically greater than 300 m^2.
Countryside and woodland	Managed and unmanaged areas used for recreational purposes by the public (eg footpaths, national parks, moorland). Managed and unmanaged deciduous and coniferous woods and forests used for recreation purposes by the public.

Table 1.3 Surfaces in inhabited areas

Surface	Description of surface
Buildings - external surfaces	External hard surfaces (eg walls, roofs, windows and doors of all buildings)
Buildings - indoor surfaces and objects	Indoor building surfaces (eg walls, floors, ceilings, soft furnishings and furniture)
Semi-enclosed	Transport networks (train and bus stations, underground systems)
Vehicles	All vehicles used for public transportation (ie cars, lorries, trains, buses, trams, boats and aircraft).
Roads and paved areas	All roads, pavements, large paved or asphalt areas (eg playgrounds, yards and car parks)
Soil and vegetation	Lawns, flowerbeds and vegetable plots associated with the gardens of residential dwellings, landscaping around commercial and public buildings, allotments, parks, playing fields and other managed green areas. Also includes all woody plants (eg trees, shrubs and bushes) associated with the gardens of residential dwellings, landscaping around commercial/public buildings, orchards, allotments, parks, playing fields and other managed green areas.

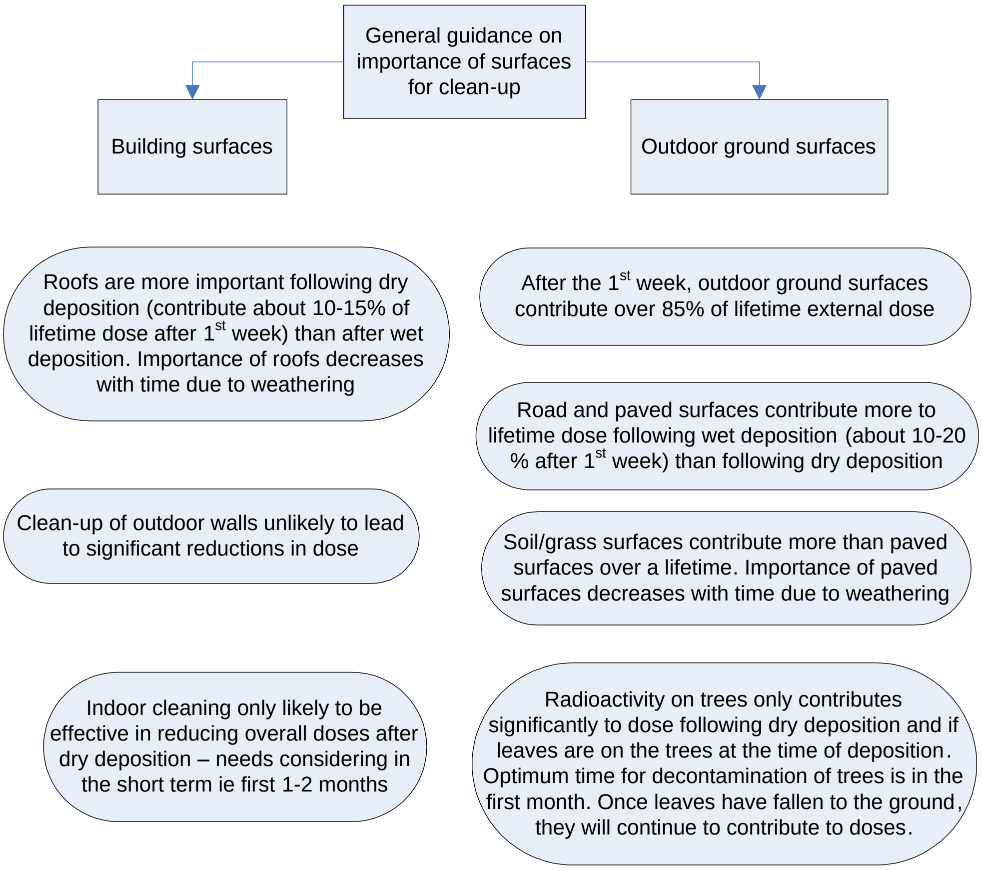
Figure 1.4 Link between types of inhabited area and surfaces



1.9.1 Importance of different surfaces in influencing radiation exposure

The relative importance of the various surfaces in contributing to doses from external exposure and resuspension depends on a number of specific factors, such as the radionuclides released and their physical/chemical forms, the type of area, the amount of precipitation at the time of deposition, weathering and redistribution of the radionuclides on to other surfaces. If the source of contamination is outdoors, contamination on outdoor surfaces always plays a major role. If the deposition occurs during rainfall (wet deposition) doses from deposition on indoor surfaces are likely to be much lower than doses from deposition on outdoor surfaces. If deposition occurred at a time when there is no rain (dry deposition) doses from indoor surfaces assume higher importance. Furthermore, deposition of radioactive material under dry or wet weather conditions results in different distributions of the contamination on different surfaces (see Appendix A for further information). For example, wet deposition on to house walls is minimal, owing to their vertical orientation. In addition, surfaces with the highest radioactive contamination may not provide the highest contribution to the exposure of the inhabitants of a contaminated area, as these people may spend more time close to less contaminated surfaces. In estimating doses to the public, it is therefore necessary to carefully evaluate exposure contributions from contamination on each surface. Figure 1.5 gives an indication of the likely importance of surfaces found in inhabited areas in contributing to external gamma doses following deposition of a long-lived radionuclide, eg ^{137}Cs, in a typical inhabited area following a release outside the inhabited area, such as a reactor accident (Brown et al, 1996). The relative importance of time spent outdoors and indoors on doses is taken into account by assuming that people spend 90% of their time indoors.

Figure 1.5 Likely importance of surfaces in contributing to external dose



The information in Figure 1.5 is also likely to be applicable to long-lived beta emitting radionuclides such as ^{90}Sr. This information is not necessarily appropriate for releases occurring within an inhabited area (eg a dirty bomb), as the distribution of contamination between surfaces may be very different.

Table 1.4 provides some guidance to aid the user in determining whether outdoor surfaces are likely to be of concern in a contaminated region.

Table 1.4 Guidance on importance of outdoor land surfaces

Question	Possible importance
1. Do you have measurements of deposition or dose rates above different surfaces?	No - likely to be reliant, at least initially, on models to indicate from which surfaces doses may be coming from. Yes - Information can be used to help identify which surfaces are likely to be contributing to total dose.
2. How much of your outdoor area is covered by soil or grass compared to roads or paved areas?	The proportion of the area covered by the land surface multiplied by the deposition on to the surface gives an indication of the relative importance of the surface in contributing to the total outdoor dose.
3. Do people spend a significant amount of time outdoors in the area?	The total outdoor dose is a function of the time people spend outdoors. If people do not spend significant time outdoors in this area, it may not be necessary to undertake substantial clean-up of outdoor surfaces. However, these surfaces also contribute to indoor doses and therefore, although doses are substantially lower indoors, they may be reduced by cleaning outdoor land surfaces.
4. Can the outdoor area (or part of it) be cordoned off to restrict access?	Outdoor doses can be reduced by cordoning off the area. This may reduce the need to clean-up outdoor surfaces, particularly if the deposited radioactivity is short-lived.
5. Are there a lot of trees in the area?	Contamination on trees, particularly after dry deposition can contribute significantly to outdoor doses. This is only the case if leaves are on the trees at the time of deposition. Outdoor doses can be reduced by cordoning off the area. This may reduce the need to clean-up trees, particularly if the deposited radioactivity is short-lived. Outdoor doses can be reduced by collecting leaves after leaf-fall (and pine needles and cones from coniferous trees) as most of the activity associated with trees is on the leaves.

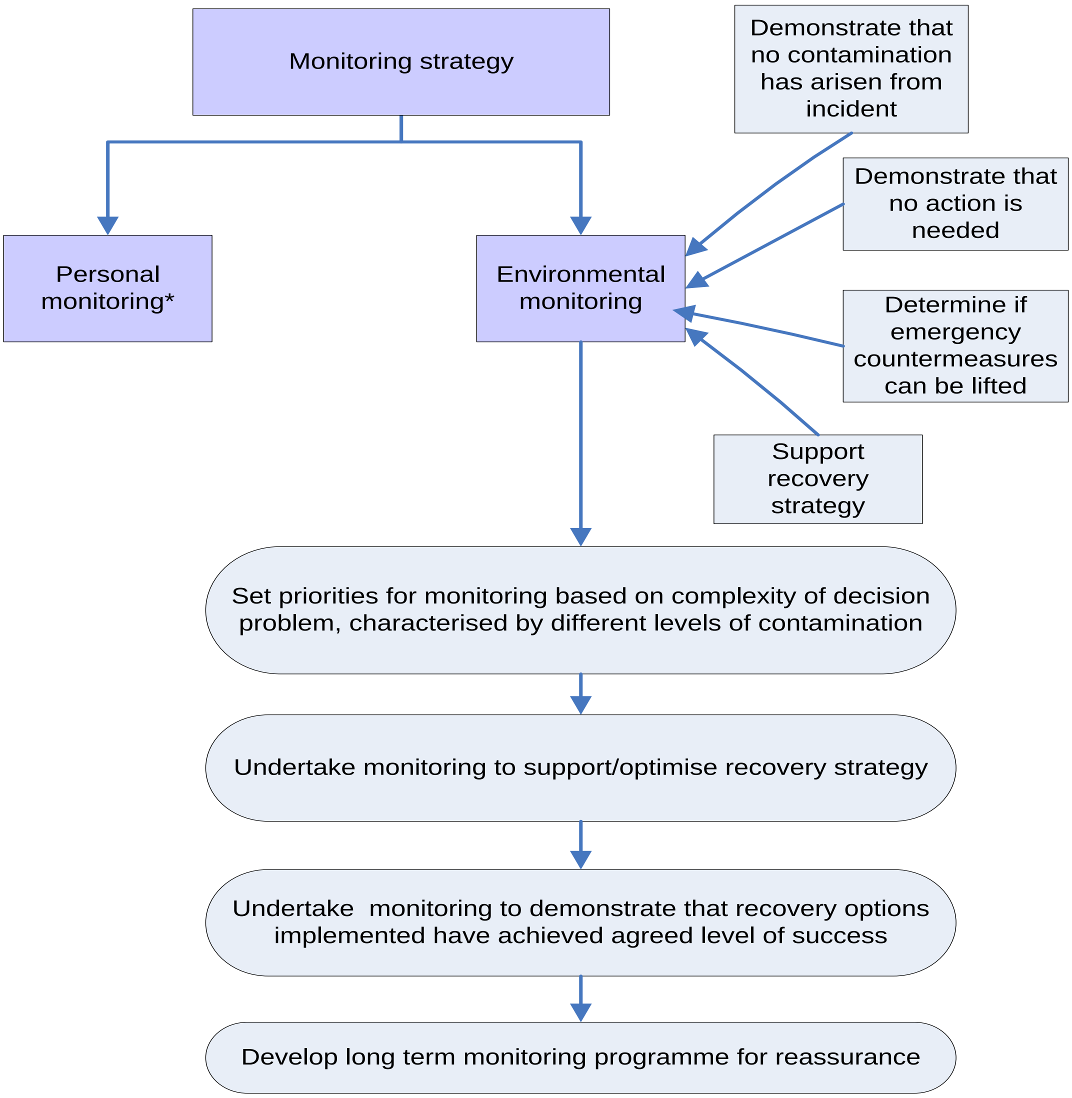
1.10 Determining the nature and extent of the incident and characterising the contamination

It is unlikely that, at the start of the recovery phase, decision makers have a detailed picture of the full distribution of the contamination deposited on the ground. Since it is important to base recovery decisions on as clear a picture as possible of the contamination pattern and the likely doses to people, an appropriate strategy for detailed monitoring for both people and the environment needs to be implemented (Morrey et al, 2004). This strategy needs to identify priorities for monitoring as well as the types and scale of monitoring required and should also consider the needs for monitoring in different situations. Key requirements for monitoring are:

- to demonstrate that no contamination has arisen from the incident
- to demonstrate that no action is needed
- to determine if emergency countermeasures can be lifted
- to determine people’s exposures (personal monitoring)
- to support a recovery strategy, ie to determine where clean-up is needed and demonstrate that options implemented have achieved an agreed level of success to provide long-term reassurance

Figure 1.6 provides an overview of the role of environmental monitoring in the recovery phase. The development of a detailed monitoring strategy is not discussed further.

Figure 1.6 General roles of environmental monitoring for inhabited areas



* Personal monitoring is not considered further in this Handbook.

1.11 Radiological protection criteria for inhabited areas

Any protection criterion aimed at reducing the risks of stochastic health effects, ie cancer, must take into account all the wider consequences of the proposed protective measure, such as cost and disruption, and balance these aspects against the expected benefits provided by the measures implemented, including public reassurance. This balance needs to take account of the specific circumstances of the event is likely to vary between different types of incidents and contamination.

Radiological protection principles for living and working in contaminated areas follow those for existing exposure situations and include the justification of implementing recovery strategies and the optimisation of the protection afforded by these strategies. Reference levels of dose are used to constrain the optimisation process by either assisting in the planning of recovery strategies so that individual doses fall below the reference level or acting as a benchmark for judging the effectiveness of strategies after implementation. These concepts are consistent with those recommended by ICRP (2007; 2009) and are elaborated further below.

Justification of a recovery strategy goes far beyond the scope of radiological protection as implementation of recovery options may also have various economic, environmental, social and psychological impacts. What is important is that the overall recovery strategy is justified in as much as it brings sufficient individual or societal benefit to offset any associated detriments. For example, a range of individually justified options may be available but not provide a net benefit when considered as an overall strategy because, collectively they may bring too much disruption or may be too complex to manage. The principle of optimisation is applied to situations where the implementation of a recovery strategy is already justified.

Optimisation should ensure selection of the best strategy under the prevailing circumstances to maximise the margin of good over harm, and to meet key recovery goals. Unlike emergency situations, where there is a need to take urgent action, the optimisation process during recovery can be implemented step by step. The best strategy is not necessarily the one that results in the lowest dose for individuals. Furthermore, it is not relevant to determine, a *priori*, a dose level below which the optimisation process should stop as this depends on incident specific and location specific factors.

1.12 Application of reference levels

For most foreseeable situations in the UK, reference levels of effective dose recommended by the international community for existing exposure situations (CEC, 2014; ICRP, 2009) are appropriate for guiding recovery decisions. Effective doses < 20 mSv y^{-1} would adequately constrain the optimisation process for wide area contamination, except for very large and highly unlikely events, when a higher dose criterion may have to be applied. Conversely, for smaller incidents the use of a lower dose criterion may be appropriate. The value of the rReference level selected should reflect a careful balance of many inter-related factors, including the sustainability of social, economic, environmental and overall health of the affected populations. Furthermore, it should consider the views of all the stakeholders.

1.13 Estimating doses in inhabited areas

As mentioned in previous sections, the dose to an individual from exposure to a given amount of radioactive material deposited following a radiation incident can vary widely, depending on the radionuclides involved, the spread of the contamination between different surfaces and the time spent by the individual at locations with different levels of contamination. The dose an individual living in a contaminated environment receives is the sum of the doses (external and resuspension) arising from the differing levels of contamination on different surfaces at a variety of locations. The total dose received by an individual is therefore determined by the time spent in each location and the dose rate at that location, which varies with time as the activity of the radionuclides decay.

In general, members of the public should be equally protected in all areas where they spend time or, in other words, the dose rates in areas where they work and spend their spare time should be no higher than those where they live. PHE advice should be applicable to any location in the contaminated area. This means that the doses at which the various categories of options should be considered should be calculated assuming that people spend all their time at that location, taking account of the time spent indoors at the location if appropriate.

If there are very good reasons why people may need to be exposed to higher dose rates, eg those maintaining critical facilities and infrastructure, the doses to these people must be controlled and all other people must be excluded from the area. In this case, it would be reasonable to take into account the amount of time spent in the specific environment being considered.

Ideally, the estimation of doses in an area should take account of the characteristics of the area (eg the types of building in the area, the level of urbanisation, the surface area of gardens, parks and other amenities) and the temporal variation of the contamination as a function of time. Appendix B provides some guidance on basic methods to estimate doses in inhabited areas from given levels of contamination.

1.14 References

Brown J, Cooper JR, Jones JA, Flaws L, McGeary R and Spooner J (1996). *Review of decontamination and clean-up techniques for use in the UK following accidental releases of radioactivity to the environment.* Chilton, NRPB-R288.

CEC (2014). Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. *Off J Eur Commun* **L13/1**.

DECC (2013). *Nuclear Emergency Planning Consolidated Guidance. Chapter 18: UK Nuclear Recovery Plan Template.* Department for Energy and Climate Change.

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ICRP (2009). Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation emergency. ICRP Publication 111. *Ann ICRP* **39**(3).

Morrey M, Nisbet A, Thome D, Savkin M, Hoe S and Brynildsen L (2004). Response in the late phase to a radiological emergency. *Radiat Prot Dosimetry* **109**(1-2), 89-96.

NCRP (2014). *Decision Making for Late-Phase Recovery from Major Nuclear or Radiological Incidents.* National Council on Radiation Proection and Measurements, Bethseda, Maryland, NCRP Report No. 175.

2 Management Options

The term management option is defined as an action intended to reduce or avert the exposure of people to radioactive contamination. Management options were previously referred to as countermeasures. This handbook has identified 29 potential management options for use in contaminated inhabited areas. These are listed in Table 2.1.

Management options for inhabited areas can be divided into two main groups: options that limit exposure by restricting access and those that require remediation. Remediation can be achieved by either removing contamination (decontamination) or by providing protection from the contamination (shielding). The implementation of management options is generally the responsibility of the authorities, however self-help options, which may be implemented by the affected population can also be useful (see Section 2.3). It is also important to note that the option not to carry out any recovery can be a valid alternative; more information on this topic is provided in Section 2.5.

Figure 2.1 to Figure 2.4 give the options considered in the handbook for each of the surface types described in Figure 1.3. In these figures, protection/shielding options are shaded green and decontamination options are shaded in yellow. The number in brackets refers to the relevant datasheet (Section 7).

Table 2.1 List of all management options for inhabited areas

No	Name
Restrict access	
1	Control workforce access
2	Impose restrictions on transport
3	Permanent relocation from residential areas
4	Restrict public access
5	Temporary relocation from residential areas
Remediation	
6	Collection of leaves
7	Cover grass/soil with clean soil/asphalt
8	Demolish/dismantle and dispose of contaminated material
9	Fix and strip coatings
10	Grass cutting and removal
11	Manual and mechanical digging
12	Modify operation/cleaning of ventilation systems
13	Natural attenuation (with monitoring)
14	Ploughing methods
15	Pressure and fire hosing
16	Reactive liquids
17	Roof cleaning including gutters and downpipes
18	Snow/ice removal
19	Storage, covering, gentle cleaning of precious objects
20	Surface removal (buildings)
21	Surface removal (indoor)
22	Surface removal and replacement (roads)
23	Tie-down
24	Topsoil and turf removal
25	Treatment of walls with ammonium nitrate
26	Treatment of waste water
27	Tree and shrub pruning and removal
28	Vacuum cleaning
29	Water based cleaning

Figure 2.1 Management options for buildings (external, internal and semi-enclosed surfaces)

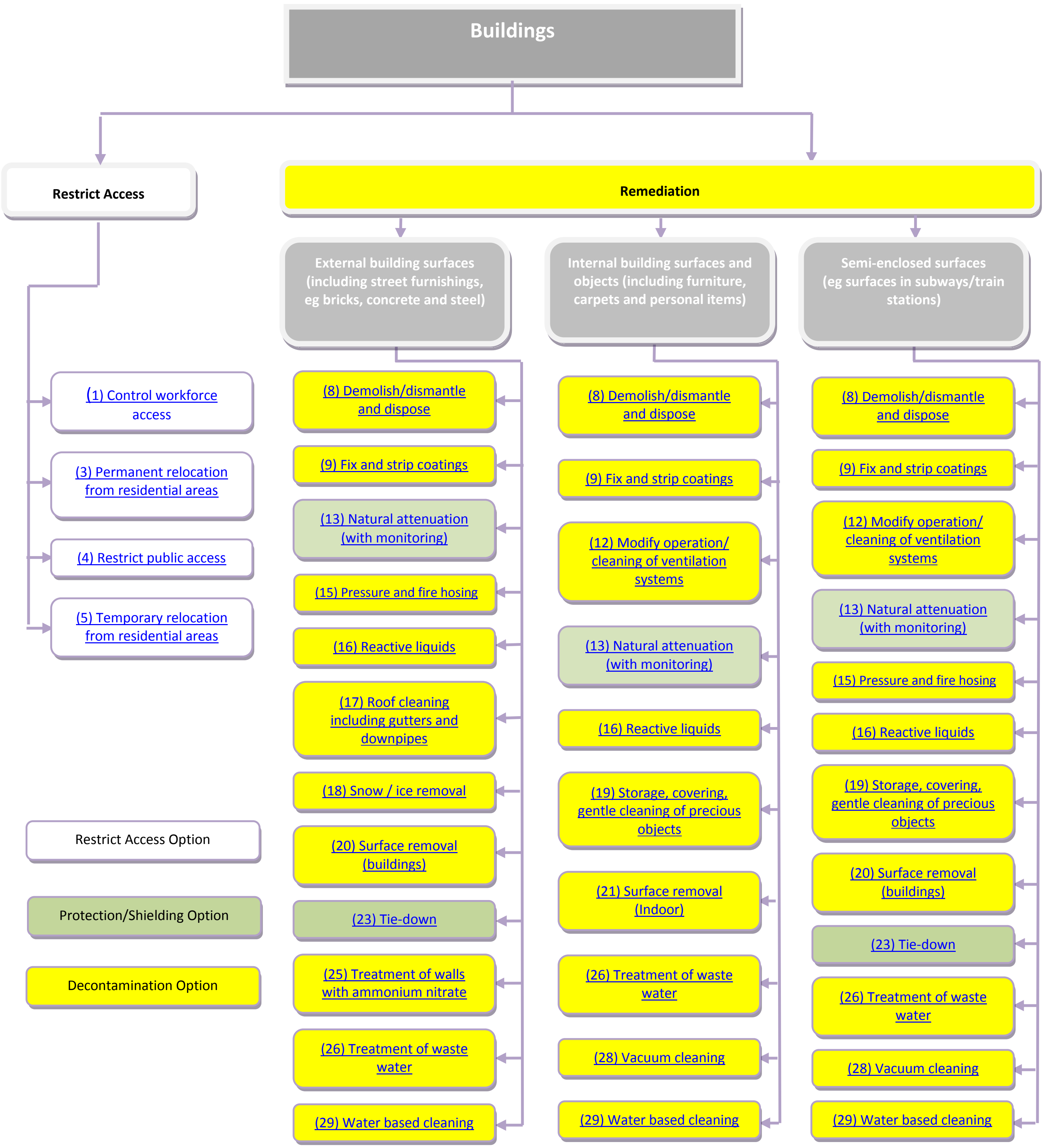


Figure 2.2 Management options for roads and paved areas

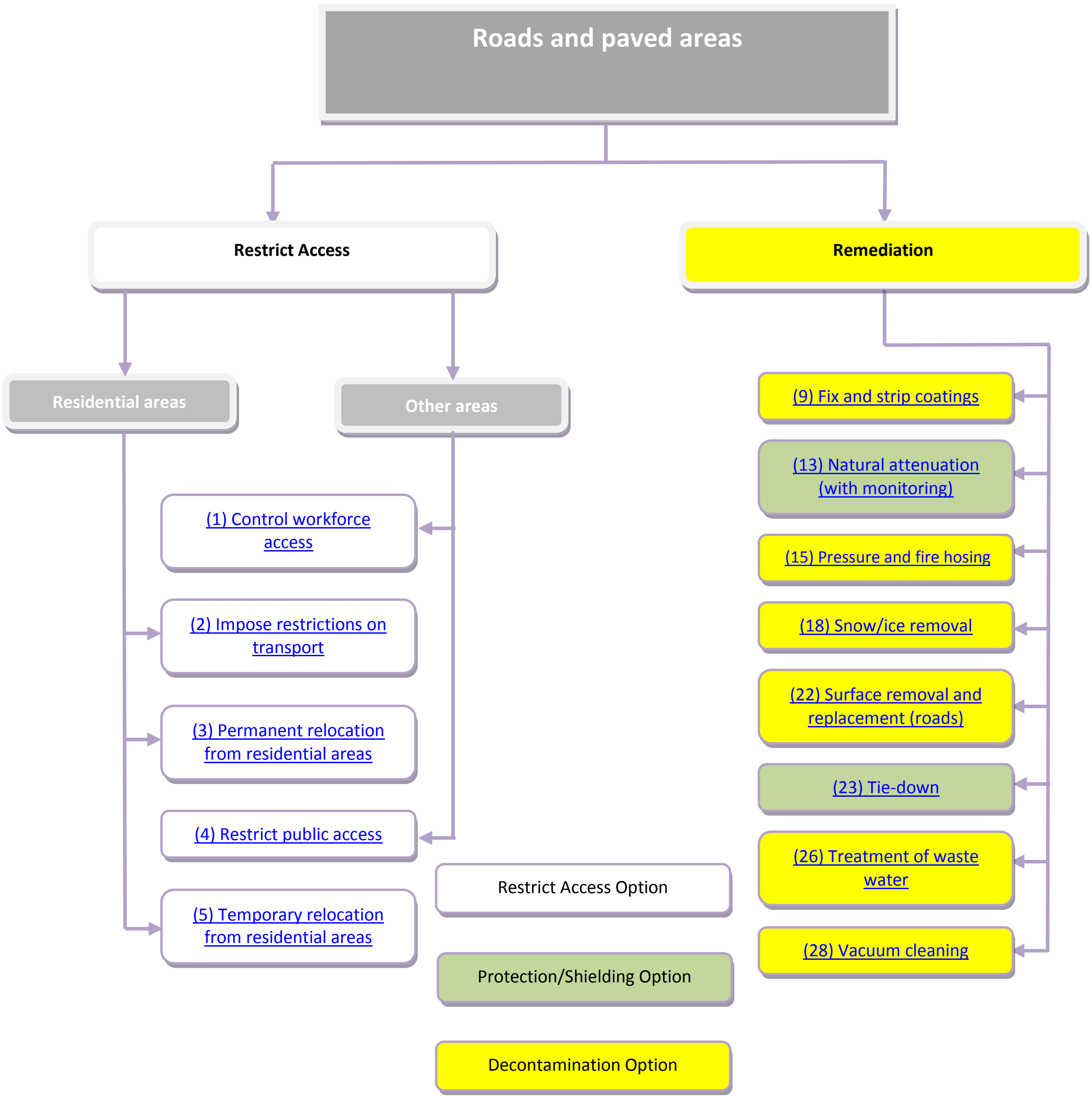


Figure 2.3 Management options for vehicles (including aeroplanes, cars, trains and boats)

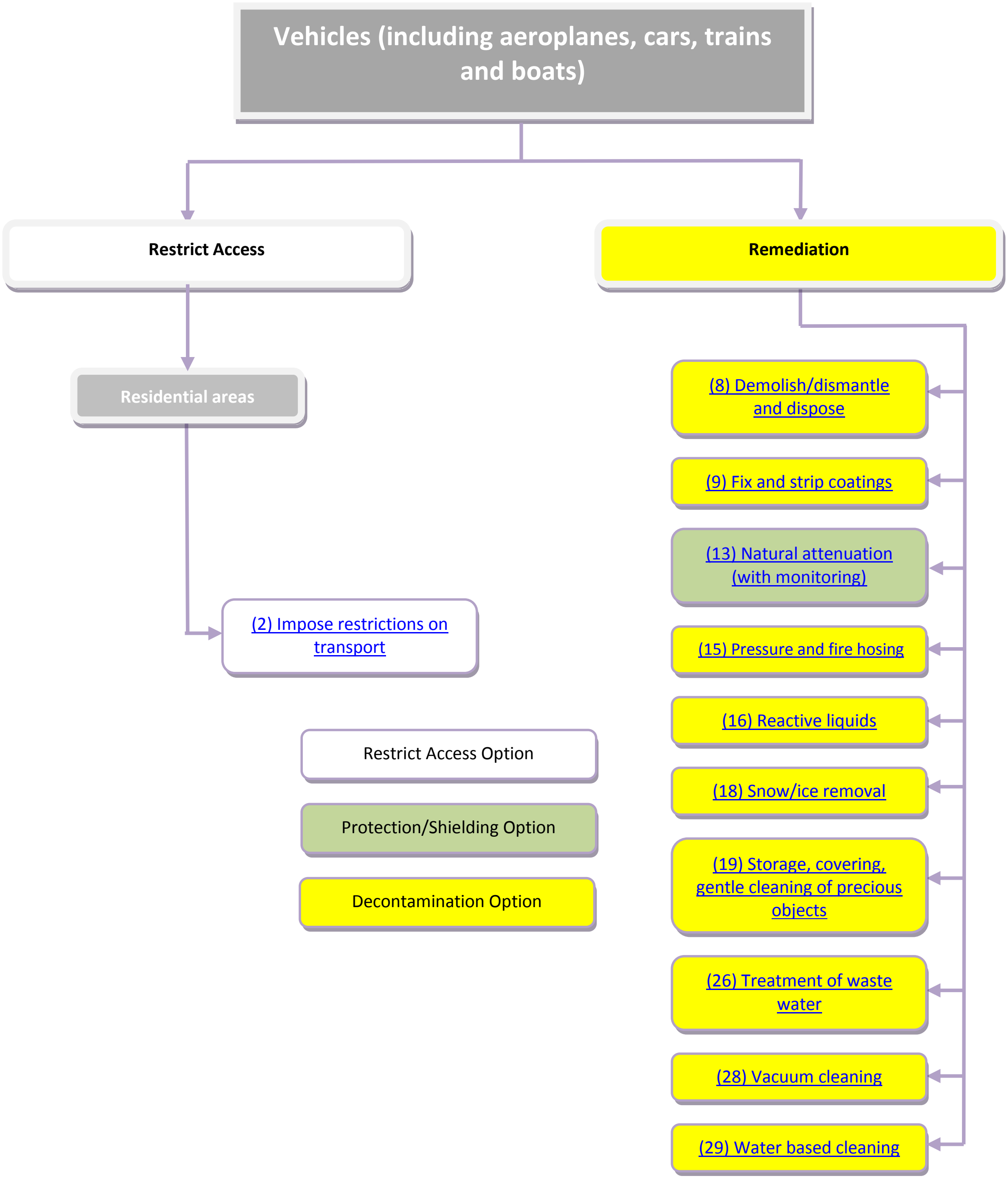
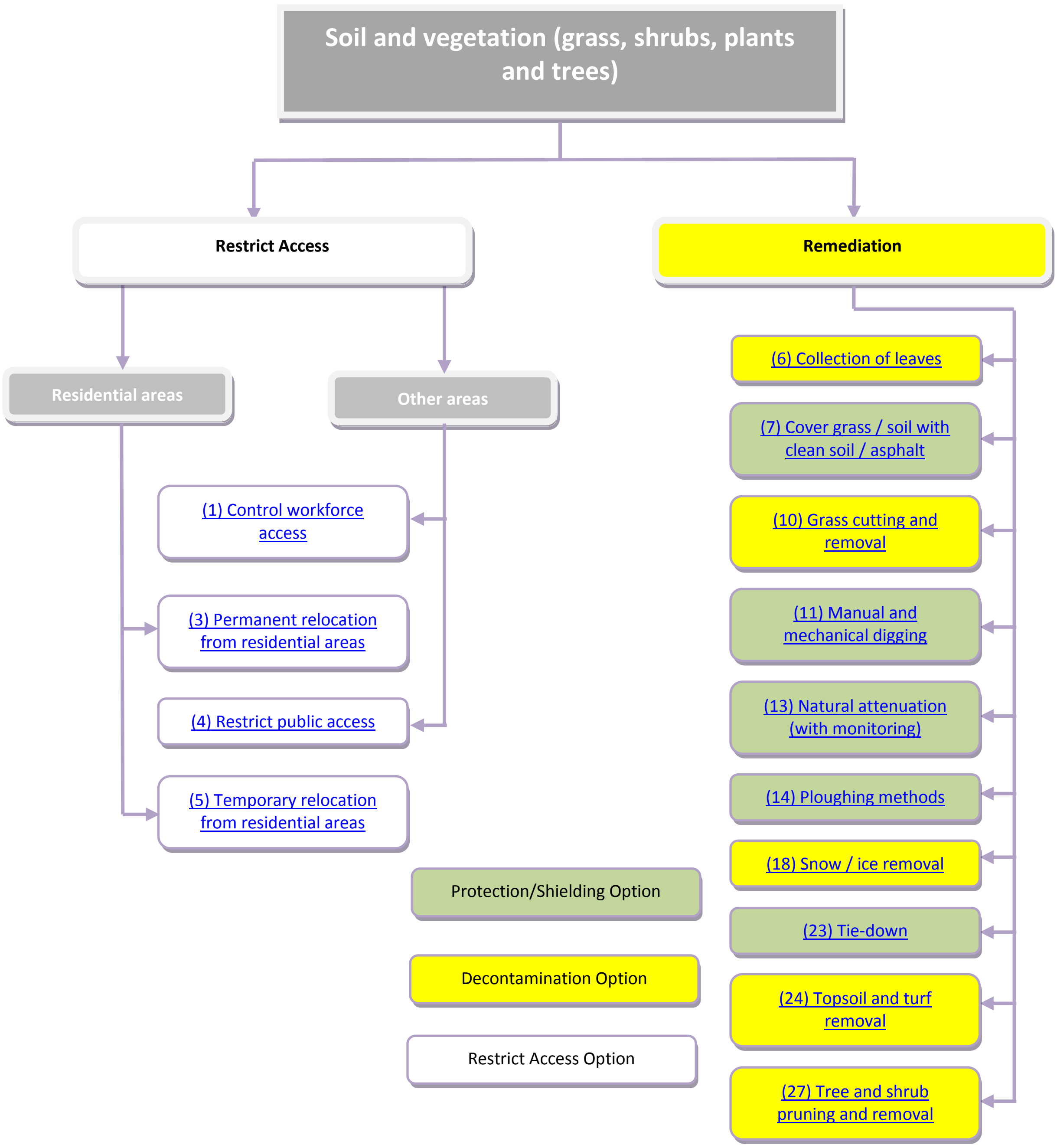


Figure 2.4 Management options for soil and vegetation (grass, shrubs, plants and trees)



2.1 Shielding options

Shielding options can be used to reduce both external exposure and the intake of contaminated material, but are usually particularly effective in providing protection against either one of these exposure pathways. The use of shielding materials is potentially a very effective option for radionuclides emitting alpha or beta radiation, particularly if they are relatively short-lived. Some more permanent shielding options, such as burial of contaminated material or the permanent relocation of people from a contaminated area are also effective for long-lived radionuclides and gamma emitting radionuclides. A3 provides detailed information on the use of shielding materials for reducing doses.

2.1.1 Types of shielding

There are two main types of shielding option:

- burial of contamination; covering and/or storage of contaminated objects
- fixing of contamination

In addition, restricting access of people to, or relocating people from a contaminated area can also be considered a special form of shielding where air acts as the shielding medium. Such options are 100% effective against all radioactive contaminants while they are in place, as people do not receive any dose from the area from which access is restricted. If this type of shielding is used, suitable barriers will be required to clearly indicate the extent of the restricted area, and depending on the situation entry points into restricted areas may need to be controlled by personnel to ensure access is sufficiently limited. When access into contaminated areas is permitted there should be particular control of egress from the area, with suitable monitoring and decontamination on exit to avoid spreading contaminated material.

If the primary aim is to reduce external exposure, shielding materials can be placed between the contamination and people (burial and covering of objects). Examples include the use of clean topsoil in gardens and other open areas and digging to bury contaminated soil. In general, these types of options are more effective in reducing external dose rates from radionuclides emitting beta radiation than for those emitting gamma radiation. Inhalation doses from resuspended material are also reduced while the shielding material is in place.

If the primary aim is to protect against the intake of contaminated material into the body, shielding material is used to fix the contamination to the surface and restrict its mobility. Fixing options also have the benefit of providing shielding from external exposure but the effectiveness of the shielding is likely to be secondary to the dose reduction achieved for internal exposure. Furthermore, removal of fixing materials can also remove some of the underlying contamination held on the surface as dust. The main advantages and disadvantages of shielding options are outlined in Table 2.2.

Table 2.2 Advantages and disadvantages of shielding options

Advantages
No waste is generated directly.
They are unlikely to have a lasting negative effect on the environment. Some options may make the environment look cleaner (eg resurfacing roads).
People can remain in the area during implementation, except for relocation.
They are easier and quicker to implement than removal options, except relocation.
Fixing contamination to a surface is very effective at protecting against alpha emitters and may also provide good shielding for beta emitters and limited shielding for gamma emitters, depending on the material used and its thickness. Fixing options also prevent resuspension while the fixing material is in place.
Disadvantages
Contamination is not removed from the affected area. Therefore it may be necessary to deal with a public perception that the contamination, albeit shielded from people, still exists.
If burial options such as ploughing are implemented, it is important to be sure that they are effective in reducing doses such that there will be no need to remove contamination at a later date. Once contamination is buried, its subsequent removal will result in more radioactive waste being produced, albeit with lower levels of contamination.
Restricting access to areas, buildings and objects limits a return to normal living.
Permanent shielding by fixing contamination to the surface may cause problems with future maintenance of the surface, which could give rise to doses to the workforce and waste disposal issues.
The integrity of the fixing material may diminish with time, reducing its effectiveness.
If shielding is provided by temporarily fixing contamination to a surface, the disposal of the materials used may be required, as they can become contaminated.

2.2 Decontamination options

Decontamination options involve the removal or clean-up of contaminated surfaces and objects. The main advantages and disadvantages of removal options are listed in Table 2.3. One of the main disadvantages is that contaminated waste material is produced, often in large quantities. There may also be major constraints on the use of removal options on historic buildings or buildings that are in poor condition where unacceptable damage to the fabric of the buildings may occur. For example, high pressure hosing and sandblasting may cause significant damage to old or poorly maintained brick or stone buildings.

Similarly, it may not be practicable to carry out decontamination techniques that directly affect the surface of objects due to the damage that such techniques may cause. For example, this may be particularly true for objects found in heritage buildings and museums. These objects may, however, withstand gentle washing or vacuuming without causing damage to their surfaces. It is likely that disposal of such objects will be unacceptable because of their monetary or heritage value, and therefore if all decontamination techniques prove unacceptable or impracticable, storage or shielding of the objects could be considered. It should be recognised that these objects would mostly contribute relatively little to the dose and their cleaning would therefore often have the primary purpose of public reassurance.

Table 2.3 Advantages and disadvantages of decontamination options

Advantages
They remove contamination from the affected area.
Effectiveness in reducing external doses and inhalation doses arising from resuspended material. However, it is likely that the techniques will have to be used on several surfaces to provide significant dose reductions.
Physical removal works equally well for all types of contaminant, although the thickness of surface layers to be removed may be dependent on the contaminant(s). Use of chemical reagents may or may not be contaminant-specific.
Disadvantages
All removal options create waste.
They create disruption.
Unacceptable damage may be done to building surfaces and objects, particularly if old or in poor condition.
Negative effect on the environment.
Some contamination may remain in the affected area unless drastic, environmentally damaging removal options are undertaken.
For some options it may be necessary to move people out of the area while the contamination is removed. This would almost certainly imply temporary closure of schools, hospitals and businesses, for example.

2.3 Self-help management options

Self-help management options are simple measures that may be carried out by people living in the affected areas rather than by skilled workers and which, in general, require no specific expertise or experience to be implemented. Information on the suitability of the management options considered in the handbook for self-help is given in each datasheet under the heading 'Required skills' (Section 3). The advantages and disadvantages of management options being implemented by affected inhabitants rather than other workers are given in Table 2.4. After the Chernobyl accident, self-help schemes introduced in the highly contaminated areas of the former Soviet Union have generally been perceived by the affected populations as very positive (Beresford et al, 2001). Some technical factors require specific consideration prior to initiation of self-help management options (see Table 2.5).

Table 2.4 Advantages and disadvantages of implementing self-help options

Advantages
Involve people affected in the effort to improve their own situation. This can help people understand the relative importance of different exposure routes and lead to a better understanding of how exposures can be reduced.
Affected inhabitants get a better feeling that they are in control of the situation and the knowledge obtained through direct involvement can prevent unnecessary anxiety.
Affected inhabitants know exactly what has been done to improve the situation and how well it has been done.
They are comparatively cost-effective in terms of costs of labour.
They have the benefit of introducing an extra labour resource in cases where large areas need to be treated over a relatively short time period (eg grass cutting and collection).
They comply with the important ethical values of autonomy, liberty and dignity.
Disadvantages
People participating in recovery operations would be subject to the dose limitation system for members of the public.
People participating in recovery operations would require protection.
They need to be carried out on a voluntary basis.
Carefully worded and detailed communication with the people participating would be required. This could take considerable time to implement.
Techniques may not be implemented effectively.

Table 2.5 Technical factors to consider for self-help management options

Factor	Comment
Safety precautions	These are listed in datasheets (see Section 3). As self-help management options introduce a higher degree of autonomy, it needs to be stressed that no management option should be implemented before adequate safety instructions and equipment are in place.
Specific protection of unskilled people	Methods involving undue risk (eg work at elevated height or use of chainsaws) have been excluded by default. People may also not be physically fit for the work.
Safety in connection with waste handling	People may receive relatively high doses near piles or vessels containing concentrated contaminated material generated by self-help measures (eg from grass cutting and collection). Inhabitants would need careful instruction to minimise time spent in such locations over the period before the waste is collected.
Information on objective	The objective of a management option should be clear. This may partially be done through leaflets, but for some management options (eg digging), initial supervision would be recommended, as adverse effects of incorrect implementation can be irreversible.
Availability of equipment	Most of the primary equipment required would need to be available in the majority of households. Some additional equipment may need to be secured and this will need to be made available on the required timescale.
Monitoring in optimisation	Monitoring by skilled workers to determine the contaminant distribution should precede techniques involving soil digging or removal of soil layers.

2.4 Implementing management options with people in-situ

It may be difficult to undertake management options in an area in which people are still living and working, particularly in residential areas. It is recognised, however, that it might not be possible to relocate people temporarily during this time, particularly if the number of people involved is large.

If decision makers wish to avoid either moving people temporarily out of an area or restricting access to it during the implementation of management options, the following factors need to be considered:

- awareness that many people may self-evacuate anyway, in which case the area will need to be made secure
- provision of a comprehensive information service. With good advice and information, many people will be happy to stay in their homes
- management options should be carried out as quickly as possible. If people are left in a residential area, the length of time they can be asked to stay indoors while management options are implemented in surrounding outdoor areas limited
- it is unlikely to be acceptable for workers implementing management options to wear special clothing and personal protective equipment (PPE) if people remain in the area. Workers may be required to wear respirators since they may cause some resuspension by their actions. In this case, prior information would need to be provided to the watching public as to why similar protection was not provided for them

2.5 Decision not to implement any management options

In some circumstances, authorities may decide that the best course of action is not to implement any management option. It is important that if this decision is taken it should always be accompanied by a monitoring strategy aimed at reassuring the local population. This option, also known as ‘natural attenuation with monitoring’ should be considered if the information available (measurements from environmental monitoring and results of assessments) indicate that the doses to people living in the area would be low. No judgement is made here on what would constitute a low dose. Other factors could make the decision not to implement any recovery action attractive, such as availability of limited resources or a very large area being affected. Table 2.6 gives the main advantages and disadvantages of carrying out no recovery.

Table 2.6 Advantages and disadvantages of carrying out no recovery options (natural attenuation with monitoring)

Advantages
Implementing management options may be perceived as indicating that there is a problem even if doses are so low that they are being undertaken to provide reassurance.
Perception of affected area from outside may be better (ie incident is not perceived as a real problem; people are living normally). Economic blight may be less.
It sends out a clear message that risks are low and builds public confidence in decision-makers. Saying that the risk is low and still undertaking management options may give out a mixed message.
No waste is produced. Some clean-up options that may be undertaken for public reassurance can create a lot of contaminated waste, such grass cutting.
If management options are implemented the public may be reluctant to return to their homes.
Promotes return to normal living in the area.
Disadvantages
It requires very good communication with the community in order to convince people that risks are low and that they should accept the decision not to implement management options.
The implementation of management options is visible and may provide reassurance to people inside and outside the contaminated area.
It needs to be linked with a very rigorous monitoring strategy. Such a monitoring strategy might not be time or resource effective compared to the implementation of management options.
Not implementing any management options may send out a message that the response organisations and other organisations do not care enough about the community.
Decision-makers need to define the boundaries of the area in which management options are not implemented.
If restrictions have been placed on food consumption, there will need to be careful explanation of why these are required while no action is taken to deal with the contamination in inhabited areas.

2.6 Reference

Beresford NA, Voigt G, Wright SM, Howard BJ, Barnett CL, Prister B, Balonov M, Ratnikov A, Travnikova I, Gillett AG, Mehli H, Skuterud L, Lepicard S, Semiochkina N, Perepeliantnikova L, Goncharova N and Arkhipov AN (2001). Self-help countermeasure strategies for populations living within contaminated areas of Belarus, Russia and Ukraine. *J Environ Radioact* **56**(1-2), 215-239.

3 Factors Influencing Implementation of Management Options

There are a number of factors that need to be taken into account when developing a management strategy for the long term recovery of a contaminated inhabited area. The most important of them are:

- temporal and spatial factors
- effectiveness of management options
- protection of workers
- waste disposal issues
- societal and ethical aspects
- environmental impact
- economic cost
- communication and information issues

Each factor is considered in more detail in the following sections.

3.1 Temporal and spatial factors

The consequences of a radiation incident depend on the time of the release. If the release occurred in the middle of the night, fewer people are likely to be outside and directly contaminated.

Some radionuclides decay very quickly, whereas others can stay in the environment for decades; in addition, radionuclides will transfer from the location where they deposit because of weathering. The time since the release of radioactivity can therefore be of great importance, depending on the radionuclides involved. Furthermore, the spread of contamination in the area will increase over time causing a change in activity concentrations of radionuclides over time.

The type of area affected and its location and size can have an impact on the choice of management options. Area size affects the speed with which a recovery strategy can be implemented, what it entails and the timescale on which it can be completed. Small areas of contamination may be more easily cleaned than large areas and more options may be practicable. Furthermore the type of area and its location are important factors. If a residential area with high numbers of inhabitants is contaminated, there will be a great pressure from the public to ensure that it is still safe to live there and send children to school or play in the parks. If the location of an incident affects priorities which may be linked to tourism, political sensitivities, economic stability or critical facilities and infrastructure, there will also be increased pressure to minimise contamination promptly.

3.2 Effectiveness of management options

As mentioned in Section 1, the primary aim of most of the management options considered in this handbook is to reduce external doses from deposited radionuclides and inhalation doses from resuspension of contaminated material.

The effectiveness of management options is influenced by technical and societal factors, some of which are very specific to one or two options. Comprehensive guidance on effectiveness is provided on individual datasheets (Section 7).

3.2.1 Effectiveness of shielding options

The **effectiveness of a shielding option** is defined as the reduction in the external dose rate from a surface (eg buildings, paved surfaces, grass, soil, and shrubs), generally expressed as a percentage, after the implementation of the option.

The effectiveness of shielding provided by an option depends on the radionuclides present and the thickness of the shielding material. The effectiveness of different shielding options is included in the relevant datasheets (Section 7). Estimates have also been made of the typical thicknesses of materials that would be required to reduce gamma dose rates by factors of two and ten. The thicknesses can be applied to a range of normal solid materials that could be used for shielding in an inhabited area, ranging from wallpaper to concrete, and are given in Table 3.1 for three gamma energy bands (< 0.1 MeV, 0.1 - 1.0 MeV, > 1 MeV). All thicknesses are approximate values and should be used for scoping calculations only. The thicknesses are only appropriate for materials with densities up to about 2500 kg m^{-3}. Table 1.1 provides the gamma energy of all radionuclides considered by the handbook. For other radionuclides, this information can be found in an ICRP publication (ICRP, 1983). It should be stressed that this approach has been developed for materials most likely to be practicable within contaminated areas. It is recognised that other materials such as lead provide the best shielding against gamma emitting radionuclides; however, their use is unlikely to be practicable on a medium or large scale in inhabited areas.

Table 3.1 Material thickness required to reduce external gamma dose rates by a factor of two and ten as a function of gamma energy

		Thickness of material (cm)	
Energy range*	**Radionuclides**	**Reduction factor of 2**	**Reduction factor of 10**
Low energy (< 0.1 MeV)	^{238}Pu, ^{239}Pu, ^{241}Am	< 5	< 20
Medium energy (0.1 - 1 MeV)	^{75}Se, ^{95}Zr, ^{95}Nb, ^{99}Mo, ^{103}Ru, ^{106}Ru, ^{131}I, ^{132}Te, ^{134}Cs, ^{137}Cs, ^{169}Yb, ^{192}Ir, ^{235}U	< 10	Few 10s
High energy (> 1 MeV)	^{60}Co, ^{136}Cs, ^{140}Ba, ^{140}La, ^{144}Ce, ^{226}Ra	Few 10s	Few 10s - 100

*: The energy with the highest probability of emission has been used. The energies of daughter radionuclides have been taken into account. Energies were taken from ICRP (1983).

The reductions in beta dose rate that could be expected from the use of shielding materials within inhabited areas are given for ^{90}Sr in Table 3.2 (this radionuclide has a high energy beta emitting daughter radionuclide, ^{90}Y). For radionuclides emitting weak beta radiation* (see Table 1.1) shielding will be very effective in reducing external dose rates from the surface.

3.2.2 Effectiveness of fixing options

The **effectiveness of a fixing option** is defined as the reduction in the inhalation dose from reducing resuspension of contaminated material from a surface (eg buildings, paved surfaces, grass, soil, and shrubs), generally expressed as a percentage, after implementing the option.

Possible fixing options considered for each surface are given in Table 3.3 along with the possible benefits for the radionuclides under consideration in the handbook. It should be noted that fixing options are sometimes also known as tie-down options. The primary aim of fixing options is to reduce the intake of contamination into the body, for example, by inhalation. These options can also provide some shielding from the contamination and hence reduce external dose rates. An indication of how effective fixing options may be in reducing external dose rates is also given in Table 3.3. Values provided in the table are for ^{90}Sr and its daughter ^{90}Y. These radionuclides have been chosen as they emit high-energy beta radiation. For many beta emitting radionuclides, the reductions in dose rate will be greater. Values in the table are approximate and should only be used for scoping the effectiveness of fixing material as shielding media. Most fixing options provide very little protection against gamma emitting radionuclides. If soil, sand or bitumen are used as a fixing material, there are some benefits in terms of reducing external dose rates above the contaminated surface, as shown in Table 3.3.

Fixing can be either temporary or permanent, depending on the material used, as specified in Table 3.3. In the table it was assumed that fixing methods are of benefit if reductions in doses of more than 30% can be achieved. Temporary fixing options are only likely to be effective for a day or so, after which their integrity is likely to be compromised unless the application is repeated. Permanent fixing options remain in place until they are subsequently removed (eg bitumen coatings on roads), although it should be noted that all fixing materials are likely, to some extent, to lose integrity over time and become less effective. Fixing options considered in this handbook are unlikely to be suitable for specialised building surfaces. Water is expected to be used only to dampen the surface prior to removal to reduce inhalation doses to workers arising from material resuspended during the removal. For contaminated soil, water also has the benefit of aiding the bonding of activity to the soil particles and can wash the contamination below the surface of porous soils, both of which actions reduce long-term resuspension. However, it should be noted that resuspension often does not contribute significantly to doses and that radioactive material washed off grass or plants produces higher activity concentrations in the soil. For roads and paved areas, water is also likely to wash some contamination off the surface into the drains or on to neighbouring soil and grass surfaces. It should be noted that soil could also be used to cover material on roads and paved areas. Such thin layers are potentially disturbed by vehicles, pedestrians, wind and other means. Sand and soil on roads can interfere with rainwater run-off gulleys, unless given special attention.

* For the purposes of the handbook, a weak beta emitter has a maximum energy of less than 2 MeV.

Table 3.2 Effectiveness of some fixing options in reducing external beta dose rates for beta emitters

	Reductions in external beta dose rate above the surface while shielding material is in place	
Fixing option	**Thickness of material* (mm)**	**Dose rate reduction above surface (%)**
Paint on external building surfaces	1	45
Water on roads and paved areas	1	45
Sand on roads and paved areas	2	90
Bitumen on roads and paved areas	1	70
Soil on outdoor ground surfaces	50	100
Peelable coatings on outdoor hard surfaces	2	65

*: Thicknesses of materials assumed are those stated in the datasheets (Section 7)

Table 3.3 Protection provided by implementation of fixing options for contaminated outdoor surfaces in inhabited areas

Fixing option	Protection against inhalation of resuspended material	Protection against external gamma	Protection against external beta
Paint on external building surfaces (T/P)*	Yes	No	Yes
Water on roads and paved areas (T)	Yes	No	Yes
Water on soil, grass and plant surfaces (T)	Yes	No	No
Sand on roads and paved areas (T)	Yes	No	Yes
Bitumen on roads and paved areas (T/P)	Yes	No	Yes
Soil on outdoor ground surfaces (T/P)	Yes	Yes	Yes
Peelable coatings outdoor hard surfaces (T)	Yes	No	Yes

Key: T = temporary; P = permanent

*: Paint could also be considered for indoor surfaces. Similarly, laying carpet or wallpapering would also fix.

3.2.3 Effectiveness of removal options

The **effectiveness of a removal option** is defined as the ratio of the activity initially present on a specific surface (eg buildings, paved surfaces, grass, soil and shrubs) to that remaining after implementing the option. This ratio is usually called the decontamination factor (DF).

A DF of 5, for example, means that 80% of the activity on the surface can be removed by a particular technique. It should be noted that the DF is only a measure of the efficiency of a technique in removing activity from a specific surface; it is not a measure of the reduction in the overall exposure from deposited material on all surfaces in the environment where an individual resides.

In cases where the contamination can penetrate significantly into a surface, such as soil, the use of a DF is not, in general, appropriate. Instead, the reduction in the dose rate at a reference height above the surface (typically 1 m), after the partial or total removal of contamination to a given depth, is used to express the effectiveness of implementing a particular option on that surface.

For hard surfaces, it is reasonable to assume that much of the activity on the surface is available for resuspension and, therefore, techniques that remove contamination from the surface also reduce the resuspended activity in air from that surface. For permeable surfaces, such as soil, it is generally accepted that only the surface layer of the soil (typically 10 mm deep) contributes to the resuspended activity. The reduction in activity in the surface layers of the soil following the implementation of removal options is therefore an important measure of the possible reduction in resuspension and the resultant concentration in air will be reduced by the value of the DF.

All values of DF, reductions in dose rate above the surface, and reductions in resuspension presented in this handbook should be treated as indicative only. The actual values achieved greatly depend on the specific circumstances of the incident. In the event of a radiation emergency, it may be necessary to trial the proposed technique on a small part of the area to be decontaminated, in order to determine more accurately the effectiveness that could be expected.

3.2.4 Social factors affecting the effectiveness of management options

The effectiveness of management options is influenced by a wide array of social factors including the ability of authorities to control the movement of people in and out of contaminated areas and their compliance with instructions and advice; people cannot be forced to comply, may not understand the instructions or be may not be able or willing to follow them.

Management options will not be fully effective unless there are enough people trained to implement them. While the tasks carried out by recovery workers will be covered by a risk assessment, and a system of radiological protection to control occupational exposure (Section 3.3.1), there may still be reluctance to carry out the required tasks if radiation is involved. Therefore, some basic training in radiological protection should be considered, for example in the correct use of radiological personal protective equipment (PPE). This may be particularly important where a management option requires workers with a particular skill (eg the ability to operate a specific piece of machinery), or when the number of people trained to do a particular task may already be limited. Even carrying out simple tasks such as washing down surfaces or collecting leaves may benefit from training to overcome reluctance to deal with any radiation present.

3.3 Protection of workers

Workers can be divided into two groups: members of the public who work in the area or who come into the affected area to work, termed normal workforce, and people implementing the recovery strategy, including clean-up, monitoring and other operations.

3.3.1 Workers implementing a recovery strategy

If workers implementing management options are subjected to additional risks, these should be taken into account in the justification and optimisation of the recovery strategy (ICRP, 2007). A prior risk assessment for any task involving radiation is a fundamental requirement of the Ionising Radiations Regulations 1999 (HSE, 2000). People involved in recovery operations should be subject to the normal system of radiological protection for occupational exposure (see Table 3.4) as their work can be planned and their exposure controlled (ICRP, 2007). This system of dose limitation also applies to the handling and disposal of any wastes produced during the implementation of recovery actions. Health and safety legislation and the duty of care requirements placed upon employers make it necessary to ensure that deployed personnel are provided, within an appropriate timescale, with training in radiological protection, ensuring the correct use of radiological PPE.

Table 3.4 Dose limits for practices for workers and the public (HSE, 2000)

Category	Effective dose (mSv y^{-1})	Skin dose (mSv y^{-1})	Lens of eye (mSv y^{-1})
Workers	20	500	150
Members of the public	1	50	15

3.3.2 Types of specific worker risks

Radiation risks to workers will particularly be related to external exposure to contamination in the environment, external exposure from radioactive contamination on the body, and internal exposure from inhalation of resuspended radioactive substances.

A number of protective measures may be chosen to reduce the risks to workers, according to the requirements in the specific situation. Such measures include: delaying implementation of management options; work time restrictions; shielding; ventilation; fixation; respiratory protection; protective tight fitting safety glasses; and protective clothing.

Use of PPE should be optimised for the task. Excessive, unnecessary and clearly visible worker protection may contribute to the anxiety of local inhabitants of the area; therefore its use should be justified. Some of the management options can be difficult to carry out when wearing PPE, especially where heavy, physical work is involved. In such cases difficult working conditions may limit the time for which a worker can operate, possibly resulting in shifts as short as 20 minutes. However, these arguments should not prevent the use of PPE if it is required to ensure workers' safety. If PPE is necessary, depending on the task, and factors such as the scale of application, the number of workers involved, and the duration for which the management option will continue, the amount of PPE required may be substantial and consideration should be given to its availability in the required timescale. Safety precautions are discussed, in general terms, for each management option in the datasheets (see Section 7).

3.4 Disposal of radioactively contaminated waste

The contamination of an inhabited area following a radiation incident generates both solid and liquid radioactive waste regardless of whether any recovery strategy is implemented. Three categories of radioactive waste are considered in this handbook:

- contaminated waste (refuse) and goods

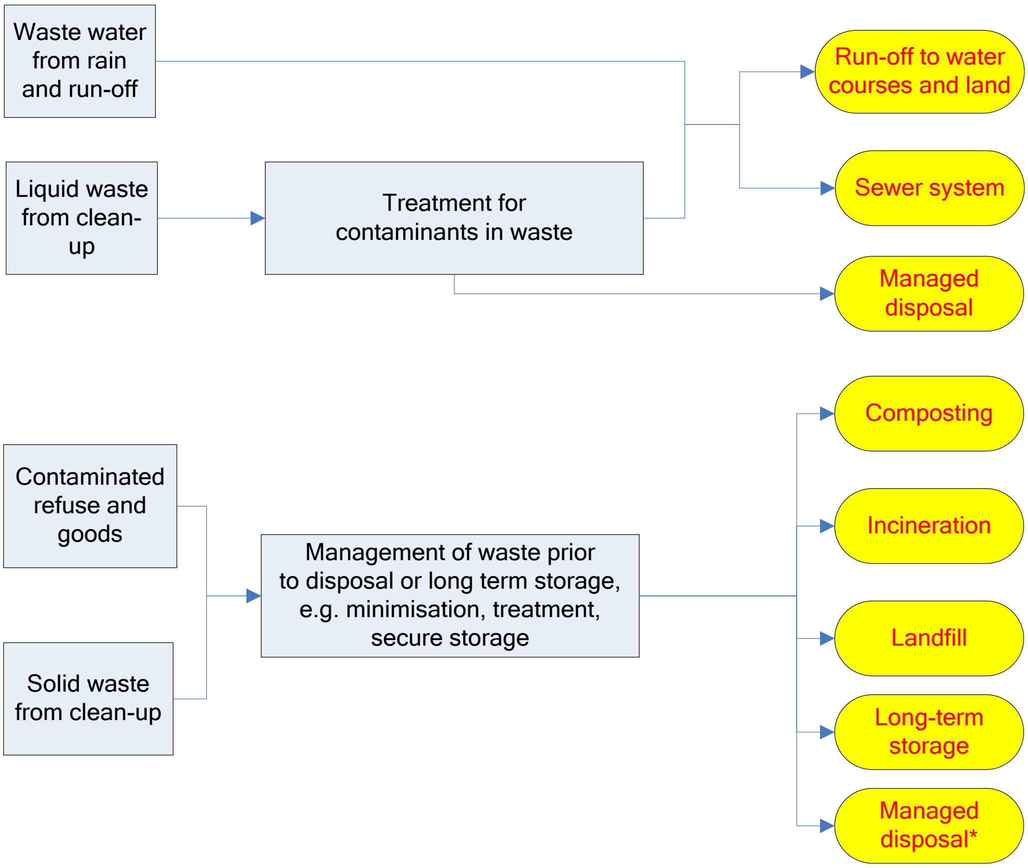
- waste from clean-up of the contaminated area (solid and liquid)
- waste water from rainfall and natural run-off

It is therefore important to consider the impact of the contaminated waste on the public, workers handling the waste, the environment and normal waste disposal practices. Figure 3.1 illustrates an overview of the waste management routes for solid and liquid waste contaminated with radioactivity.

3.4.1 Legislation

Within England and Wales, the Environmental Permitting Regulations (EPA 2010) (Department for Environment Food and Rural Affairs, 2010) specify activities, including accumulation or disposal of wastes, which require an environmental permit from the Environment Agency (EA) or Natural Resources Wales (NRW). In Scotland and Northern Ireland, accumulation and disposal of radioactive waste is controlled under the Radioactive Substances Act (RSA 93) (MAFF, 1993) and requires prior authorisation from regulatory authorities (Scottish Environment Protection Agency (SEPA) in Scotland and Environment and Heritage Service of the Department of the Environment in Northern Ireland).

Figure 3.1 Waste management routes



*Managed disposal = disposal via authorised routes (e.g. Drigg or future deep geological disposal)

3.4.2 Management of solid and liquid waste arising from clean-up

A number of management options generate radioactive waste. Efficient and effective waste management is critical to restoration and rehabilitation of communities and the environment. Any decision to undertake clean-up which generates radioactive waste should be supported by an assessment of the impact that the generated waste will have on the public, workers and the environment and considerations on the method of disposal of the waste. This assessment involves an estimation of the activity levels in the waste, an estimation of the quantities of waste produced and an assessment of the exposures to workers and public from the waste. Appendix C contains more information on the management of solid and liquid waste from clean-up. Estimates of the quantities of waste that could be expected from the implementation of clean-up options are indicated in the datasheets for each option (Section 7) and in Table 5.13. The selected waste disposal option will depend on the nature of the waste, the level of activity in the waste and the availability and acceptability of waste disposal routes. It is important that end points (eg method of disposal) are defined for each waste type produced, and that any requirements associated with the intended end point (eg packaging requirements for disposal) are understood. Disposal may not be straightforward for some waste types. This may be due to the type of material, eg organic material, or possibly as a result of the management option used, eg a chemical may be used in the decontamination process, meaning that the specifications of the LLWR are not met. Problems with disposal can also arise if extremely large volumes of waste materials are involved, which can be the case with some management options. In such cases, careful consideration will be required about how to manage these wastes, and some negotiation with the regulators may be required. Therefore, it may be beneficial to have a centralised view overseeing the management of wastes, especially when several waste streams are involved.

Some of the management options will generate liquid wastes. If water has been used for clean-up, eg pressure hosing, there is potential for generating large volumes of contaminated waste water. There are options for treatment of waste water, with more information available in the ‘treatment of waste water’ datasheet or the Drinking Water Supplies Handbook. Collection of waste water can be difficult however, so unless treatment (eg zeolite blocks) can be built into the management option such that waste water is treated as it is generated, discharge of waste water to sewers may be unavoidable. The processes involved at a sewage treatment works (STW) will remove radioactive material from the water, but this then requires consideration of doses to STW workers and members of the public following discharge of treated effluent and sludge from the STW. In order to help identify if disposal of aqueous waste direct to sewers is likely to be a problem, estimates have been made of the likely contamination levels in the waste arising from clean-up options as a function of deposition level. The data presented in Table 3.5. Data should be taken as illustrative only and monitoring would be required to demonstrate the actual contamination levels in any waste produced. It may be technically feasible to segregate the aqueous waste produced into contaminated dust/sludge and water. Depending on the radionuclide and its physical form in the waste, it may be possible to dispose of the water without constraints. However, this is likely to be very expensive. Table 3.5 gives both activity concentrations in the total waste (dust plus water) as well as likely concentrations in dust/sludge following filtering for the clean-up options producing aqueous wastes.

Table 3.5 Estimates of activity concentrations in liquid waste arising from clean-up as a function of deposition[a]

Clean-up option	Surface	Waste material	Activity concentration per unit deposition (Bq kg^{-1} per Bq m^{-2})		
			^{137}Cs	^{131}I	^{239}Pu
Following wet deposition					
Fire hosing	Roads/paved	Water and dust	$3\ 10^{-1}$	$8\ 10^{-2}$	$2\ 10^{-1}$
High Pressure Hosing	Roads/paved	Water and dust	$9\ 10^{-2}$	$2\ 10^{-3}$	$4\ 10^{-2}$
		Dust sludge only	$4\ 10^{1}$	$8\ 10^{-1}$	$2\ 10^{1}$
Vacuum sweeping	Roads/paved	Water and dust	1	$2\ 10^{-1}$	$5\ 10^{-1}$
Sandblasting	Roads/paved	Water and dust	$6\ 10^{-2}$	$1\ 10^{-3}$	$3\ 10^{-2}$
		Dust sludge only	$1\ 10^{-1}$	$3\ 10^{-3}$	$6\ 10^{-2}$
Foam	Roads/paved	Aqueous waste + dust	$2\ 10^{1}$	5	$1\ 10^{1}$
Fire hosing	Buildings-external walls	Water and dust	$1\ 10^{-2}$	$5\ 10^{-3}$	$6\ 10^{-3}$
		Dust sludge only	1	$5\ 10^{-1}$	$6\ 10^{-1}$
High pressure hosing	Buildings-external walls	Water and dust	$1\ 10^{-3}$	$5\ 10^{-5}$	$7\ 10^{-4}$
		Dust sludge only	3	$1\ 10^{-1}$	1
Sandblasting	Buildings-external walls	Water and dust	$2\ 10^{-3}$	$6\ 10^{-5}$	$8\ 10^{-4}$
		Dust sludge only	$5\ 10^{-3}$	$2\ 10^{-4}$	$2\ 10^{-3}$
Foam	Buildings-external walls	Aqueous waste + dust	$6\ 10^{1}$	$3\ 10^{-1}$	$3\ 10^{-1}$
Fire hosing	Buildings-external roofs	Water and dust	$2\ 10^{-1}$	$5\ 10^{-2}$	$8\ 10^{-2}$
		Dust sludge only	$8\ 10^{1}$	$2\ 10^{1}$	$3\ 10^{1}$
High pressure hosing	Buildings-external roofs	Water and dust	$8\ 10^{-2}$	$2\ 10^{-3}$	$4\ 10^{-2}$
		Dust sludge only	$1\ 10^{2}$	3	$7\ 10^{1}$
Sandblasting	Buildings-external roofs	Water and dust	$9\ 10^{-2}$	$2\ 10^{-3}$	$4\ 10^{-2}$
		Dust sludge only	$3\ 10^{-1}$	$6\ 10^{-3}$	$1\ 10^{-1}$
Foam	Buildings-external roofs	Aqueous waste + dust	$3\ 10^{1}$	8	$2\ 10^{1}$
Following dry deposition					
Fire hosing	Roads/paved	Water and dust	$8\ 10^{-2}$	$3\ 10^{-2}$	$4\ 10^{-2}$
High pressure hosing	Roads/paved	Water and dust	$2\ 10^{-2}$	$6\ 10^{-4}$	$8\ 10^{-3}$
		Dust sludge only	7	$3\ 10^{-1}$	4
Vacuum sweeping	Roads/paved	Water and dust	$1\ 10^{-1}$	$6\ 10^{-2}$	$7\ 10^{-2}$
Sandblasting	Roads/paved	Water and dust	$8\ 10^{-3}$	$3\ 10^{-4}$	$4\ 10^{-3}$
		Dust sludge only	$2\ 10^{-2}$	$6\ 10^{-4}$	$8\ 10^{-3}$
Foam	Roads/paved	Aqueous waste + dust	3	1	2
Fire hosing	Buildings -external walls	Water and dust	$4\ 10^{-2}$	$2\ 10^{-2}$	$2\ 10^{-2}$
		Dust sludge only	5	2	2
High pressure hosing	Buildings -external walls	Water and dust	$5\ 10^{-3}$	$2\ 10^{-4}$	$5\ 10^{-3}$
		Dust sludge only	$1\ 10^{1}$	$4\ 10^{-1}$	9
Sandblasting	Buildings -external walls	Water and dust	$6\ 10^{-3}$	$3\ 10^{-4}$	$3\ 10^{-3}$
		Dust sludge only	$2\ 10^{-2}$	$8\ 10^{-4}$	$9\ 10^{-3}$
Foam	Buildings -external walls	Aqueous waste + dust	2	1	1
Fire hosing	Buildings -external roofs	Water and dust	$1\ 10^{-1}$	$8\ 10^{-2}$	$5\ 10^{-2}$
		Dust sludge only	$4\ 10^{1}$	$3\ 10^{1}$	$2\ 10^{1}$
High pressure hosing	Buildings -external roofs	Water and dust	$4\ 10^{-2}$	$3\ 10^{-3}$	$4\ 10^{-2}$
		Dust sludge only	$8\ 10^{1}$	5	$7\ 10^{1}$
Sandblasting	Buildings -external roofs	Water and dust	$5\ 10^{-2}$	$3\ 10^{-3}$	$2\ 10^{-2}$
		Dust	$1\ 10^{-1}$	$1\ 10^{-2}$	$7\ 10^{-2}$
Foam	Buildings -external roofs	Aqueous waste + dust	$2\ 10^{1}$	$1\ 10^{1}$	$1\ 10^{1}$

* Estimates of activity concentrations in waste calculated using CONDO (Charnock et al, 2003).

3.4.3 Management of contaminated waste (refuse) and goods

When no contamination is present, domestic and commercial refuse is normally sent to landfill or is incinerated. This may include a sorting stage, where the waste is manually sorted and suitable items are sent for recycling. Organic waste such as grass cuttings from gardens may be collected separately and sent to composting facilities. In the event of a radiation emergency, some refuse will be uncontaminated because it will have been placed in covered bins prior to deposition. Other refuse and garden waste collected after passage of the plume is likely to be contaminated. Some of the different factors requiring consideration for the management of domestic and commercial refuse following a radiation incident are outlined in Table 3.6. Responsibilities for handling the waste will depend on the levels of contamination present.

Table 3.6 Factors to consider for the management of domestic/commercial refuse

Household/commercial waste collection
Domestic and commercial refuse may be perceived by members of the public to be contaminated, even if it is not. A monitoring scheme should be put in place to enable release of waste that can be disposed of under normal practice (see Appendix C).
Delays in collection of household refuse may result in fly-tipping by the public and hence loss of control of the waste. Therefore, it is not generally acceptable to ask people to hold on to waste.
Temporary suspension of sorting and recycling of refuse should be considered.
Segregation of garden waste from other refuse should be considered if this is not normal practice.
If people are living as normal in an area, any specific precautions or differences in the way waste is collected may raise questions about the risks to the people living in the area.
Activity concentrations in the waste
Any covered, sealed or otherwise protected waste awaiting collection at the time of the release will not be contaminated, although, the containment or packaging itself may be contaminated.
Garden prunings may also be of concern if pruning is carried out in the first few months after deposition. Waste food from food grown in gardens and allotments in the contaminated area may have similar contamination levels to grass cuttings.
Activity concentrations in garden waste are likely to be in the order of 1 - 10 Bq kg^{-1} shortly after a deposition of 1 Bq m^{-2}. These concentrations will decrease with time due to natural weathering and removal of activity with garden waste. Activity concentrations in waste contaminated indoors will be significantly lower, probably at least 100 times.
Monitoring
A monitoring programme is needed to demonstrate that contamination levels in refuse meet disposal criteria and to support the segregation of wastes and subsequent disposal or storage if required.
Monitoring may be required to demonstrate that contamination levels in household refuse and in garden waste decrease with time.
Transport of waste
Transport of waste through uncontaminated areas may be unacceptable, although unavoidable.
Doses to workers involved in transport of waste should be assessed (see Appendix C).
Workers involved in refuse collection, transport and other activities
Risks to workers who normally collect refuse should be assessed as required (see Appendix C). These workers need to be able to be reassured that it is safe to handle the waste.
If people are living in an area then the external doses received by people working outdoors collecting refuse will be of the same order as those for someone spending time outdoors in that area. Contact doses should be controlled eg using of gloves. Use of specialist contractors should be considered as an alternative.
Temporary suspension of manual sorting should be considered.

Table 3.6 Factors to consider for the management of domestic/commercial refuse

Waste storage
Facilities to temporarily store waste prior to monitoring and selection of the appropriate disposal route need to be identified.
Storage facilities for radioactive waste are unsuitable for normal disposal. Local communities may not be willing to store waste in their area. Consider nuclear sites, site of incident, Ministry of Defence (MoD) sites, relocated areas (ie areas of high contamination where access is prohibited).
Would commercial premises with contaminated products (eg warehouses, supermarkets) be able to operate under the exemption orders provided by the relevant legislation? (Environmental Permitting Regulations (Department for Environment Food and Rural Affairs, 2010) in England and Wales; Radioactive Substances Act (MAFF, 1993) in Scotland and Northern Ireland) Authorisations may be required depending on levels of contamination.

3.4.4 Contaminated waste water: rain and natural run-off

Following the deposition of radioactivity by rainwater the subsequent natural run-off from an inhabited area is unlikely to be controllable. It is important therefore to have information to aid the assessment of the impact of this contaminated water. This will include likely doses to members of the public, doses to the workers involved in the management of waste water and the impact on the normal operation of sewage treatment works and practices for disposal of waste water. Table 3.7 contains information on possible destination routes for rainwater and run-off and also potential exposure pathways for members of the public. Rainwater may enter the sewer system, although this depends on the type of drainage system present. Many modern residential and industrial areas have separate rainwater run-off and foul water systems; in such cases, rainwater does not enter the sewers. Built-up areas may have combined systems which can allow rainwater to enter the sewer system. Properties in rural settlements are most likely to have combined systems, although some, particularly isolated dwellings, may have septic tanks. In the latter case, run-off water and rain will be directed to soakaways. Septic tank drainage is not considered further in the handbook. It should be noted that storm water may be handled differently to run-off under normal weather conditions.

Table 3.7 Rainwater routes and potential exposure pathways for members of the public

Rainwater route	Potential exposure pathways
Run-off from inhabited area surfaces enters water courses such as rivers	Use of watercourses for fishing, swimming, drinking water supplies or irrigation
Run-off enters sewers (foul water system)	Treated effluent from the sewage treatment works can be discharged into rivers or coastal waters Sewage sludge may be incinerated, send to landfill or spread on land.
Soakaways (eg drainage from roofs via gutters and down-pipes into the ground)	Use of gardens for recreation, ingestion of food grown in gardens

As well as entering sewers, contaminated water may enter groundwater (eg leachates from landfill or from composting contaminated material) and contaminate drinking water supplies if water is obtained from such sources. Other drinking water sources will also have to be considered and potentially monitored (see the Drinking Water Supplies Handbook).

3.4.4.1 Estimates of activity concentrations in rainwater and run-off

A conservative estimate of the activity concentration in rainwater, if deposition has occurred through rainfall, is 1 Bq l^{-1} per Bq m^{-2} deposited (Brown et al, 2008). Run-off from buildings and other land surfaces in an inhabited area due to subsequent uncontaminated rainfall will remove very small quantities of contaminated material from the surfaces. The activity concentrations in the run-off water will be low and could be expected to be in the region of 1 10^{-3} Bq l^{-1} per Bq m^{-2} initially deposited for long-lived radionuclides (Charnock et al, 2003). Long-term run-off is unlikely to be of concern for short-lived radionuclides.

Contaminated waste water may enter the sewage system depending on the drainage system. Appendix C contains information for situations where contamination has entered sewers and sewage treatment systems.

3.5 Societal and ethical aspects of the recovery strategy

3.5.1 Social considerations

Previous experience of wide scale contamination following a nuclear accident has revealed that all aspects of the daily life of the inhabitants are affected. These are complex situations which cannot be managed by radiation protection considerations alone, and must address all relevant dimensions such as such as health and wellbeing, social and ethical aspects (ICRP, 2009).

Despite the beneficial consequences of implementing management options some of the associated implications can decrease the quality of life of those affected. The implementation of management options are disruptive to normal social and economic life and may cause panic, stress or upheaval to those affected, possibly resulting in damage to health and well-being. Those particularly susceptible are elderly people, parents with young families and pregnant women.

However, the implementation of management options may help provide reassurance to members of the public and workforce. They may also have a positive impact by making an area look cleaner than it was originally or improve the conditions of the infrastructures (eg improvements to the road and railway network). Local companies may be involved in the clean-up operations and thus may benefit financially.

ICRP (2007; 2009) highlights the need to directly involve the affected population and local professionals in the management and implementation of protection strategies. Stakeholder involvement is also an important component of the decision-aiding process, and in some cases it is essential for arriving at an accepted solution and for building trust in decision-making authorities (eg Lochard, 2013). Social and ethical aspects of radiation risk management are described in more detail in several chapters of Oughton and Hansson (2013).

Societal factors which may influence the priorities given to a recovery strategy are listed in Table 3.8.

Table 3.8 Societal factors that may influence recovery priorities

Factor	Comments
Location	The location of a radiation emergency affects priorities, which may be linked to tourism, political sensitivities, economic stability or critical facilities and infrastructure.
Numbers of people affected	If large populations are affected, the impact for public health may be significant even if individual doses are not high. Similarly, the collective disruption caused by implementing management options will be high. There may be pressure to give priority to highly populated residential areas or areas where many people work compared with sparsely inhabited rural areas.
Are people living in the contaminated area? Have they been evacuated in the emergency phase?	Priority may be given to residential areas where people have not been evacuated. Subsequently, priorities within residential areas may be set based on predicted doses. Practicability of options and priorities within an area may be affected by people not having been relocated. If people have been evacuated it may be possible to extend the time that they are out of the affected area in order to implant the chosen options. Some management options require access to public areas to be temporarily restricted. In addition, restrictions may be placed on some public activities following completion of management options (eg digging beyond a certain depth will be forbidden). Such restrictions may not be practicable or publicly acceptable and this needs to be considered when developing a recovery strategy
Type of radiation emergency or incident	Incidents involving specific radioactive substances, such as plutonium, may lead to enhanced fear within the affected population and outside the affected area.
Economic stability. Need to keep businesses and infrastructure open.	Priorities may be biased towards commercial businesses, shops, roads, railways and other activities to ensure that the economy of the area is not unduly affected and to support people living in the area.
Return to life as normal. Need to keep critical facilities and infrastructure open.	Public or commercial facilities in the area which are considered critical may require high priority in any recovery strategy to ensure that they remain viable and safe. It is likely that additional burdens may be placed on public services (eg schools and hospitals). Keeping schools and other public buildings open and allowing people to move freely in the affected area may become a priority in order to demonstrate life has returned to normal
Damage to personal property	Personal property and objects, amenities and objects of heritage may be damaged or contaminated following the implementation of management options.
Public perception of the affected areas from people living outside it	Public perception that the area is significantly contaminated can have profound social consequences. Industries and businesses may be affected as well as the identity of local communities and groups. It can be expected that tourists will not return to the affected area until the people have returned to living normally. It may take several years before the tourism industry is restored to the area, depending on the size of the incident.
Environmentally sensitive areas (officially designated or otherwise)	Pressure may be applied to give priority to a recovery strategy which favours the environment and protection of wildlife. Restricting access may be sufficient to meet these needs.)
Politically sensitive issues	At all levels of government political sensitivities and political agendas may influence recovery priorities.

3.5.2 Ethical considerations

The key ethical considerations that should be taken into account when developing a recovery strategy are given below. The issues are explored more comprehensively in Oughton and Hansson (2013).

- self-help: options that are carried out by the affected population such as grass cutting, digging and indoor cleaning, can increase personal understanding or control over the situation. Furthermore, through their involvement, the population reinforce their autonomy, liberty and dignity. Conversely, imposed management options such as relocation can infringe upon liberty or restrict normal behaviour
- animal welfare: animal welfare is concerned with the amount of suffering the management option may inflict on animals such as zoo animals, pets or wild animals
- environmental risk from changes to the ecosystem: management options that change or interfere with ecosystems may have uncertain or unpredictable consequences for the environment. Environmental risk raises a variety of ethical issues including consequences for future generations, sustainability, cross-boundary pollution, and balancing harms to the environment/animals against benefits to humans. The acceptability of the management option will be highly dependent on the ecological status of the area and the degree to which the management option diverges from usual practice (eg shallow ploughing may be a normal practice while deep ploughing may be not)

3.6 Environmental impact

The impact on the environment of management options should be considered during the decision making process in order to make sure that the action is justified. There are both positive and negative environmental impacts from the implementation of management options.

3.6.1 Positive environmental impacts

The replacement or treatment of roads and paved surfaces may lead to an improvement in their condition (depending on its original state).

3.6.2 Negative environmental impacts

If a significant number of people are relocated temporarily, the area they are sent to will experience increases in traffic which may result in a negative environmental impact through, for example, an increase in noise and air pollution. Where populations are permanently relocated, the siting of new buildings and infrastructure could impact negatively on the aesthetics of the environment. Similarly, where workforce access is prohibited to a building, the building and surrounding land could fall into disrepair.

Management options for grass, soil and outdoor surfaces can lead to a number of negative environmental impacts. For example, they can result in a decrease in biodiversity, a loss of plants and shrubs, a risk of soil erosion, partial or full loss of soil fertility, landscape changes, and other adverse effects. In addition, chemicals used for a tie-down option can themselves contaminate soil. The acceptability of covering a grass or soil area with tarmac in order to shield the population from contamination is likely to have a negative impact on the aesthetics of the environment.

3.7 Economic cost

The implementation of management options incurs economic costs, both direct and indirect. Examples of direct and indirect costs are given in Table 3.9. The magnitude of these costs depends on many factors, including:

- period of time over which a management option is implemented
- scale of the event: costs are proportional to the area of land affected
- land use
- availability of equipment and consumables

Table 3.9 Economic costs of the implementation of management options

Direct costs
Labour. It includes the salaries of workers implementing the management options and overhead costs for organising the work and an allowance for additional staff that may be required.
Cost of protection measures such as dosemeters and medical follow-up.
Loss of production because of the closure of businesses and industries.
Consumables and specific equipment necessary for particular management options, including handling of waste (see the datasheets in Section 7).
Communication, support, transportation and the need to verify laboratory analyses or screening techniques for quality assurance purposes.
Indirect costs
Changes to outdoor areas can have an impact on soil structure, fertility and may raise the risk of soil erosion. If options such as deep ploughing are implemented in areas where the water table is high, groundwater may be contaminated.
Temporary or permanent restriction of access and a reduction or loss of tourism may have an impact on businesses (particularly small businesses). Impact may also be experienced on the whole region if tourists avoid areas near to the contaminated area for fear of contamination.
Restrictions on subsequent land use once management options have been implemented may mean that people cannot live or work in certain areas or return to a normal lifestyle. This may result in relocation costs or business closures.

3.8 Information and communication issues

Numerous studies have highlighted the importance of effective risk communication in enabling people to make informed choices following disasters, including nuclear and radiation incidents (Becker, 2007; Covello, 2011). Effective communication requires accurate information that can be disseminated in a timely manner in order to both enhance the response effort and mitigate potential psychological and social impacts, including discrimination. It is thus important to address such issues in the pre-event planning stage recognising that the later phases of recovery will necessitate a more sophisticated approach toward communication to address the complex decisions that have to be made and the uncertainties involved. The information needs of stakeholders will be great and it is therefore important that all available communication methods are used to disseminate and share information. There will be a need to use traditional media outlets (television, radio, online news) supplemented by full use of other delivery channels such as social media. Effective risk communication can help people to find peace and be connected, hopeful, adaptable and cooperative, instead of feeling unsafe, anxious, isolated, pessimistic, inflexible, uncooperative, helpless, dependent, fatalistic and victimised.

Some of the communication and information issues that should be considered when developing a management strategy are:

- during the pre-deposition and early phases of a radiation incident, there is generally a lack of information available. Therefore, at these stages, there is much reliance on predictions about the scale and impact of the contamination and expected consequences. The authorities are the main communicators of information in the early phase
- as the situation develops, sources of information and routes for dissemination grow rapidly. The more sources for dissemination there are available, the greater the chance of contradictory information being released. The authorities would need to cope with this situation and be in a position to provide accurate information
- prior to and during implementation of management options in a contaminated inhabited area, a well-focused communication strategy and dialogue should function with and between affected populations and other stakeholders. Information should deal with what management options have been selected and why, how do they work, how they are applied and by whom, what the societal economic and environmental impact
- as the situation changes and develops, conflict or disagreements may develop between affected populations. The reason for such dissent could be differences in the distribution of costs and benefits in the community from implementing the management options. It is essential that every opportunity for dialogue and debate about appropriate management strategies is taken to pre-empt these situations as much as possible

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4 Planning for Recovery in Advance of an Incident

The response to the effects of a major UK accident or emergency is managed primarily at the local level. It is a general principle that there should be a detailed emergency planning zone (a few square kilometres) for civil nuclear accidents up to the worst case most reasonably foreseeable accident (also known as the reference or design basis accident) and extendibility for accidents in excess of this. Emergency plans are drawn up in advance of an incident in order to provide an effective response within an emergency planning zone. They are easily applied and are universally accepted. Emergency plans do not include actions to be taken in the post-emergency phase (ie recovery phase) when it is much more difficult to be prescriptive about actions to take due to variations in local circumstances. Nevertheless it is recognised that there should be planning for recovery up to the reference basis accident, albeit in much less detail.

The purpose of this chapter is to support the planning process by identifying the key topics that would need to be addressed and information that is needed to support the development of recovery strategies. Although much depends on the nature of the emergency or incident (eg its magnitude and the extent of radioactive contamination), consideration of topics such as 'requirements for information' and 'outline arrangements' prior to the occurrence of an incident would benefit the speed of recovery response and may also ensure a more successful outcome. Table 4.1 provides a breakdown of topics covering data and information requirements that could usefully be gathered in advance of an incident. The development and sharing of localised databases on businesses, suppliers of raw materials, contractors, waste disposal facilities and other information need to be considered. Although some of these databases may already exist in some form, the point of contact may not be widely known. Furthermore, it is important that the information is kept up to date and is maintained. Responsibility for this task for each database would need to be assigned. Due to the wide ranging nature of the information presented in Table 4.1, it is not yet clear how it would be assembled. Priorities would need to be assigned to help ensure the best use of available resources. Organisations at the local level would need to develop their own approach for preparing for a radiation emergency, according to their responsibilities and involvement.

Under the auspices of the Nuclear Emergency Planning Liaison Group (NEPLG), a UK Nuclear Recovery Planning Group has been established to provide a focus for sharing and driving improvements in recovery planning for civil and military nuclear accidents. The Group has developed the UK Nuclear Recovery Plan Template (DECC, 2013), which is a living document that provides guidance on all aspects of the decision-making process, including who to involve, issues to address and a template for a recovery action plan.

Table 4.2 gives a list of factors, in addition to the information requirements listed in Table 4.1 that might need to be considered when developing outline arrangements for a recovery strategy, focused at the local level, in advance of an incident. Dialogue between different stakeholders is important in order to gain a balanced view on various aspects of topics at the national, regional or local level. It enables a common language and a shared understanding of the challenges to be developed. Various approaches for co-developing regional handbooks with stakeholders can be used, including scenario-based workshops, feedback sessions on the datasheets and handbook and the establishment of subgroups for more detailed planning on specific topics (eg waste management).

Table 4.1 Data and information that could be usefully gathered in advance of an incident

Topic	Category	Data and information requirements
Population	General issues	Distribution and size. Groups, eg school children, religious groups, patients,prisoners, tourists. Movements, eg commuters, students, holidaymakers. Time that the population spend outdoors, eg farmers versus office workers.
	Relocation	Numbers of people. Availability of and provision of resources for accommodation / housing. Availability of transport, private car ownership. Transport infrastructure, eg roads, railways.
Type of buildings		Construction method. Configuration, eg multi-storey, terraced, semi-detached, detached. Location factors. Air exchange / ventilation.
Types of sub-area / land use		Industrial. Recreational. Public buildings. Residential. Food production. Critical facilities (factories, hospitals etc). Infrastructure (water treatment works, sewage treatment plants, roads, railways etc). Designated sites (special protection areas, nature reserves, areas of outstanding natural beauty, Ramsar sites).
Background dose rates (to aid monitoring and communication with the public)		Determine the typical background gamma dose rates in the area are
Management options	Technical feasibility	Will the development of specific skills and methods be required? Identification of necessary training
	Available resources to implement recovery strategy	Local and regional availability of equipment and materials required. Costs of resources: labour costs, cost of materials and equipment. Need to maintain any 'call-on' equipment for response purposes, eg fire tenders. Are skilled workers required to operate equipment? How many skilled workers are available? Would they work in contaminated areas?
	Personnel to implement management options	List of available contractors and organisations that can be contacted for advice on techniques, equipment, staff protection etc.
	Impact of geography and weather on management options	Availability of meteorological information, including weather forecasts. Use of geographical information systems to provide information on soil types, topography etc.
	Impact of management options on economy and environment	What is the likely scale of the economic impact from implementing management options? What options may have a positive impact? What options may have a negative impact?
	Acceptability of 'do no recovery' option / return to 'normality'	Draw on experience from other emergencies / natural disasters to identify what factors drive the return to normality, including experience of using different types of equipment. Look at whether decontamination or other management options promote or hinder this?
	Acceptability of management options	This is likely to be influenced by the type of radiation emergency/incident, its size, how the response is handled, the cause of the emergency etc. Public and other stakeholder views on the acceptability of the types of management options available could be sought to reduce the number of options to be considered in the event of a radiation emergency.

Table 4.1 Data and information that could be usefully gathered in advance of an incident

Topic	Category	Data and information requirements
Waste management	Solid wastes	Establish who has ownership of the waste
		Identification of suitable contractors
		Plans for segregation and clearance of waste
		Authorised limits for incinerators, landfill sites, composting facilities etc.
		Number, type and capacities of facilities.
		Quantities of domestic refuse produced weekly, including garden waste.
		Ways to segregate contaminated garden waste from household domestic refuse.
		Normal practices for disposal of waste arising from the treatment of refuse, eg sewage sludge, incinerator ash, composted material.
		Disposal options for contaminated commercial goods that are unsaleable (not necessarily because they are highly contaminated)
		Site of waste storage and disposal facilities.
		Transport to the waste facility
		Legislation on construction of waste facilities.
	Contaminated waste water from natural run-off	Understanding of drainage and sewage plant systems in local area. What happens to excess water that bypasses treatment, eg water following rain storms or floods? What level of staff intervention is there during the sewage treatment process?
Legislation	Options	Environmental legislation may preclude implementation of some management options in the contaminated area (eg restriction placed on removal of trees).
	Workers and public	Establish dose limits for all those involved in recovery
		Establish criteria for transportation of radioactive wastes
Training		Consider developing a training programme for the roles required to be performed, eg decision-makers, decontamination workers and civil protection personnel.
		Provision of information on the objectives of the management option to ensure that those implementing the option understand why it is being undertaken and how the objective can be achieved.
		Leaflets to provide instruction on how to implement options correctly and effectively for situations where major training exercises are not possible.
Contacts		Lists of contacts in organisations that have a role in the event of a radiological emergency.
		Lists of contacts with local information.
		Lists of country / regional / local databases that provide useful background data and information on how to access them.
Communication	Members of the public	Arrangements for communications via local/national TV and radio, websites. Timeline.
		Plan for engaging local people in decisions that will affect them.
		Compensation rights, including international agreements on compensation for radiation emergencies.
		Pre-prepared information that can be circulated to affected businesses. Receipts and record keeping.
		Pre-prepared information for others who may suffer financial losses due to the incident.
	Provision of information to implementers of management options	Provision of information on the objectives of the management option to ensure that those implementing the option understand why it is being undertaken and how the objectives can be achieved.
		Leaflets to provide instruction on how to implement options correctly and effectively.

Table 4.2 Factors and actions that may need to be considered when developing an outline recovery strategy for inhabited areas in advance of an incident

Topic	Factors and actions to consider
Generic strategy	Ensure information requirements (see Table 4.1) are prioritised, put into action, achieved and maintained - it is important to have confidence that information is complete, reliable and up-to-date. Establish mechanisms for accessing information. Procedures to characterise the longer-term situation will most likely be initiated in the emergency response phase. Therefore, recovery response plans should be consistent with their emergency response counterparts in order to ensure an uninterrupted flow of information and response. Think about how the recovery response strategy will link to management options implemented in the emergency phase. Think about employing a phased approach in which some contaminated areas are dealt with promptly, whereas other are treated later. Think about the role of self-help. Consider what the impact of different weather conditions and the geography of the area will have on the strategy and choice of management options. Produce and maintain a risk register for things that could go wrong in the development of the strategy (eg non-compliance). Identify barriers and establish which ones that will make the biggest difference.
Recovery criteria	Identify appropriate criteria to be used to determine the need for and scale of recovery management options and to measure their success.
Roles and responsibilities	Make sure the roles and responsibilities of those agencies that would undertake tasks in the recovery phase are well known (ie through dissemination of NEPLG guidance). Identify leading agencies and legal responsibilities. Establish how the roles and responsibilities change along the timeline. Consider for each management option how available resources will be co-ordinated and moved to the affected area, eg the use of army, civil protection. This should be done at the national level to ensure consistency. Explore the best role of the local government and local agencies.
Role of stakeholders	Identify existing stakeholder groups in the area eg parish councils, community groups, schools. Investigate whether these could/would be prepared to provide feedback on a recovery strategy for the area. Consider processes that could be used to establish bespoke stakeholder panels where no relevant groups exist. Establish steps for each process considered.
Management options	Identify practicable and acceptable recovery options for use at the local level based on information provided in the UK Recovery Handbook in advance. Try engaging with the stakeholders. Consider: any constraints on use of options (from Table 5.1 and datasheets in Section 7) impact of weather conditions, ie when will options not be practicable due to snow, frozen surfaces, thunderstorms etc. which options might be applicable to the range of possible emergency/incident scenarios? How might they be implemented? How will waste be managed? Aspects for each management option that will require consideration in advance of a radiation emergency and those that will be of particular importance to be taken into account in the event of a radiation emergency. Trials of the management options, to obtain a better understanding of the effectiveness and feasibility.
Protection of workers	Agreement between regulatory bodies, radiological protection specialists and employers on which recovery management options are likely to require the use of respiratory protection equipment and/or protective clothing. This should take into account the nature and extent of contamination, the time since the radiation emergency started and whether people are still living in the area. Consideration should be given to where stocks of personal protective equipment (PPE) and respiratory protection equipment (RPE) can be sourced from, bearing in mind the amount of PPE/RPE likely to be required (which may be quite considerable, depending on the scale of application, the number of workers involved, and the duration for which the management option will continue) and the timescale within

Table 4.2 Factors and actions that may need to be considered when developing an outline recovery strategy for inhabited areas in advance of an incident

Topic	Factors and actions to consider
	which equipment will be required.
Criteria for a successful strategy	Identify appropriate criteria to be used to determine the need for and scale of recovery countermeasures and to measure their success.

4.1 Reference

DECC (2013). *Nuclear Emergency Planning Consolidated Guidance. Chapter 18: UK Nuclear Recovery Plan Template.* Department for Energy and Climate Change.

5 Constructing a Management Strategy

The ‘recovery cycle’ described in Section 1.7 can be used as the basis for developing an overall recovery strategy. As part of this process, due consideration should be given to the doses received from the various exposure scenarios for people living and working in the affected area and not per se on the levels of contamination on surfaces or in environmental media. This is because the time and effort required for removing contamination beyond certain levels from everywhere does not automatically lead to a reduction in doses and can generate unnecessarily large amounts of waste. The assessments must be realistic and take into account prevailing environmental conditions and the potential for elevated background radiation coming, for example, from direct shine from adjacent sites or contaminated objects such as trees.

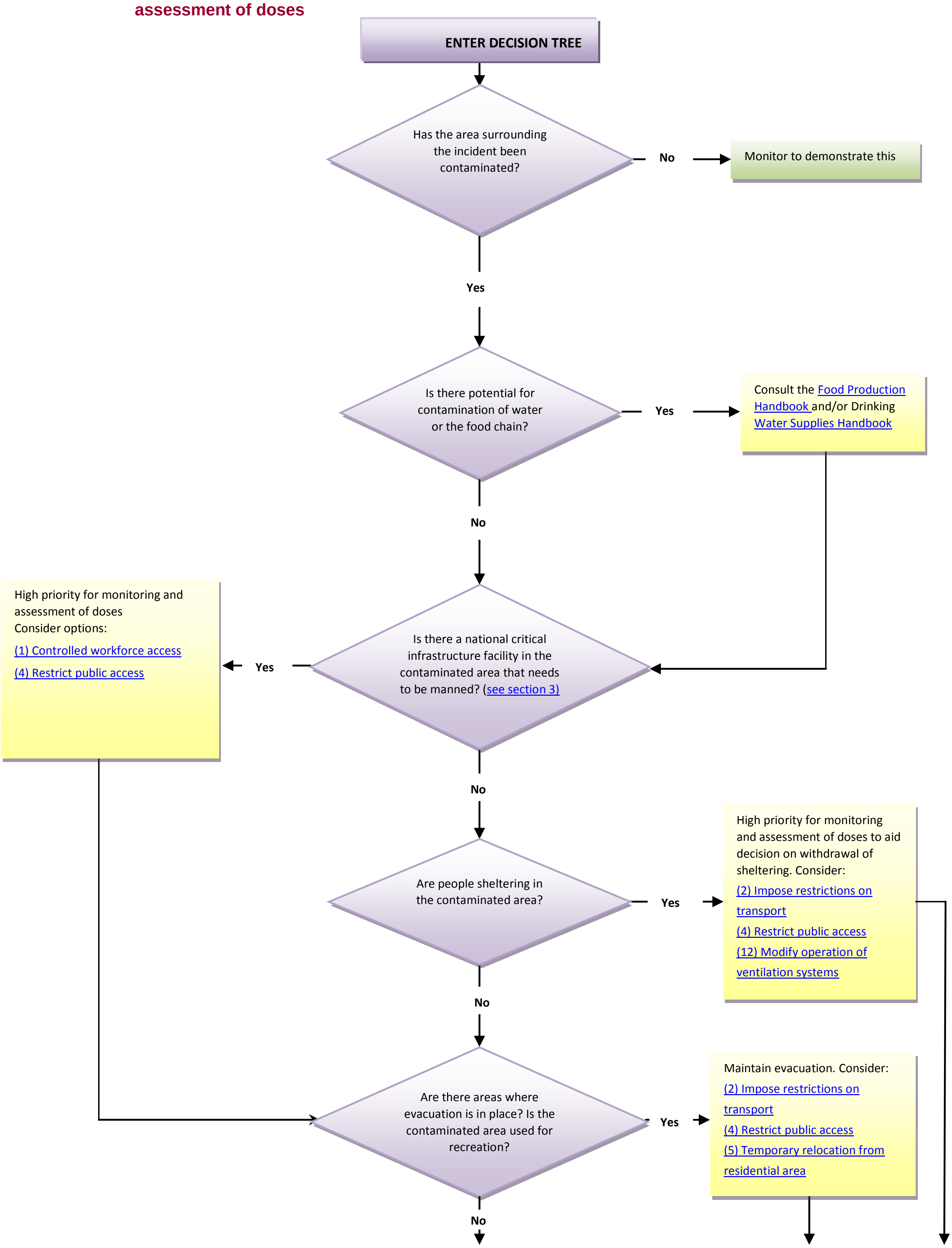
Identification and selection of management options will depend on the goals of the recovery strategy. For example, experience following the accident at Fukushima, suggested that dose reduction to certain population subgroups, such as children in school playgrounds, could merit rigorous decontamination activities while delaying clean-up elsewhere, such as forests. Another important consideration when selecting decontamination options is the volume of waste material that can be generated and the requirements for an accompanying, well-planned waste management strategy. The absence of suitable interim and final sites for storage and disposal of such waste can limit the success of the protection strategy. Consequently, the generation of radioactive waste should be kept to a minimum and options that produce either no waste or very little waste should be favoured where possible.

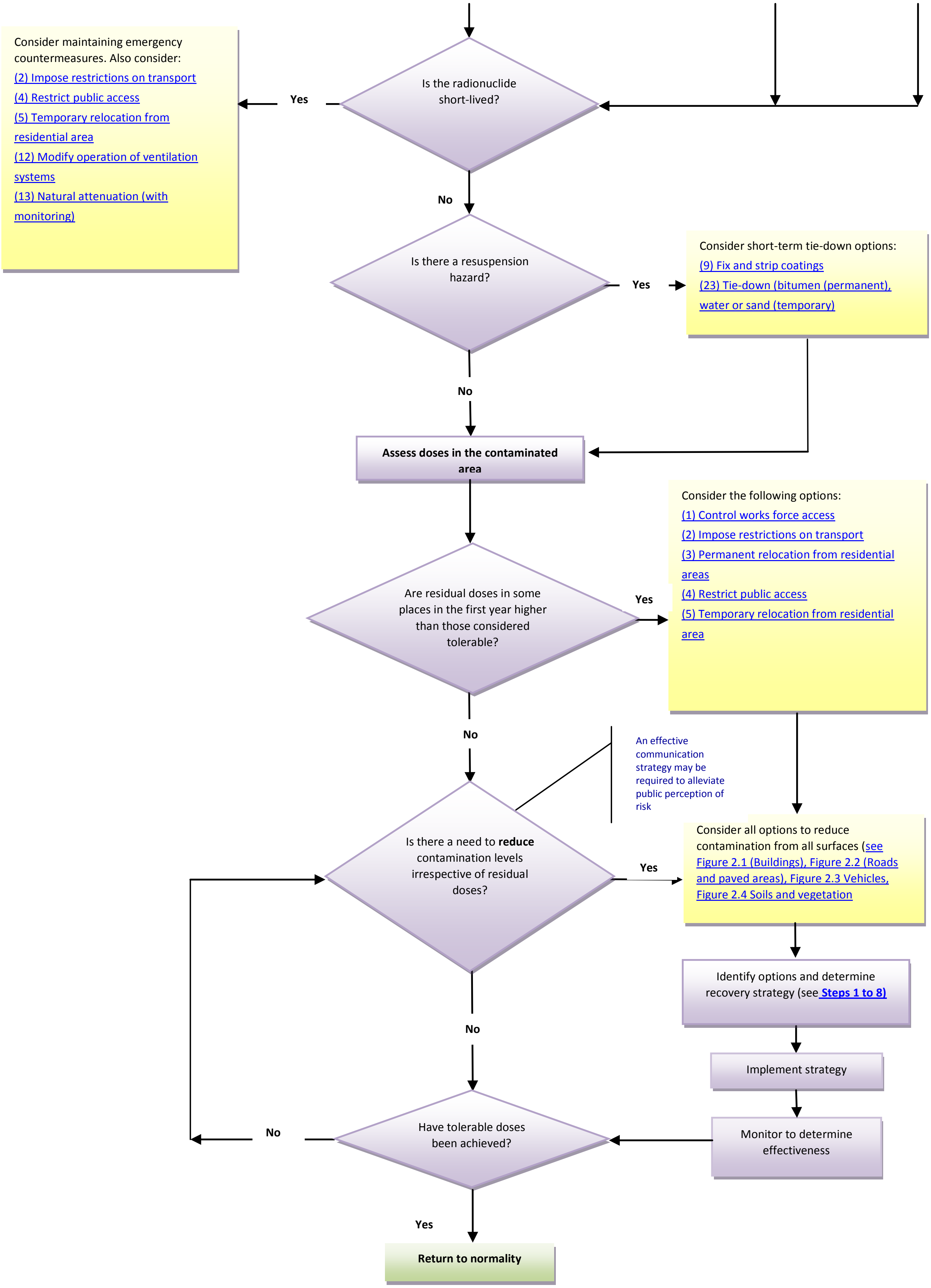
A decision tree to indicate the initial priorities for characterising the situation, requirements for monitoring and assessment of doses is presented in Figure 5.1. It illustrates the importance of restricting access until levels of contamination and doses have been estimated.

The handbook provides information on 29 management options (Section 7) to assist in recovery of buildings, roads and paved areas, soils, grass and plants, and trees and shrubs. The selection of individual options depends on a wide range of criteria (temporal and spatial distribution of the contamination, availability of equipment, effectiveness, economic cost, radiological and environmental impact, waste disposal, legislative issues and societal and ethical aspects, for example), which are discussed in Section 3. For any one accident scenario only a subset of options will be applicable according to the size and nature of the area(s) contaminated and the radiological composition of the deposit. Therefore, it will not be possible to devise a generic strategy and flexibility must be retained in the choice of options, in order to accommodate the actual circumstances of the accident.

The following section provides a series of tables to guide decision makers to the most appropriate subset of management options through elimination of inappropriate options. Some options may need to be applied concurrently, while others will be applied sequentially. Two worked examples are given in Section 6 on how to select and combine management options following contamination of an inhabited area with ^{137}Cs (example 1) and ^{239}Pu (example 2).

Figure 5.1 Decision tree for characterisation of the accident, requirement for monitoring and assessment of doses




Is the radionuclide short-lived?
Yes
Consider maintaining emergency countermeasures. Also consider:
(2) Impose restrictions on transport
(4) Restrict public access
(5) Temporary relocation from residential area
(12) Modify operation of ventilation systems
(13) Natural attenuation (with monitoring)
No
Is there a resuspension hazard?
Yes
Consider short-term tie-down options:
(9) Fix and strip coatings
(23) Tie-down (bitumen (permanent), water or sand (temporary)
No
Assess doses in the contaminated area
Are residual doses in some places in the first year higher than those considered tolerable?
Yes
Consider the following options:
(1) Control works force access
(2) Impose restrictions on transport
(3) Permanent relocation from residential areas
(4) Restrict public access
(5) Temporary relocation from residential area
No
An effective communication strategy may be required to alleviate public perception of risk
Is there a need to reduce contamination levels irrespective of residual doses?
Yes
Consider all options to reduce contamination from all surfaces (see Figure 2.1 (Buildings), Figure 2.2 (Roads and paved areas), Figure 2.3 Vehicles, Figure 2.4 Soils and vegetation
Identify options and determine recovery strategy (see Steps 1 to 8)
Implement strategy
Monitor to determine effectiveness
No
Have tolerable doses been achieved?
No
Yes
Return to normality

5.1 Key steps in selecting and combining options

There are 8 key steps involved in selecting and combining options. These steps are summarised in Table 5.1 and described in more detail below.

Step 1: Identify the surfaces that are likely to have been contaminated (ie buildings, roads and paved areas, soils, grass and plants, shrubs and trees)

Step 2: Refer to selection tables for specific surfaces (Table 5.2 **-** Table 5.7). These selection tables provide a list of all of the applicable management options for the surface selected. The tables indicate whether the management options are suitable for implementation in the early or medium-late phases. The tables also provide an indication of whether the management options are likely to be practicable taking into account potential technical, logistical, economic or social constraints. The constraints are listed in more detail for each option in a subsequent look-up table and in the individual datasheets in Section 3. The colour-coding classification used in the selection tables is intended to be a guide and would certainly require customisation at local or regional level by relevant stakeholders.

Step 3: Refer to look-up Table 5.8 and Table 5.9 showing applicability of management options for each radionuclide being considered. This allows various options listed in the selection tables to be eliminated if they are not suitable, based on the radiological hazard and half-life of the radionuclide(s).

Step 4: Refer to look-up Table 5.10 and Table 5.11 showing checklists of major and moderate constraints for each management option. These are constraints that would make implementation of an option very difficult if not impossible.

Step 5: Refer to look-up Table 5.12 showing the effectiveness of each management option in removing contamination from a surface or shielding people from contamination or reducing resuspension doses. This information may enable some of the least effective options to be eliminated, although management options are sometimes chosen for reasons other than radiological protection.

Step 6: Refer to look-up Table 5.13 showing which management options generate waste, including the type and quantities of waste produced. This information will not necessarily eliminate options but serves to warn the decision makers that selection of a particular option may have implications for waste disposal that requires further assessment.

Step 7: Refer to individual datasheets (Section 7) for all options remaining in the selection table and note the relevant constraints. It is likely that on a site specific basis, several more options will be eliminated from the selection tree as a result of additional constraints.

Step 8: Based on steps 1-7, select and combine options for managing each phase of the accident and returning the area to normality.

By following steps 1-8 it should be possible to devise a strategy, based on a combination of management options, which could be implemented following a release of radioactivity. These steps should be based on a participative approach with the stakeholders.

Table 5.1 Generic steps involved in selecting and combining options

Step	Action
1	Identify surfaces that are likely to be/have been contaminated
2	Refer to selection tables for specific surfaces (Table 5.2 - Table 5.7). These selection tables provide a list of all of the applicable management options for the surface selected
3	Refer to look-up tables Table 5.8 and Table 5.9 showing applicability of management options for each radionuclide being considered
4	Refer to look-up tables Table 5.10 and Table 5.11 showing a checklist of key constraints for each management option
5	Refer to look-up table Table 5.12 showing effectiveness of options
6	Refer to look-up table Table 5.13 showing type and amount of waste produced from implementation of management options
7	Refer to individual datasheets (Section 7) for all options remaining in the selection table and note the relevant constraints
8	Based on the outputs from Steps 1-7, select and combine options that should be considered as part of the recovery strategy

5.2 Selection tables

Selection tables are presented for the following surfaces:

- buildings: Table 5.2 (external surfaces), Table 5.3 (internal surfaces) and Table 5.4 (semi-enclosed surfaces)
- roads and paved areas (Table 5.5)
- vehicles (Table 5.6)
- soils and vegetation (Table 5.7)

These selection tables provide:

- a list of all of the applicable management options for the surface selected
- an indication of whether the management options are suitable for implementation in the first few days and weeks (classified here as the early phase) or months and years (classified here as or medium to long-term phase) after the incident
- an indication of whether the management options are likely to be practicable based on knowledge of potential technical, logistical, economic or social constraints. The colour-coding distinguishes between: options that would usually be justified or recommended having few if any constraints; options that would also be recommended but would require further analysis to overcome potential constraints; options that would have to undergo a full analysis and consultation with stakeholders before implementation because of serious economic or social constraints and options that would only be justified in specific circumstances following full analysis and consultation due to major technical or logistical constraints. The classification used in the selection tables is intended to be a guide and requires customisation at local or regional level by the relevant stakeholders. The numbers in brackets in Table 5.2 to Table 5.7 refer to the datasheet number

Go to greyscale table

Table 5.2 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Demolish/dismantle and dispose (8)		
Fix and strip coatings (9)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Roof cleaning including gutters and downpipes (17)		
Snow/ice removal (18)		
Surface removal (buildings) (20)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of walls with ammonium nitrate (25)		
Treatment of waste water (26)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 5.3 Selection table of management options for buildings - internal surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)	Amber	Dark red
Permanent relocation from residential areas (3)	Dark red	Dark red
Restrict public access (4)	Amber	Dark red
Temporary relocation from residential areas (5)	Amber	Dark red
Remediation		
Demolish/dismantle and dispose (8)	Dark red	Dark red
Fix and strip coatings (9)	Amber	Red
Modify operation/cleaning of ventilation systems (12)	Amber	Red
Natural attenuation (with monitoring) (13)	Amber	Dark red
Reactive liquids (16)	Amber	Red
Storage, covering, gentle cleaning of precious objects (19)	Green	Dark red
Surface removal (indoor) (21)	Amber	Amber
Treatment of waste water (26)	Amber	Amber
Vacuum cleaning (28)	Green	Green
Water based cleaning (29)	Green	Red

Key:

Green	Recommended with few constraints
Amber	Recommended but requires further evaluation to overcome some constraints
Dark red	Economic or social constraints exist, requiring full analysis and consultation period.
Red	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 5.4 Selection table of management options for buildings - semi enclosed surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Demolish/dismantle and dispose (8)		
Fix and strip coatings (9)		
Modify operation/cleaning of ventilation systems (12)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Storage, covering, gentle cleaning of precious objects (19)		
Surface removal (buildings) (20)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of waste water (26)		
Vacuum cleaning (28)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 5.5 Selection table of management options for roads and paved areas

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Impose restrictions on transport (2)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Fix and strip coatings (9)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Snow/ice removal (18)		
Surface removal and replacement (22)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of waste water (26)		
Vacuum cleaning (28)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 5.6 Selection table of management options for vehicles

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Impose restrictions on transport (2)	(amber)	(dark red)
Remediation		
Demolish/dismantle and dispose (8)	(dark red)	(red)
Fix and strip coatings (9)	(amber)	(red)
Natural attenuation (with monitoring) (13)	(amber)	(dark red)
Pressure and fire hosing (15)	(amber)	(red)
Reactive liquids (16)	(amber)	(red)
Snow/ice removal (18)	(amber)	(red)
Storage, covering, gentle cleaning of precious objects (19)	(green)	(dark red)
Treatment of waste water (26)	(amber)	(amber)
Vacuum cleaning (28)	(green)	(red)
Water based cleaning (29)	(green)	(red)

Key:

(green)	Recommended with few constraints
(amber)	Recommended but requires further evaluation to overcome some constraints
(dark red)	Economic or social constraints exist, requiring full analysis and consultation period
(red)	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 5.7 Selection table of management options for soils and vegetation

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Collection of leaves (6)		
Cover grass/soil with clean soil/asphalt (7)		
Grass cutting and removal (10)		
Manual and mechanical digging (11)		
Natural attenuation (with monitoring) (13)		
Ploughing methods (14)		
Snow/ice removal (18)		
Tie-down (23)		
Topsoil and turf removal (24)		
Tree and shrub pruning and removal (27)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

5.3 Applicability of management options for situations involving different radionuclides

Most of the practical information that is available on management options relates to radioactive isotopes of caesium following the Chernobyl and Fukushima Daiichi Nuclear power plant accidents in 1986 and 2011 respectively, and from other experimental work undertaken for radionuclides of potential significance following accidents at nuclear facilities, for example, strontium and plutonium. For many of the other radionuclides considered in the handbook there is lmited data to indicate whether a particular management option is effective or not. Nevertheless these radionuclides have certain characteristics in terms of their physical half-life, chemical properties and types of hazard posed to indicate whether an option should be considered.

In Table 5.8 and Table 5.9 an option is considered to be applicable if:

- there is direct evidence that it would be effective for a radionuclide (*known applicability*)

- the mechanism of action is such that it would be highly likely to be effective for a radionuclide (*probable applicability*)

The category of not applicable is attributed to an option if:

- there is direct evidence that it would not be effective for a radionuclide
- the chemical behaviour of the radionuclide is such that the option would not be expected to have any effect
- the hazard posed by the radionuclide would not be reduced by the management option (eg tie-down options for high energy gamma emitters)
- the physical half-life of the radionuclide is sufficiently short compared to the implementation time of the option to preclude its use (eg demolishing buildings would be unwarranted to address high levels of ^{131}I, which has a half-life of 8.04 days)

Table 5.8 Applicability of management options for radionuclides (Part 1)

Management options	Radionuclide										
	^{60}Co	^{75}Se	^{89}Sr	$^{90}Sr/^{90}Y$	^{95}Zr	$^{99}Mo/\ ^{99m}Tc$	^{103}Ru	^{106}Ru	^{132}Te	^{131}I	^{134}Cs
Radionuclide half-life	**5.27 y**	**119.8 d**	**50.5 d**	**29.12 y**	**63.98 d**	**66 h/6.02 h**	**39.28 d**	**368.2 d**	**78.2 h**	**8.04 d**	**2.06 y**
Restrict access											
Control workforce access (1)	b	✓	✓	b	✓	✓	✓	✓	✓	✓	b
Impose restrictions on transport (2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Permanent relocation from residential areas (3)	✓	a	a	✓	a	a	a	✓	a	a	✓
Restrict public access (4)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Temporary relocation from residential areas (5)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Remediation											
Collection of leaves (6)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Cover grass/soil with clean soil/asphalt (7)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Demolish/dismantle and dispose (8)	✓	a	a	✓	a	a	a	✓	a	a	✓
Fix and strip coatings (9)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Grass cutting and removal (10)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Manual and mechanical digging (11)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Modify operation/cleaning of ventilation systems (12)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Natural attenuation (with monitoring) (13)	✓	✓	e	e	✓	✓	✓	✓	✓	✓	✓
Ploughing methods (14)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Pressure and fire hosing (15)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Reactive liquids (16)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Roof cleaning including gutters and downpipes (17)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Snow/ice removal (18)	✓	✓	✓	✓	✓	a	✓	✓	a	✓	✓
Storage, covering, gentle cleaning of precious objects (19)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Surface removal (buildings) (20)	✓	✓	a	✓	✓	a	a	✓	a	a	✓
Surface removal (indoor) (21)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Surface removal and replacement (roads) (22)	✓	a	a	✓	a	a	a	✓	a	a	✓
Tie-down (23)	c	c	✓	✓	c	c	c	c	c	c	c
Topsoil and turf removal (24)	✓	✓	a	✓	a	a	a	✓	a	a	✓

Table 5.8 Applicability of management options for radionuclides (Part 1)

Management options	Radionuclide										
	^{60}Co	^{75}Se	^{89}Sr	^{90}Sr/^{90}Y	^{95}Zr	^{99}Mo/ ^{99m}Tc	^{103}Ru	^{106}Ru	^{132}Te	^{131}I	^{134}Cs
Radionuclide half-life	**5.27 y**	**119.8 d**	**50.5 d**	**29.12 y**	**63.98 d**	**66 h/6.02 h**	**39.28 d**	**368.2 d**	**78.2 h**	**8.04 d**	**2.06 y**
Treatment of walls with ammonium nitrate (25)	d	d	d	d	d	d	d	d	d	d	d
Treatment of waste water (26)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tree and shrub pruning and removal (27)	✓	✓	✓	✓	✓	a	✓	✓	a	a	✓
Vacuum cleaning (28)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Water based cleaning (29)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Key:

Half-life: h = hours, d = days, y = years

✓: Selected as target radionuclide (ie known or probable applicability, see Section 5.3)

a Comparatively short physical half-life of radionuclide relative to timescale of implementation of the management option

b Comparatively long physical half-life of radionuclide relative to timescale that the management option can be left in place

c This management option reduces doses from inhalation of resuspended material which is not an important pathway for this radionuclide (beta/gamma hazard)

d This management option is specific for radiocaesium

e No/low photon energy of radionuclide makes detection difficult

Table 5.9 Applicability of management options for radionuclides (Part 2)

Management options	Radionuclide ^{136}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{169}Yb	^{192}Ir	^{226}Ra	^{235}U	^{238}Pu	^{239}Pu	^{241}Am
Radionuclide half-life	**13.1 d**	**30 y**	**12.7 d**	**284.3 d**	**32 d**	**74 d**	**1.6 10^3 y**	**7.04 10^8 y**	**87.7 y**	**2.4 10^4 y**	**432.2 y**
Restrict access											
Control workforce access (1)	✓	b	✓	✓	✓	✓	b	b	b	b	b
Impose restrictions on transport (2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Permanent relocation from residential areas (3)	a	✓	a	a	a	a	✓	✓	✓	✓	✓
Restrict public access (4)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Temporary relocation from residential areas (5)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Remediation											
Collection of leaves (6)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Cover grass/soil with clean soil/asphalt (7)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Demolish/dismantle and dispose (8)	a	✓	a	a	a	a	✓	✓	✓	✓	✓
Fix and strip coatings (9)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Grass cutting and removal (10)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Manual and mechanical digging (11)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Modify operation/cleaning of ventilation systems (12)	a	✓	a	✓	a	✓	d	d	d	d	d
Natural attenuation (with monitoring) (13)	✓	✓	✓	✓	✓	✓	b	b,f	b,f	b,f	b,f
Ploughing methods (14)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Pressure and fire hosing (15)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Reactive liquids (16)	a	✓	a	✓	✓	✓	✓	✓	✓	✓	✓
Roof cleaning including gutters and downpipes (17)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Snow/ice removal (18)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Storage, covering, gentle cleaning of precious objects (19)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Surface removal (buildings) (20)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Surface removal (indoor) (21)	a	✓	a	✓	a	✓	✓	✓	✓	✓	✓
Surface removal and replacement (roads) (22)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Tie-down (23)	c	c	c	c	c	c	✓	✓	✓	✓	✓
Topsoil and turf removal (24)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓

Table 5.9 Applicability of management options for radionuclides (Part 2)

Management options	Radionuclide										
	^{136}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{169}Yb	^{192}Ir	^{226}Ra	^{235}U	^{238}Pu	^{239}Pu	^{241}Am
Radionuclide half-life	**13.1 d**	**30 y**	**12.7 d**	**284.3 d**	**32 d**	**74 d**	**1.6 10^3 y**	**7.04 10^8 y**	**87.7 y**	**2.4 10^4 y**	**432.2 y**
Treatment of walls with ammonium nitrate (25)	✓	✓	e	e	e	e	e	e	e	e	e
Treatment of waste water (26)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tree and shrub pruning and removal (27)	a	✓	a	✓	a	a	✓	✓	✓	✓	✓
Vacuum cleaning (28)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Water based cleaning (29)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Key:

Half-life: h = hours, d = days, y = years

✓: Selected as target radionuclide (ie known or probable applicability, see Section 5.3)

a Comparatively short physical half-life of radionuclide relative to timescale of implementation of the management option

b Comparatively long physical half-life of radionuclide relative to timescale that the management option can be left in place

c This management option reduces doses from inhalation of resuspended material which is not an important pathway for this radionuclide (beta/gamma hazard)

d This management option reduces doses from external irradiation which is not an important pathway for this radionuclide (alpha hazard)

e This management option is specific for radiocaesium

f No/low photon energy of radionuclide makes detection difficult

5.4 Checklist of key constraints for each management option

Management options invariably have constraints associated with their implementation. A detailed description of these constraints is provided in the datasheets for each option (Section 7). To assist in eliminating unsuitable options major and moderate constraints for each option are presented in Table 5.10, taking into account factors such as waste, societal needs, technical aspects, cost and timescales for implementation. The grey-scale colour coding in Table 5.11 is based on an evaluation of the evidence database and stakeholder feedback. The colour coding gives an indication of whether options have ‘none or minor’, ‘moderate’ or ‘major’ constraints associated with their implementation. The classification used is a generic guide and not radionuclide specific. If a major constraint is identified it does not indicate that the recovery option should necessarily be eliminated, although this may be done on a site and incident specific basis. These tables can be used in conjunction with the datasheets or beforehand to reduce the subset of options that require more in-depth analysis.

Table 5.10 Major and moderate constraints for management options

Managment options	Major (key) considerations	Moderate considerations for selected management options
Restrict access		
Control workforce access (1)	**Time:** this option should be implemented as soon as a contaminated area is identified with cordons and signage to prevent access. These measures will need to be in place until the doses have been assessed and management of the area agreed **Technical:** availability of system to monitor and control doses	**Social:** there may be issues with compliance; a guard may need to be appointed to prevent access
Impose restrictions on transport (2)	**Social:** there may be issues with compliance. Disruptions to normal travel, disruptions to transport which may delay emergency vehicles and people requiring the urgent use of vehicles may not be perceived well by the public. Effective communication will therefore be required to deliver information on access to emergency services vehicles - ambulance etc and possible alternative transport methods	**Technical:** for this measure to be implemented successfully road blocks need to be erected, combined with notices, signs and traffic cameras
Permanent relocation from residential areas (3)	**Social:** evacuation leading to permanent relocation is generally a very difficult and disturbing exercise to the community, Disruption can affect those being relocated, those within the receiving communities and those left behind. This measure should therefore not be undertaken unless clearly necessary ie significant contamination posing serious risk to health **Technical:** availability of new housing and infrastructure to support relocated populations	**Cost:** this measure can prove to be very expensive to local authorities responsible for relocating the residents from an affected area
Restrict public access (4)	**Time:** this option should be implemented as soon as a contaminated area is identified with cordons and signage to prevent access. These measures will need to be in place until the doses have been assessed and management of the area agreed	**Social:** effective communication is required to inform the public about the restriction and the potential health risks posed by the contaminant with the aim of ensuring compliance. Possible disruption and access to an area may not be well received by members of the public with pressure to reopen the area

Table 5.10 Major and moderate constraints for management options

Managment options	Major (key) considerations	Moderate considerations for selected management options
Temporary relocation from residential areas (5)	**Social:** temporary relocation can cause disruption to the community and have a large impact on businesses **Technical:** availability of alternative accommodation (hotels, bed and breakfast, self-catering, hostels etc) availability of transport. Transport availability needs to be considered to aid the relocation process, especially if the affected area has an elderly population or people with disabilities (population profile)	**Technical:** provision of leaflets. To minimise the social disruptions caused by relocation, certain measures should be taken to assist the process, for example leaflets consisting of important information for people being relocated need to be distributed (effective communication) monitoring strategy. An effective monitoring strategy needs to be implemented to determine the risk of adverse health effects to occupants upon return to the area **Cost:** this measure can prove to be expensive for local authorities responsible for relocating residents from an affected area. Cost is also influenced by the length of time residents will be temporarily relocated for, and the quality of the temporary housing offered (hotels vs. hostels) **Time:** the maximum period of time that temporary relocation could be tolerated would depend on a range of social and economic factors. For example, there might be increasing discontent with the temporary accommodation, possible related health problems or the need to establish settled social patterns. Therefore it is unlikely that the period of temporary relocation should be more than a year
Remediation		
Collection of leaves (6)	**Time:** must be carried out soon after leaf fall for deciduous trees. Repeated application for coniferous species	**Cost:** removal of leaf litter has been effective in forest areas, but this can have high economic costs.
Cover grass/soil with clean soil/asphalt (7)	**Social:** acceptability in gardens likely to be low **Technical:** complicates further options involving removal of contaminated soil the technique cannot be carried out in severe cold weather (frost and snow) can only be implemented on a small scale and even then very large quantities of soils are required	**Social:** this method may be negatively perceived by the public as the contamination remains in-situ, it may also cause adverse aesthetic effects including the loss of plants and shrubs. An effective communication strategy is therefore essential **Technical:** use in conservation areas/historic sites may be restricted not appropriate for stony soils or where there are steep slopes
Demolish/dismantle and dispose (8)	**Social:** demolishing homes and dismantling street furnishing or personal items will be disruptive to residents. Dust emissions from building demolition could be a nuisance to the public **Waste:** this option is likely to generate large amounts of contaminated material which will require disposal and/or storage under a waste transfer licence **Cost:** Likely to be high. Demolition and dismantling are highly labour intensive. Additionally the large amount of waste generated will be costly to dispose of appropriately	**Time:** the maximum benefit is achieved if this option is carried out soon after an incident when the maximum contamination is still on the contaminated material before it can be dispersed into the environment. very slow work rate **Technical:** may be restrictions on use on listed and historic buildings

Table 5.10 Major and moderate constraints for management options

Managment options	Major (key) considerations	Moderate considerations for selected management options
Fix and strip coatings (9)	**Technical:** technique may be affected by severe cold weather and wet weather	**Social:** residents of the contaminated area may be sceptical of the contamination remaining in-situ, fears are likely to arise concerning potential future exposure **Technical:** fixative coatings can be applied over a large area but strippable coatings are more suitable for smaller areas. Fixatives can complicate further options involving removal of surface. May be restrictions on use on listed and historic buildings
Grass cutting and removal (10)	**Technical:** not effective if there is heavy rain after deposition. Also cannot be carried out in severe cold weather (frost and snow). The technique requires grass mowers with collection boxes **Time:** needs to be implemented quickly and before rain	**Technical:** not appropriate for stony soils or where there are steep slopes
Manual and mechanical digging (11)	**Technical:** complicates further options involving removal of contaminated soil the technique cannot be carried out in severe cold weather (frost and snow) area must not have been tilled since deposition and afterwards, the area must not be re-dug can only be implemented on a small scale	**Technical:** use in conservation areas/historic sites may be restricted very slow work rate tie-down may be needed to suppress resuspension of contamination in dust **Social:** this method may be negatively perceived by the public as the contamination remains in-situ
Modify operation/cleaning of ventilation systems (12)	None	**Technical:** it may be difficult for workers to access ventilation systems to clean them effectively **Time:** the maximum benefit is achieved if this option is carried out shortly after a contamination as it can have a significant effect on reducing the spread of contamination
Natural attenuation (with monitoring) (13)	**Technical:** monitoring equipment and skilled personnel are required to take measurements and samples it may take a prolonged period of time for the radionuclides to undergo radioactive decay and weathering from surfaces may be more feasible for rural areas rarely used, than in a commercial district of a large city	**Social:** this option may be perceived as doing ‘nothing’ by the public which may have negative implications **Cost:** may be high**,** considering, monitoring equipment, consumables, skilled personnel (including laboratory analysis) and time (natural attenuation can take months-years)

Table 5.10 Major and moderate constraints for management options

Managment options	Major (key) considerations	Moderate considerations for selected management options
Ploughing methods (14)	**Technical:** the technique cannot be carried out in severe cold weather (frost and snow) a soil depth > 0.3 m is required for normal shallow ploughing or > 0.5 m for deep ploughing and skim and burial can only be implemented in large areas where deep ploughing or skim and burial are considered, they must be implemented before normal ploughing has been undertaken	**Technical:** use in conservation areas/historic sites may be restricted complicates further options involving removal of contaminated soil. In some cases, the contamination is moved closer to the groundwater tie-down may be needed to suppress resuspension of contamination in dust ploughing may result in soil erosion **Social:** this method may be negatively perceived by the public as the contamination remains in-situ, it may also cause adverse aesthetic effects including the loss of plants and shrubs. An effective communication strategy is therefore essential
Pressure and fire hosing (15)	**Waste:** pressure washers may produce large volumes of effluent and waste water. To prevent run off on to other sensitive surfaces such as soil and ground water, the effluent needs to be effectively collected and may require disposal and/ or storage under a waste transfer licence **Technical:** walls and roofs must be resistant to water at high pressure. The technique cannot be carried out in severe cold weather **Time:** needs to be implemented quickly and preferably before rain	**Technical:** the effectiveness of this option depends on the nature of the surface in question, for example the type, evenness and condition of the surface use on listed and historic building may be restricted the height of the buildings also needs to be considered eg high rise blocks may limit the effectiveness
Reactive liquids (16)	None	**Waste:** depends on which liquid is used; waste products in various forms can be generated which may require disposal and/ or storage under a waste transfer licence. **Technical:** surfaces must be resistant to the reactive liquid use on listed and historic building may be restricted **Time:** needs to be implemented soon after an incident as weathering processes may disperse the contaminant from the surface of the affected area into the environment
Roof cleaning including gutters and downpipes (17)	**Technical:** roof construction must resist water at high pressure. The technique cannot be carried out in severe cold weather	**Technical:** very slow work rate use on listed and historic building may be restricted
Snow/ice removal (18)	**Time:** maximum benefit is achieved if carried out soon after contamination. This method must be carried out before the first thaw following the contamination to (a) prevent the contaminants from reaching the underlying ground surface; and (b) to prevent human activity from compressing the snow thus making it more difficult toremove	**Waste:** depending on the thickness of the ice and the size of the area, this method could potentially generate large quantities of contaminated snow and resulting melt-water which will require appropriate disposal

Table 5.10 Major and moderate constraints for management options

Managment options	Major (key) considerations	Moderate considerations for selected management options
Storage, covering, gentle cleaning of precious objects (19)	None	**Technical:** use on small areas only **Social:** people may be anxious about cleaning methods causing damage to their belongings. Potential damage or personal possessions or significant objects
Surface removal (buildings) (20)	**Waste:** this option is likely to produce significant quantities of contaminated surface material. The solid phase may be disposed of at a hazardous waste landfill but this can be influenced by the chemicals involved	**Technical:** effectiveness depends on the surface in question eg ease of removal, thickness of the surfaces and the scale. Also, its use in listed and historic buildings
Surface removal (indoor) (21)	None	**Technical:** use in listed and historic buildings **Social:** ownership and access to property
Surface removal and replacement (roads) (22)	**Waste:** large quantities of contaminated tarmac/concrete will be produced, which will require disposal and/or storage under a waste transfer licence	**Technical:** uneven surface and road camber can make surface removal difficult. Some form of tie-down may be needed to suppress resuspension of contaminated dust **Social:** there may be disruptions to access routes due to damage to roads or pavements. This method may also cause aesthetic issues **Time:** the maximum benefit is achieved if this option is carried out soon after an incident when the maximum contamination is still on the surface, before it can be dispersed into the environment
Tie-down (23)	**Technical:** technique may be affected by severe cold weather and wet weather	**Social:** residents of the contaminated area may be sceptical of the contamination remaining in-situ, fears are likely to arise concerning potential future exposure **Technical:** fixatives can complicate further options involving removal of surface. May be restrictions on use on listed and historic buildings. May need repeating to remain integrity of covering
Topsoil and turf removal (24)	**Waste:** large quantities of contaminated soil/vegetation will be produced, which will require disposal and/or storage under a waste transfer licence **Technical:** slow work rate if carried out manually can only be implemented on a small scale the technique cannot be carried out in severe cold weather (frost and snow). It is also not appropriate for stony soils	**Technical:** some form of tie-down may be needed to suppress resuspension of contaminated dust. Use in conservation areas/historic sites may be restricted **Social:** may cause damage to habitats and biodiversity. May also cause soil erosion
Treatment of walls with ammonium nitrate (25)	**Time:** needs to be implemented quickly and preferably before rain **Technical:** walls must be water resistant the technique cannot be carried out in severe cold weather	**Technical:** very slow work rate use on listed and historic building may be restricted

Table 5.10 Major and moderate constraints for management options

Managment options	Major (key) considerations	Moderate considerations for selected management options
Treatment of waste water (26)	**Technical:** availability of ion exchange resins and other media for removing radionuclides from waste water	**Waste:** activity concentrations of target radionuclides will be elevated in the resins and require careful handling and disposal
Tree and shrub pruning and removal (27)	**Technical:** dependent on time of year. Only if leaves on plants and shrubs needs to be implemented quickly and before rain	**Technical:** use in conservation areas/historic sites may be restricted severe cold weather (frost or snow)
Vacuum cleaning (28)	None	**Waste:** potential for large amounts of dust contaminated filters which may have high contamination levels being generated. This waste may require disposal and/or storage under a waste transfer licence **Technical:** the nature and condition of the surface in question can determine the effectiveness of this measure. Also, its use in listed and historic buildings and on precious furniture/ objects **Time:** maximum effectiveness is achieved soon after an incident when the maximum contamination is on surfaces. However, over longer periods, contamination may be brought into buildings eg on the soles of shoes, and so repeated application regularly may be beneficial until any surrounding soil or grass areas are cleaned
Water based cleaning (29)	**Waste:** produces water based wash solutions that are likely to be contaminated which may require disposal and/ or storage under a waste transfer licence	**Technical:** surfaces must be robust and resistant to intensive cleaning. Use on listed and historic buildings and precious objects may be restricted **Time:** needs to be implemented soon after an incident as weathering processes may disperse the contaminant from the surface of the affected area into the environment

Table 5.11 Overview of key constraints for management options *greyscale colour coding is based on evaluation of evidence base and stakeholder input

Management option	Waste	Social	Technical	Cost	Time
Restrict access					
Control workforce access (1)		▒	■		■
Impose restrictions on transport (2)		■	▒		
Permanent relocation from residential areas (3)		■	■	▒	
Restrict public access (4)		▒			■
Temporary relocation from residential areas (5)		■	■	▒	▒
Remediation					
Collection of leaves (6)				▒	■
Cover grass/soil with clean soil/asphalt (7)		■	■		
Demolish/dismantle and dispose (8)	■	■	▒	■	▒
Fix and strip coatings (9)		▒	■		
Grass cutting and removal (10)			■		■
Manual and mechanical digging (11)		▒	■		
Modify operation/cleaning of ventilation systems (12)			▒		▒
Natural attenuation (with monitoring) (13)		▒	■	▒	
Ploughing methods (14)		▒	■		
Pressure and fire hosing (15)	■		■		■
Reactive liquids (16)	▒		▒		▒
Roof cleaning including gutters and downpipes (17)			■		
Snow/ice removal (18)	▒				■
Storage, covering, gentle cleaning of precious objects (19)		▒	▒		
Surface removal (buildings) (20)	■		▒		
Surface removal (indoor) (21)		▒	▒		
Surface removal and replacement (roads) (22)	■	▒	▒		▒
Tie-down (23)		▒	■		
Topsoil and turf removal (24)	■	▒	■		
Treatment of walls with ammonium nitrate (25)			■		■
Treatment of waste water (26)	▒		■		
Tree and shrub pruning and removal (27)			■		
Vacuum cleaning (28)	▒		▒		▒
Water based cleaning (29)	■		▒		▒

Considerations/ constraints	None or minor	Moderate ▒	Important (major) ■
Time - when to implement recovery option	No restrictions on time	Weeks to months/years	Hours to days

5.5 Effectiveness of management options

The primary aim of management options in inhabited areas is to reduce doses from external irradiation from deposited radionuclides and inhalation from resuspension of contaminated material.

Management options are directed at shielding people from contamination, fixing the contamination so that it cannot be resuspended and inhaled, or removing the contamination so that exposure is reduced, providing waste is disposed of properly. Effectiveness of management options, in terms of the reduction in contamination people are exposed to, is expressed in different ways according to the purpose for which it is implemented:

- the effectiveness of shielding is expressed as the percentage reduction in external dose rate from a surface following implementation of the option
- the effectiveness of fixing is expressed as the percentage reduction in inhalation dose rate from a surface following implementation of the option
- the effectiveness of removal is expressed as a decontamination factor (DF), which is the ratio of the amount of contamination initially present on a specific surface to that following implementation of the option

The overall impact of the management option on the doses received by an individual living in an inhabited area depends on the contributions from contamination on each surface and the time people spend close to these surfaces (see Section 1.13).

Table 5.12 summarises the effectiveness of each management option considered in the handbook. The dose reductions presented in the table are illustrative and should only be used to scope the level of reduction that is likely to be achieved. The dose reductions achieved will be dependent on the specific situation, habits of the population and the effectiveness of the management option. Dose reductions are given following initial deposition under dry and wet conditions in the first year following deposition. Further details can be found in the datasheets. Doses are for a typical inhabited area comprising a variety of housing types and surrounding land. In this hypothetical inhabited area, all surfaces are present and the amounts of these surfaces have been estimated. The reductions in external dose given in the datasheets assume that a person spends all of their time in this environment, of which 90% is spent indoors. The reductions in dose are estimated taking into account the contribution of the dose over time from all the surfaces in the environment and any reduction in the contamination levels on a surface due to cleaning removal or mixing. ^{137}Cs is illustrative of a long-lived beta/gamma emitter, where external gamma doses dominate and resuspension doses are not significant; ^{239}Pu is illustrative of a long-lived alpha emitter where resuspension doses dominate and external doses are insignificant.

Table 5.12 Effectiveness of management options in reducing doses

Management option	Mode of action	Principal exposure pathway	Effectiveness	Comments
Restrict access				
Control workforce access (1)	Shielding	External gamma External beta Resuspension	See comments	Effective in controlling doses to an essential workforce as long as people comply and controls are enforced. This option does not reduce contamination levels in the environment. Particularly useful for short-lived radionuclides.
Impose restrictions on transport (2)		Resuspension	See comments	This option will not reduce contamination levels, although it may prevent resuspension of radionuclides
Permanent relocation from residential areas (3)	Shielding	External gamma External beta Resuspension	Up to 100% reduction in dose	It does not reduce contamination levels in the environment. However, if people comply, this option is fully effective at removing doses during the period of relocation.
Restrict public access (4)	Shielding	External gamma External beta Resuspension	Up to 100% reduction in dose (all pathways) from areas where access is prohibited	Particularly useful for short-lived radionuclides. Effectiveness depends on individuals complying. It does not reduce contamination levels in the environment
Temporary relocation from residential areas (5)	Shielding	External gamma External beta Resuspension	Up to 100% reduction in dose (all pathways) while individual is away from affected area	Particularly useful for short-lived radionuclides. It does not reduce contamination levels in the environment. However, if people comply, this option is fully effective at removing doses during the period of relocation.
Remediation				
Collection of leaves (6)	Removal	External gamma External beta Resuspension	DF of up to 50 for reduction in contamination. External dose rates in surrounding areas may reduce by up to 90%, with an average reduction of 30% seen in Japanese tests removing leaf litter/ground cover.	Most contamination on trees and shrubs is associated with the leaves. So, the decontamination factor (DF) is likely to be similar to that for tree removal if leaves are on the trees at the time of deposition and all the leaves are collected. This option will be less effective for coniferous trees, even if collection is repeated several times. Reductions in external gamma dose could be expected to be similar to those given for tree removal if the trees were predominantly deciduous.

Table 5.12 Effectiveness of management options in reducing doses

Management option	Mode of action	Principal exposure pathway	Effectiveness	Comments
Cover grass/soil with clean soil/asphalt (7)	Shielding	External gamma External beta Resuspension	100% for external beta dose rates above the surface. 30-80% reductions in external gamma dose rate above the surface depending on radionuclide Resuspended concentrations in air above the surface will be reduced by up to 100%	While the clean layer remains undisturbed, the external gamma dose rate above the surface will also be reduced by a factor which is dependent on the energy of the gamma rays emitted and the depth of the clean soil layer used. Reductions in external gamma dose received by an individual living in the area will be very dependent on the amount of the soil and grass area that is covered with clean soil. Likely to only be used for small areas or locations that are particularly sensitive, eg schools.
Demolish/dismantle and dispose (8)	Removal	External gamma External beta	All contamination is removed if all debris is removed and contamination is not spread during demolition.	100% reduction in doses from buildings after demolition may enable resettlement of the area in the future.
Fix and strip coatings (9)	Removal, fixing	External gamma External beta Resuspension	DF of around 1.5 achieved in decontamination work following the Fukushima accident in Japan. DF of up to 5 may be achieved if implemented within a few weeks. While the peelable coating is in place, resuspended activity in air will be reduced by almost 100%.	This option is likely to be most effective when used on smooth surfaces. Later application is likely to give a lower DF, particularly on porous building materials such as bricks and tiles.
Grass cutting and removal (10)	Removal	External gamma External beta Resuspension	Decontamination factor (DF) of 3 following dry deposition and DF of 1.3 following wet deposition can be achieved if this option is implemented within one week of deposition and before significant rain occurs.	Effectiveness is significantly reduced after rain has occurred or if grass has been already cut post deposition.

Table 5.12 Effectiveness of management options in reducing doses

Management option	Mode of action	Principal exposure pathway	Effectiveness	Comments
Manual and mechanical digging (11)	Shielding	External gamma External beta Resuspension	External gamma and beta dose rates above the surface are likely to be reduced by up to 80% in the short-medium term for manual digging and 50-65% for mechanical digging. Resuspended concentrations in air above the surface will be reduced by 90 to 95%	Effectiveness depends on the success of mixing within the soil. Dose rate reductions are likely to be higher for manual digging than for mechanical digging since rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth.
Modify operation/cleaning of ventilation systems (12)	Removal	External gamma External beta	DF 5-30 for high pressure hosing. DF 5-10 for vacuum brushing	
Natural attenuation (with monitoring) (13)	Protection	External gamma External beta Resuspension	See comments	Effectiveness depends on physical half-life of the radionuclide as well as its ecological half-life
Ploughing methods (14)	Shielding	External gamma External beta Resuspension	External gamma dose rates above the surface will be reduced by: 50-80% for shallow ploughing 80-90% for skim and burial and deep ploughing for medium to high energy gamma emitters. Resuspended concentrations in air above the surface will be reduced by 90 - 95% Skim and burial ploughing with give up to 100% reduction for external beta doses	The reductions in external gamma dose rate will depend on the radionuclides involved, the ploughing depth and the soil contamination profile with depth at the time of implementation. Beta dose rate reduction is likely to be significantly higher than the values given for gamma dose rates if the technique is implemented. By effectively burying most of the contamination, resuspended activity in air above the surface will be reduced by a factor significantly larger than the external gamma dose rate reduction

Table 5.12 Effectiveness of management options in reducing doses

Management option	Mode of action	Principal exposure pathway	Effectiveness	Comments
Pressure and fire hosing (15)	Removal	External gamma External beta	Buildings: DF of 1.3 can be achieved by fire hosing if implemented within 1 week of deposition and before significant rain. High pressure hosing gives greater effectiveness (1.5-5) than fire hosing. Roads and paved areas: DF of 2-5 for fire hosing and 3-7 for high pressure hosing if implemented within one week of deposition and there has been no significant rain.	Repeated application is unlikely to provide any significant increase in DF. A higher DF can be achieved following dry deposition rather than wet deposition.
Reactive liquids (16)	Removal	External gamma External beta	For metal surfaces: DF 2-10 (soft techniques) and DF >10 for hard techniques For plastic and coated surfaces: DF 10-100	The effectiveness depends on the reactive liquid used, the radionuclide and the surface that is being decontaminated
Roof cleaning including gutters and downpipes (17)	Removal	External gamma	DF of 2-7 could be achieved if implemented soon after deposition (DF of 2-4 after 10 years).	Repeated application is unlikely to provide any significant increase in DF. If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
Snow/ice removal (18)	Removal	External gamma External beta	DF of 10 - 30 if implemented prior to snow melt and as long as snow is removed to a depth to include contamination	Resuspension from a snow-covered surface will be generally low.
Storage, covering, gentle cleaning of precious objects (19)	Shielding, removal	External gamma External beta Resuspension	100 - 200 mm of concrete or brick and 10mm of lead will typically give a reduction in gamma dose rate of a factor of 2. 1 - 5 mm of glass will prevent external beta dose rates.	Effectiveness depends on the radionuclides present and the thickness of the shielding material. A gamma emitter will need a greater thickness of shielding material than a low energy beta emitter.

Table 5.12 Effectiveness of management options in reducing doses

Management option	Mode of action	Principal exposure pathway	Effectiveness	Comments
Surface removal (buildings) (20)	Removal	External gamma External beta Resuspension	DF of 4 - 10 could be achieved if implemented soon after deposition (will decrease with time).	Repeated application is unlikely to provide any significant increase in DF.
Surface removal (indoor) (21)	Removal	External gamma External beta Resuspension	If carried out carefully, virtually all the contamination on the surface may be removed.	The process of removing paper, paint or plaster may result in the spread of contamination on to other surfaces via dust, reducing the effectiveness.
Surface removal and replacement (roads) (22)	Removal	External gamma External beta Resuspension	Decontamination work in Japan stripping the surface or shot blasting asphalt pavements and roads gave DFs between 2 and 20.	Repeated application is unlikely to provide any significant increase in DF.
Tie-down (23)	Fixing, shielding (low energy beta emitters)	Resuspension External beta	Up to 100% reduction in resuspension dose from surface while integrity of covering is maintained. Reductions in external beta dose rates above roads and paved surfaces: 90% for sand, 70% for bitumen and 45% for water. Small reductions in external beta dose rates above soil surfaces could be expected.	This option may be effective at reducing external beta dose rates above the surface (for low energy beta emissions) while the tie-down remains intact, but is not effective at reducing external gamma dose rates. Sand (2 mm) would be the most effective at reducing beta dose rates, typical thicknesses of bitumen (1 mm) and water (1 mm) will give less protection. Applying water to soil surfaces will aid the bonding of activity to soil particles and can wash contamination below the surface, both of which will reduce resuspension in the longer term.
Topsoil and turf removal (24)	Removal	External gamma External beta Resuspension	DF of 10 - 30 can be achieved if implemented within a few years of deposition. Experience in Japan following the Fukushima accident gave DFs of 2 -20, with indications that the DF could potentially be much higher if soil is replaced.	The removal depth needs to be chosen to ensure maximum removal of contamination in order to achieve maximum effectiveness. If a standard removal depth is used, the effectiveness will reduce in time after this as contamination migrates to deeper soil depths.
Treatment of walls with ammonium nitrate (25)	Removal	External gamma from radioacesium	DF of 1.5-2 could be achieved if implemented soon after deposition (DF of 1.5 could be expected up to a few years)	Repeated application is unlikely to provide any significant increase in DF.

Table 5.12 Effectiveness of management options in reducing doses

Management option	Mode of action	Principal exposure pathway	Effectiveness	Comments
Treatment of waste water (26)	Removal	External gamma External beta	Removal efficiencies are mostly in the range 40-70%	
Tree and shrub pruning and removal (27)	Removal	External gamma External beta Resuspension	For pruning, a DF of 2-10 can be achieved if implemented within one week of deposition and before significant rain occurs. If a whole tree is felled, and all the leaves are collected, a DF up to 50 could be achieved.	The reduction in contamination is proportional to the fraction of the tree/shrub removed. Effectiveness is significantly reduced after rain has occurred. Pruning is only effective before foliage dies back in autumn/winter.
Vacuum cleaning (28)	Removal	External gamma External beta Resuspension	Indoors: DF of 5-10 achievable assuming that this option is implemented within a few weeks of deposition and no previous cleaning has taken place. Roads and paved areas: DF of 2-3 if implemented within one week of deposition and before rain.	Repeated application is unlikely to provide any significant increase in DF.
Water based cleaning (29)	Removal	External gamma External beta Resuspension	DF up to 10 assuming that this option is implemented within a few weeks of deposition and no previous cleaning has taken place.	The highest DFs can be expected from cleaning smooth surfaces (ie wood, tiles, linoleum, glass and painted surfaces). Lower DFs are likely for cleaning rough surfaces (concrete, stone, brick, and for carpets, rugs, tapestries, upholstery, bedding and soft furnishings.

5.6 Quantities and types of waste produced from implementation of management options

One important criterion to consider when assessing the practicability of a management option is whether it generates waste. Shielding options have an advantage in that they do not usually produce any waste because the contamination is left in situ. Removal options will generate contaminated waste material (liquid and/or solid) which will require management (eg storage or disposal). Table 5.13 presents information on the quantities and types of waste produced for each management option considered in the handbook. All values are for illustrative purposes to enable the impact of the implementation of the various options to be scoped and a comparison across options to be made. No collection of waste and segregation is assumed unless stated. If waste materials can be segregated into contaminated and exempt waste, quantities of contaminated waste will be much smaller. For example, water can be collected, filtered and re-used.

Table 5.13 Quantities and types of waste produced by the management options

Management option	Waste arising kg m^{-2} unless otherwise stated	Type of waste material produced
Restrict access		
Control workforce access (1)	None	
Impose restrictions on transport (2)	None	
Permanent relocation from residential areas (3)	None	
Restrict public access (4)	None	
Temporary relocation from residential areas (5)	None	
Remediation		
Collection of leaves (6)	$5\ 10^{-1}$	Leaves, pine needles and pinecones
Cover grass/soil with clean soil/asphalt (7)	None	
Demolish/dismantle and dispose (8)	$7\ 10^{1}$	Rubble
	$2\ 10^{1}$ - $5\ 10^{1}$	Roofing material
	$2\ 10^{1}$ - $3\ 10^{1}$	Flooring
	$5\ 10^{1}$	Fixtures
Fix and strip coatings (9)	1	Rubber-like material
Grass cutting and removal (10)	< $1\ 10^{-3}$ amount depends on height and density of grass	Grass
Manual and mechanical digging (11)	None	
Modify operation/cleaning of ventilation systems (12)	$5\ 10^{-2}$ - $1\ 10^{-1}$	Solid waste (dry from filters, wet sludge from pressure washing)
Natural attenuation (with monitoring) (13)	None	
Ploughing methods (14)	None	
Pressure and fire hosing (15)	$1\ 10^{-1}$ - $2\ 10^{-1}$ (fire hosing) $2\ 10^{-1}$ - $4\ 10^{-1}$ (high pressure)	Dust
	$5\ 10^{1}$ litres m^{-2}(fire hosing)	Water
	$2\ 10^{1}$ litres m^{-2}(high pressure)	

Table 5.13 Quantities and types of waste produced by the management options

Management option	Waste arising kg m^{-2} unless otherwise stated	Type of waste material produced
Reactive liquids (16)	Variable	Various
Roof cleaning including gutters and downpipes (17)	$2\ 10^{-1}$ - $6\ 10^{-1}$	Dust and moss
	$1.5\ 10^{1}$ - $3\ 10^{1}$ litres m^{-2}	Water
Snow/ice removal (18)	$5\ 10^{-1}$ (5 cm depth removed)	Snow
Storage, covering, gentle cleaning of precious objects (19)	Small quantities	Water from cleaning
Surface removal (buildings) (20)	3	Dust and sand
	$5\ 10^{1}$ litres m^{-2}	Water
Surface removal (indoor) (21)	$4\ 10^{-1}$	Carpet
	$1\ 10^{-1}$	Plaster
	1	Paint, wallpaper
	4	Linoleum
	7	Wood
Surface removal and replacement (roads) (22)	$1.5\ 10^{1}$ (per cm depth removed)	Asphalt
	$3\ 10^{1}$ (per cm depth removed)	Paving slabs, concrete
Tie-down (23)	$3\ 10^{-1}$ litres m^{-2}	Water and dust
	1 - 2	Sand and dust
	No waste	Bitumen (permanent)
	$4\ 10^{-1}$	Paint
Topsoil and turf removal (24)	$6\ 10^{1}$ - $7\ 10^{1}$ (5 cm depth removed)	Soil and turf
Treatment of walls with ammonium nitrate (25)	6 litres m^{-2}	Liquid waste
Treatment of waste water (26)	Information not available	Zeolite blocks/resins
Tree and shrub pruning and removal (27)	1 - $2\ 10^{1}$ (fresh mass)	Vegetation, shrubby material and wood
Vacuum cleaning (28)	$5\ 10^{-3}$ (buildings) 40 g m^{-2} (buildings) $1\ 10^{-1}$ - $2\ 10^{-1}$ (roads/paved)	Dust Filters Dust and sludge
Water based cleaning (29)	$1\ 10^{-3}$ - 1.3	Dust, water, detergent, filters

5.7 Comparing the remaining management options

Once options have been eliminated from the selection tables, if appropriate, the next step is to identify all the remaining options that could be considered for the type of surface affected. These options need to be evaluated on a site specific basis using detailed information provided in the datasheets (Section 7). The Recovery Navigation Tool and Recovery Record Form may be used to help with this, and to generate a record of the management options being considered, together with a record of decisions about why other management options are eliminated. Software tools such as ERMIN (Charnock, 2010; Charnock et al, 2009) may help to evaluate some of the consequences of implementing management options. In terms, for example, of dose reductions, resources necessary, costs and amounts of waste generated, which may help to identify options that are not worth pursuing.

5.8 Greyscale tables

Go to colour

Table 5.2 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Demolish/dismantle and dispose (8)		
Fix and strip coatings (9)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Roof cleaning including gutters and downpipes (17)		
Snow/ice removal (18)		
Surface removal (buildings) (20)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of walls with ammonium nitrate (25)		
Treatment of waste water (26)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 5.3

Table 5.3 Selection table of management options for buildings - internal surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Demolish/dismantle and dispose (8)		
Fix and strip coatings (9)		
Modify operation/cleaning of ventilation systems (12)		
Natural attenuation (with monitoring) (13)		
Reactive liquids (16)		
Storage, covering, gentle cleaning of precious objects (19)		
Surface removal (indoor) (21)		
Treatment of waste water (26)		
Vacuum cleaning (28)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 5.4

Table 5.4 Selection table of management options for buildings - semi enclosed surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Demolish/dismantle and dispose (8)		
Fix and strip coatings (9)		
Modify operation/cleaning of ventilation systems (12)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Storage, covering, gentle cleaning of precious objects (19)		
Surface removal (buildings) (20)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of waste water (26)		
Vacuum cleaning (28)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 5.5

Table 5.5 Selection table of management options for roads and paved areas

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Impose restrictions on transport (2)		
Permanent relocation from residential areas (3)		
Restrict public access (4)		
Temporary relocation from residential areas (5)		
Remediation		
Fix and strip coatings (9)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Snow/ice removal (18)		
Surface removal and replacement (22)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of waste water (26)		
Vacuum cleaning (28)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 5.6

Table 5.6 Selection table of management options for vehicles

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Impose restrictions on transport (2)		
Remediation		
Demolish/dismantle and dispose (8)		
Fix and strip coatings (9)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Snow/ice removal (18)		
Storage, covering, gentle cleaning of precious objects (19)		
Treatment of waste water (26)		
Vacuum cleaning (28)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 5.7

Table 5.7 Selection table of management options for soils and vegetation

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)	[light grey]	[hatched]
Permanent relocation from residential areas (3)	[hatched]	[hatched]
Restrict public access (4)	[light grey]	[hatched]
Temporary relocation from residential areas (5)	[light grey]	[hatched]
Remediation		
Collection of leaves (6)	[white]	[white]
Cover grass/soil with clean soil/asphalt (7)	[light grey]	[hatched]
Grass cutting and removal (10)	[white]	[black]
Manual and mechanical digging (11)	[light grey]	[light grey]
Natural attenuation (with monitoring) (13)	[light grey]	[hatched]
Ploughing methods (14)	[white]	[white]
Snow/ice removal (18)	[light grey]	[black]
Tie-down (23)	[hatched]	[hatched]
Topsoil and turf removal (24)	[black]	[hatched]
Tree and shrub pruning and removal (27)	[light grey]	[black]

Key:

[white]	Recommended with few constraints
[light grey]	Recommended but requires further evaluation to overcome some constraints
[hatched]	Economic or social constraints exist, requiring full analysis and consultation period.
[black]	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

5.9 References

Charnock TW (2010). The European model for inhabited areas (ERMIN) - developing a description of the urban environment. *Radioprotection* **45**(5).

Charnock TW, Jones JA, Singer LN, Andersson KG, Roed J, Thykier-Nielsen S, Mikkelsen T, Astrup P, Kaiser JC, Müller H, Pröhl G, Raskob W, Hoe SC, Jacobsen LH, Schou-Jensen L and Gering F (2009). Calculating the consequences of recovery, a European Model for Inhabited Areas. Proceedings International Conference of Radioecology and Environmental Radioactivity, Bergen, Norway.

6 Worked Examples

The following worked examples have been developed to help users become familiar with the content of the handbook and its structure. They are also useful for training purposes. It should be emphasised however that the scenarios used are only illustrative and have been included solely to support training in the use of the handbook. The worked examples should not be used as proposed solutions to the contamination scenarios selected.

Two scenarios have been developed:

- a major accident at a nuclear power plant involving the release of ^{137}Cs;
- a small scale radiation emergency involving the dispersion of ^{239}Pu.

6.1 Example 1 - a major accident at a nuclear power plant involving the release of ^{137}Cs

Scenario

- a large nuclear reactor accident on 1 June at a power plant close to a city
- atmospheric release of radioactive material
- rain as the contaminated plume passes overhead, leading to wet deposition of contaminants

Current situation

- the release is over
- the contaminated plume has passed
- contamination levels have not yet been determined
- the population has not been evacuated from the city and is still sheltering

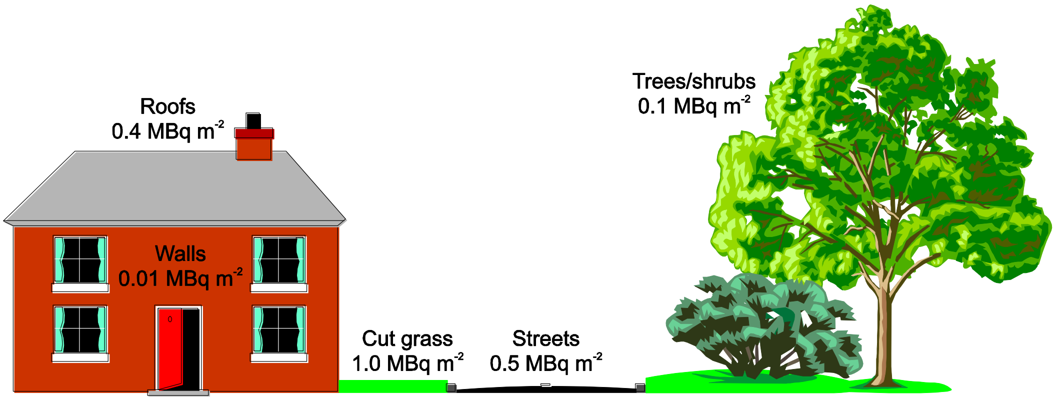
6.1.1 Decision framework for developing a recovery strategy

The following flow-diagram, based on Figure 5.1, shows the questions to address in order to characterise an accident, optimise monitoring and estimate doses to feed into the 8-step decision-aiding framework described in Section 5.1.

Has the area surrounding the incident been contaminated? → Yes	Scope the nature of contamination in the inhabited area. Refer to Section 1.10 for guidance. Monitoring*:* grass and soil samples are taken to the laboratory. Analysis shows the contamination on the surface to be dominated by 1 MBq m^{-2} ^{137}Cs (Figure 6.1) Consult Section 1.8 to find out what hazard ^{137}Cs presents. Table 1.1 shows that ^{137}Cs gives rise to a long-lived gamma hazard.
Is there a critical facility/service in the contaminated area that needs to be manned? → Yes Are people sheltering in the contaminated area? → Yes	Because the contaminated area is a city, there is a high chance of critical facilities and services (eg water supplies, power) being present which need to be manned, especially because the population has not been evacuated. Both the critical facilities and areas where people are sheltering are high priority areas for monitoring. Planning in advance should mean that a list of critical facilities is available (see Section 4 for guidance on planning in advance). People are sheltering.
Is evacuation in place or is contaminated area only used for recreation? → No Is the radionuclide short-lived? → No Is there a resuspension hazard? → No	No evacuation has taken place and it is not a recreational area. ^{137}Cs gives rise to long-lived external gamma exposure. Management options need to be selected appropriate to this exposure pathway. Resuspended material can be inhaled. Table A3 indicates that ^{137}Cs may give rise to small resuspension doses. Using the dose conversion factors in Table B4, the integrated dose from this pathway over 10 years can be estimated to be about 8 10^{-12} Sv per Bq m^{-2}. With a contamination level of 1 MBq m^{-2}, this gives 0.008 mSv, which is very low in comparison with the external gamma dose.

Assess doses	Section 1.13 on estimating doses in inhabited areas refers the user to Appendix B for further information on calculating the doses. B2 provides the equation to calculate external gamma dose from sources in the outdoor environment. Ground deposition was measured as 1 MBq m^{-2}. The external dose outdoors from Table B2 over 50 years is 1.3 10^{-7} Sv per Bq m^{-2}. The fraction of time spent outdoors is about 10%. The location factor from Table B3 ranges from 0.03 to 0.62 depending on the shielding offered by a particular type of building. Using the formula in Appendix B, an external gamma dose to inhabitants is estimated to be between 17and 86 mSv over 50 years, depending on the location factor used. Similarly, the external gamma dose over 1 year can be estimated to be 1 - 7 mSv. Other contributions to the dose are minor: Section 1.9.1 indicates that doses from indoor contamination would be low because the deposition was wet; Table A3 indicates that beta doses from ^{137}Cs would be small.
Are residual doses in some places in the 1st year higher than those considered tolerable? No Is there a requirement to reduce contamination levels irrespective of projected doses? No Consider options for each surface: Figure 2.1: buildings Figure 2.2: roads and paved areas Figure 2.3: vehicles Figure 2.4: soil and vegetation	Considering the doses estimated above, and with projected doses in the first year less than 10 mSv, it is unlikely that highly disruptive management options would be justified. Nevertheless, some intervention to reduce radiation exposures would usually be justified at the levels of dose predicted. People are sheltering in the city. Therefore it may not be practicable to carry out the more disruptive options or those that affect properties where people are living or those which produce dust. Consideration could be given to temporarily relocating people during the implementation of management options. There is no pressure to remove the contamination from the whole area. However, the city contains locations that are particularly sensitive (eg schools). In such locations, there is likely to be pressure to undertake decontamination.
Consult 8-step decision-aiding framework for selecting and combining options	The 8-step decision-aiding framework described in Section 5.1 and presented below in Table 6.1 should now be consulted. Select and combine management options for each contaminated surface.

Figure 6.1 Contamination levels of ^{137}Cs on the various types of surface in the city for the hypothetical scenario given in Example 1



6.1.2 Choosing management options

For the purposes of this example, only soil and grassed areas are considered further; these are principally assumed to be small city gardens. Justification for this choice is given in step 1 in Table 6.1. In reality, the decision making process would be much more complicated. Options would need to be assessed for all surfaces in the inhabited area. This would take into account, for example, resource implications, quantities of waste, constraints on implementation, effectiveness, cost and social impact.

The development of a recovery strategy for city gardens makes use of the decision framework described in Section 5. Before going through the generic steps involved in selecting and combining options it is important for users to appreciate that when using the Inhabited Areas handbook to develop a recovery strategy they should establish a dialogue with national and local stakeholders; be familiar with the structure and content of the handbook; develop knowledge of technical information underpinning a recovery strategy and an understanding of the factors influencing implementation of options and selection of a strategy (Section 3).

The development of a recovery strategy for city gardens areas using the accident scenario for ^{137}Cs is described in Table 6.1 below, based on the eight generic steps described in Section 5.1. The numbers in brackets in Table 6.2 to Table 6.9 refer to the datasheet number.

Table 6.1 Steps involved in selecting and combining options for city gardens contaminated with ^{137}Cs

Step	Action
1	**Identify surfaces that are likely to be/have been contaminated**
	In determining priorities, it is important to take into account the relative importance of different surfaces in contributing to the doses received. From the scenario, earlier results from the analysis of the grass/soil samples revealed that there was 1 MBq m^{-2} of ^{137}Cs on grassed surfaces. Using Table B5, it is possible to estimate the likely levels of contamination on other surfaces in the area, as shown in Figure 6.1. This provides an indication of the surfaces that are likely to have received the most contamination. Figure 1.4 also gives an indication of the surfaces that are likely to contribute to external gamma doses, taking into account both the contamination on the different surfaces and the time people are likely to spend close to/on these surfaces. Using this information, contaminated soil/grass areas, roofs and streets would generally be expected to contribute most to the doses. This would particularly be the case as the contamination occurred in rainfall. Exactly how much each of these surface types contribute depends on the sizes and locations of the surfaces in relation to the location where people spend time. To assess this, a detailed model would be required. From the scenario described in Section 6.1, city gardens are the surfaces that have been most affected. Management options are required to reduce doses from these contaminated surfaces.
2	**Refer to selection tables for specific surfaces (Table 5.2 - Table 5.7). These selection tables provide a list of all of the applicable management options for the surfaces selected.**
	The relevant selection table is Table 5.7 which lists all 14 applicable management options for soils, grass and plants. For ease of reference it is reproduced here in Table 6.2. Various options can be eliminated immediately. Snow/ice removal would not be required for the time of year of the accident (June). Also, as leaves would still be on trees, leaf collection would not be applicable. Furthermore, ploughing methods are not relevant to city gardens because they can only be implemented in large open spaces due to the size of the equipment required. At the predicted level of dose (< 10 mSv in the first year) permanent relocation would not be justified. Temporary relocation could be considered to allow the more disruptive options to be carried out, but conversely, there may be competing factors which make it preferable to leave people in the area. If management options are going to be carried out while people are still in-situ, the impact on those people needs to be considered (see Section 2.4). Restricting public access and controlling workforce access to non-residential areas are not appropriate as city gardens are in residential areas. A revised selection table (Table 6.3) has been produced to reflect only the 8 remaining options that might be appropriate. Subsequent steps will investigate whether any further options can be eliminated.
3	**Refer to look-up Table 5.9 showing applicability of management options for each radionuclide being considered**
	The relevant data for ^{137}Cs are summarised in Table 6.4. These data have been used to eliminate options from the selection tables that are not applicable to ^{137}Cs. Only 1 management option listed could be eliminated on the basis of it being targeted at radionuclides that pose a resuspension hazard (tie-down). Subsequent steps will endeavour to eliminate further options which are not applicable to this scenario.
4	**Refer to look-up tables Table 5.10 and Table 5.11 showing a major and moderate constraints for each management option**
	The major constraints for the remaining 7 management options are summarised in Table 6.5. The following option can be eliminated: Cover grass/soil with clean soil/asphalt: acceptability of covering with asphalt is likely to be low and if clean soil was to be used very large quantities would be required (up to 10 cm) for this option to be effective. The selection table for city gardens has been revised to show the 6 remaining management options that have still to be considered (Table 6.6).
5	**Refer to look-up Table 5.12 showing effectiveness of management options**
	Information on effectiveness of the 6 remaining management options is summarised in Table 6.7. The following options can be eliminated: Grass cutting and removal: not effective following wet deposition. Tree and shrub pruning and removal: not effective following wet deposition
6	**Refer to look-up Table 5.13 which shows quantities and types of waste produced from implementation of management options**
	Information on which of the remaining 4 management options generate waste is summarised in Table 6.8. Only 1 option, involving the removal of turf and topsoil (manual and mechanical) produces waste (60-70 kg m^{-2} waste in the form of soil and turf). Implementation of this option would require an agreed waste management strategy and the quantities of waste may be prohibitive if the option is implemented on a large scale.
7	**Refer to individual datasheets (Section 7) for all options remaining in the selection table and note the relevant constraints.**
	The final selection table for the 4 remaining management options is presented in Table 6.9. A detailed analysis of all remaining options by careful consideration of the relevant datasheets is required. It can only be

Table 6.1 Steps involved in selecting and combining options for city gardens contaminated with ^{137}Cs

Step	Action	
	done on a site specific basis and in close consultation with the affected local population and other stakeholders to take into account local circumstances.	
8	**Based on Steps 1-7, select and combine options that should be considered as part of the recovery strategy.**	
	The following options could be considered for reducing doses from city gardens contaminated with ^{137}Cs. Each remediation option has drawbacks which need to be considered on a site specific basis. At doses less than 10 mSv not all options may be justified everywhere, For example, the implementation of topsoil and turf removal generates large quantities of waste but in small 'sensitive' areas within the city, such as play areas and land around schools and nurseries, this may be the most appropriate option. It may be that doing no clean-up is justified, in which case natural attenuation (with monitoring) would be the preferred option. For this to be acceptable there would need to be good communication with the local community and a rigorous monitoring strategy to provide reassurance and to demonstrate that the risks are low.	
	Option	**Additional comments**
	Temporary relocation (5)	Consider this while other options are being carried out but bear in mind the disruption to the community and impact on businesses.
	Manual and mechanical digging (11)	Loss of amenity in short-medium term. Garden will need to be replanted or reseeded. Manual digging is more effective in reducing doses than mechanical digging but slower to implement. No waste generated but mixing contamination within the soil would compromise any subsequent soil removal. Leaving contamination in-situ may not be acceptable to home owners.
	Natural attenuation (13)	This option may be perceived as doing 'nothing' by the public which may have negative implications.
	Topsoil and turf removal (24)	Loss of amenity in short-medium term. Soil will have to be replaced and garden replanted or reseeded. Large quantise of waste and waste disposal route or management strategy required.

Go to greyscale table

Table 6.2 Selection table of management options for soils and vegetation (all options)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)	Amber	Dark red
Permanent relocation from residential areas (3)	Dark red	Dark red
Restrict public access (4)	Amber	Dark red
Temporary relocation from residential areas (5)	Amber	Dark red
Remediation		
Collection of leaves (6)	Green	Green
Cover grass/soil with clean soil/asphalt (7)	Amber	Dark red
Grass cutting and removal (10)	Green	Red
Manual and mechanical digging (11)	Amber	Amber
Natural attenuation (with monitoring) (13)	Amber	Dark red
Ploughing methods (14)	Green	Green
Snow/ice removal (18)	Amber	Red
Tie-down (23)	Dark red	Dark red
Topsoil and turf removal (24)	Red	Dark red
Tree and shrub pruning and removal (27)	Amber	Red

Key:

Green	Recommended with few constraints
Amber	Recommended but requires further evaluation to overcome some constraints
Dark red	Economic or social constraints exist, requiring full analysis and consultation period.
Red	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 6.3 Selection table of management options for soils and vegetation (relevant options)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (5)		
Remediation		
Cover grass/soil with clean soil/asphalt (7)		
Grass cutting and removal (10)		
Manual and mechanical digging (11)		
Natural attenuation (with monitoring) (13)		
Tie-down (23)		
Topsoil and turf removal (24)		
Tree and shrub pruning and removal (27)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Table 6.4 Step 3 - Applicability of remaining management options* for ^{137}Cs

Restrict access	
Temporary relocation from residential areas (5)	✓
Remediation	
Cover grass/soil with clean soil/asphalt (7)	✓
Grass cutting and removal (10)	✓
Manual and mechanical digging (11)	✓
Natural attenuation (with monitoring) (13)	✓
Tie-down (23)	a
Topsoil and turf removal (24)	✓
Tree and shrub pruning and removal (27)	✓

Key:

✓: Selected as target radionuclide (ie known or probable applicability, see Section 5.3)

a: This management option reduces doses from inhalation of resuspended material which would not normally be an important pathway for this radionuclide

*: Only options listed in selection table for soil and grass and plants are shown

Table 6.5 Step 4 - Checklist of key constraints to consider for remaining management options

Restrict access	Key constraints
Temporary relocation from residential areas (5)	**Social:** temporary relocation can cause disruption to the community and have a large impact on businesses **Technical:** availability of alternative accommodation (hotels, bed and breakfast, self-catering, hostels etc) availability of transport. Transport availability needs to be considered to aid the relocation process, especially if the affected area has an elderly population or people with disabilities (population profile)
Remediation	
Cover grass/soil with clean soil/asphalt (7)	**Social:** acceptability in gardens likely to be low **Technical:** complicates further options involving removal of contaminated soil cannot be carried out in severe cold weather (frost and snow) can only be implemented on a small scale and even then very large quantities of soils are required
Grass cutting and removal (10)	**Technical:** not effective if there is heavy rain after deposition cannot be carried out in severe cold weather (frost and snow) the technique requires grass mowers with collection boxes **Time:** needs to be implemented quickly and before rain
Manual and mechanical digging (11)	**Technical:** complicates further options involving removal of contaminated soil cannot be carried out in severe cold weather (frost and snow) area must not have been tilled since deposition and afterwards, the area must not be re-dug can only be implemented on a small scale
Natural attenuation with monitoring (13)	**Technical:** monitoring equipment and skilled personnel are required to take measurements and samples it may take a prolonged period of time for the radionuclides to undergo radioactive decay and weathering from surfaces may be more feasible for rural areas rarely used, than in a commercial district of a large city
Topsoil and turf removal (24)	**Waste:** large quantities of contaminated soil/vegetation will be produced, which will require disposal and/or storage under a waste transfer licence **Technical:** slow work rate if carried out manually cannot be carried out in severe cold weather (frost and snow). It is also not appropriate for stony soils can only be implemented on a small scale
Tree and shrub pruning and removal (27)	**Technical:** dependent on time of year - only if leaves on plants and shrubs needs to be implemented quickly and before rain

Go to greyscale table

Table 6.6 Selection table of management options for soils and vegetation (after Step 4)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (5)		
Remediation		
Grass cutting and removal (10)		
Manual and mechanical digging (11)		
Natural attenuation (with monitoring) (13)		
Topsoil and turf removal (24)		
Tree and shrub pruning and removal (27)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Table 6.7 Effectiveness of management options for ^{137}Cs

Management option	Effectiveness in reducing external gamma doses	Comments
Restrict access		
Temporary relocation from residential areas (5)	Up to 100% reduction in dose (all pathways) while individual is away from affected area.	Particularly useful for short-lived radionuclides. It does not reduce contamination levels in the environment
Remediation		
Grass cutting and removal (10)	DF of 2 - 10 if implemented within one week of deposition and before significant rain occurs.	Effectiveness is significantly reduced after rain has occurred or if grass has been already cut post deposition.
Manual and mechanical digging (11)	External gamma and beta dose rates above the surface are likely to be reduced by up to 80% in the short-medium term for manual digging and 50-65% for mechanical digging. Resuspended concentrations in air above the surface will be reduced by 90 - 95%	Effectiveness depends on the success of mixing within the soil. Dose rate reductions are likely to be higher for manual digging than for mechanical digging since rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth.
Natural attenuation (with monitoring) (13)	See comments.	Effectiveness depends on physical half-life of the radionuclide as well as its ecological half-life
Topsoil and turf removal (24)	DF of 10 - 30 can be achieved if implemented within a few years of deposition.	The removal depth needs to be chosen to ensure maximum removal of contamination in order to achieve maximum effectiveness. If a standard removal depth is used, the effectiveness will reduce in time after this as contamination migrates to deeper soil depths.
Tree and shrub pruning and removal (27)	For pruning, a DF of 2-10 can be achieved if implemented within one week of deposition and before significant rain occurs. If a whole tree is felled, and all the leaves are collected, a DF up to 50 could be achieved.	The reduction in contamination is proportional to the fraction of the tree/shrub removed. Effectiveness is significantly reduced after rain has occurred. Pruning is only effective before foliage dies back in autumn/winter.

Table 6.8 Quantities and types of waste produced by the management options*

Management option	Waste arising (kg m^{-2} unless otherwise stated) #	Waste material
Restrict access		
Temporary relocation from residential areas (5)	None	
Remediation		
Manual and mechanical digging (11)	None	
Natural attenuation with monitoring (13)	None	
Topsoil and turf removal (24)	60 - 70 (5 cm depth removed)	Soil and turf

* All values are for illustrative purposes to enable the impact of the implementation of the various options to be scoped and a comparison across options to be made.

No collection of waste and segregation assumed unless stated. If waste materials can be segregated into contaminated and exempt waste, quantities of contaminated waste will be much smaller. For example, water can be collected, filtered and re-used.

Go to greyscale table

Table 6.9 Selection table of management options for soils and vegetation (final)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (5)		
Remediation		
Manual and mechanical digging (11)		
Natural attenuation (with monitoring) (13)		
Topsoil and turf removal (24)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

6.2 Example 2 - small scale incident involving the dispersion of ^{239}Pu

Scenario

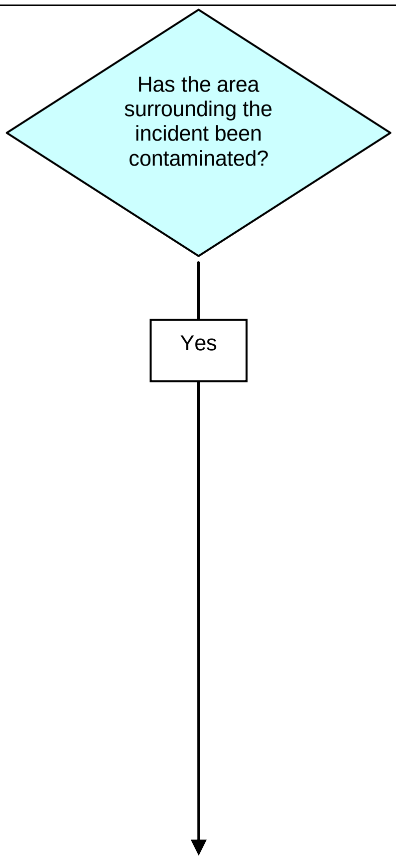
- small scale incident on 1 September
- release of radioactivity into the commercial district of a town (shops and offices)
- rain at the time of deposition

Current situation

- the population has been evacuated to a distance of 500 m in all directions

6.2.1 Decision framework for developing a recovery strategy

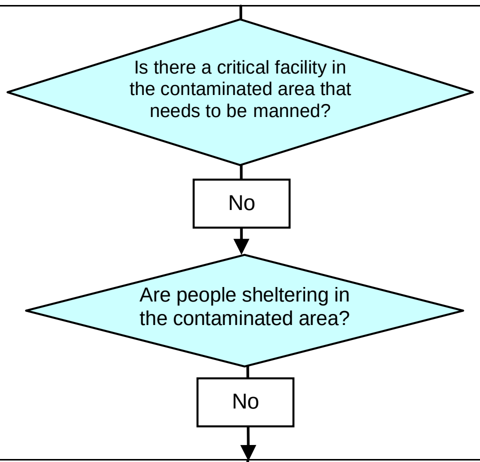
The following flow-diagram, based on Figure 5.1, shows the questions to address in order to characterise an accident, optimise monitoring and estimate doses to feed into the 8-step decision aiding framework described in Section 52.



Scope the nature of contamination in the inhabited area. Refer to Section 1.10 for guidance.

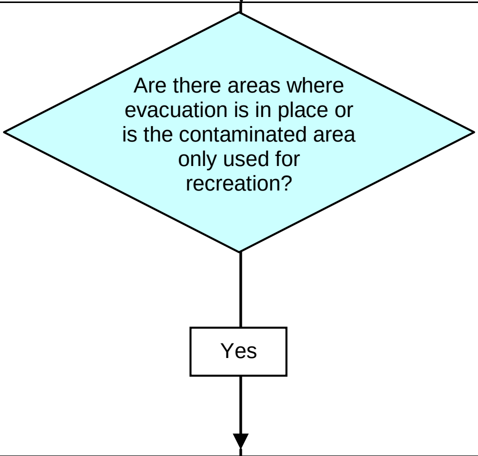
Consult Section 1.8 to find out what hazard ^{239}Pu presents. Table 1.1 shows that ^{239}Pu mainly emits long-lived alpha radiation and some gamma radiation. The exposure pathway of concern is inhalation of resuspended contaminated dust in the environment.

Monitoring*:* ^{239}Pu emits alpha particles which have a very short range in any material, including air, and their measurement is more difficult than for gamma and beta emitters. Furthermore, the gamma radiation emitted by ^{239}Pu is generally of very low intensity and energy; it would be very difficult to rapidly monitor the area to identify the extent of the contamination. This delay and uncertainty would need to be taken into account throughout the development and implementation of the recovery strategy.



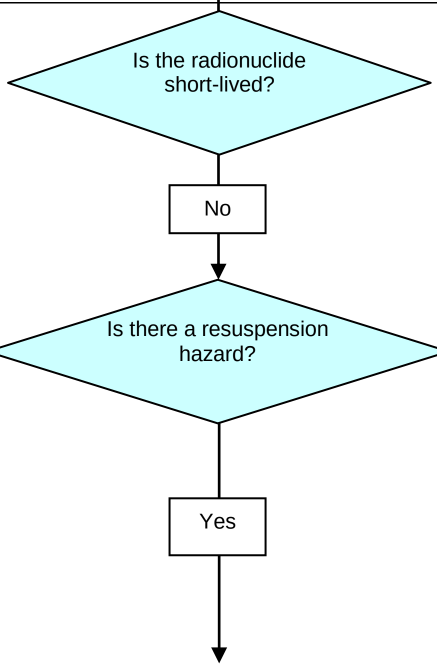
The affected area is a small section of a commercial district with shops and offices. None are critical facilities.

There is no sheltering in place in the area; everyone was evacuated. Therefore disruption shouldn't be an issue when implementing the management options. However, there is likely to be pressure to complete work quickly in order for economic activities to restart as soon as possible.



Evacuation should be maintained until monitoring of the area has taken place and an estimate of long-term doses be carried out. In this case, due to the long timescales for monitoring of plutonium, it is likely that models will be used to justify the need to maintain evacuation.

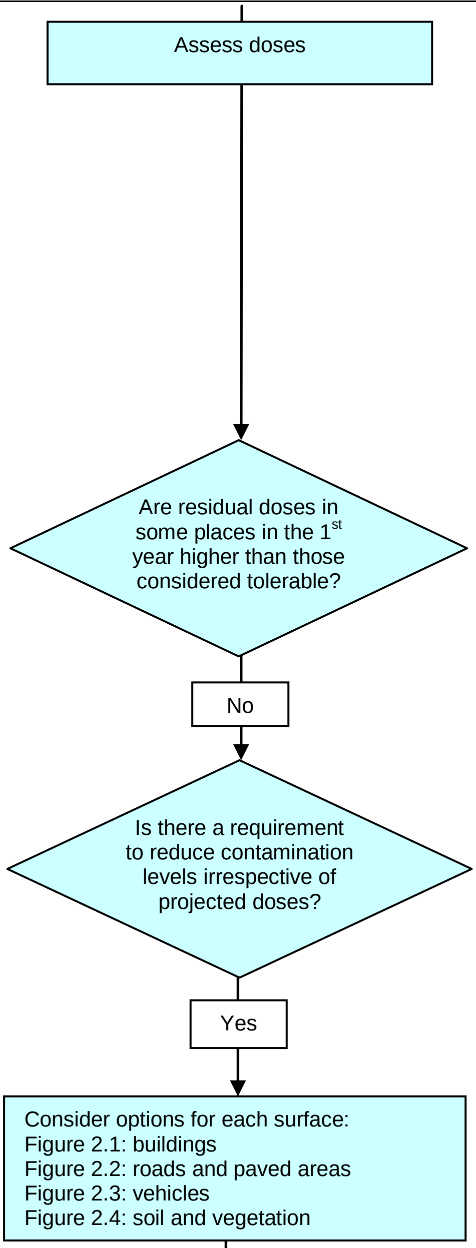
This approach needs to be balanced against the pressure to return people to the area as soon as possible. Because it is not a residential area, the disadvantages of a prolonged evacuation are not likely to be as pronounced.



^{239}Pu gives rise to a long-lived resuspension hazard. Management options need to be selected appropriate to this hazard.

The main radiological concern would be to avoid inhalation of resuspended material. Tie-down (fixing) options should be considered in the short-term. Temporary fixing materials can be applied cheaply and quickly and can be used to prevent further spread of contamination in the environment. They can also help to protect workers monitoring in the area.

In wet weather, the use of fixing materials is limited. Temporary materials, such as water and sand, are ineffective because the wet weather conditions will suppress resuspension and remove a lot of the loose contamination on the surface. The use of bitumen spray and paints could be considered once surfaces have dried.

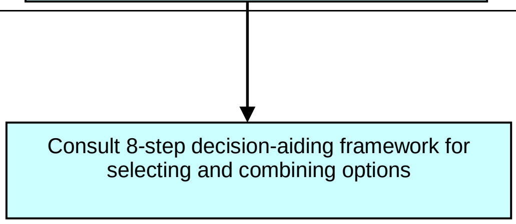


Due to the short range of alpha radiation from ^{239}Pu, problems only arise if the contaminants enter the human body. The most important exposure pathway is inhalation, particularly from resuspended material on contaminated surfaces.

Section 1.13 on estimating doses in inhabited areas refers the user to Appendix B for further information on calculating the doses. B4 contains specific information about inhalation of resuspended material. Table B4 contains data to estimate the committed effective dose from resuspended material.

For this scenario, it is assumed that lifetime doses from resuspension are very low.

Given the nature of the affected area, it is probable that doses will not be the key determining factor for reducing contamination levels and there is likely to be pressure to reduce contamination levels in the environment irrespective of doses. If people are expected to return to the area to work and shop, they will need reassurance that it is safe to do so. This could include seeing that contamination levels had been reduced to a level as low as possible rather than to a level set on purely radiological protection grounds.



The 8-step decision-aiding framework described in Section 5.1 and presented below in Table 6.10 should now be consulted for selecting and combining management options for each contaminated surface.

6.2.2 Choosing management options

For the purposes of this example, it is assumed that only external building surfaces are considered further. Justification for this choice is given in step 1 in Table 6.10. In reality, the decision making process would be much more complicated. Options would need to be assessed for all surfaces in the inhabited area. This would take into account, for example, resource implications, quantities of waste, constraints on implementation, and social impact.

The development of a recovery strategy for buildings makes use of the decision framework described in Section 5. Before going through the generic steps involved in selecting and combining options it is important for users to appreciate that when using the Inhabited Areas handbook to develop a recovery strategy they should establish a dialogue with national and local stakeholders; be familiar with the structure and content of the handbook; develop knowledge of technical information underpinning a recovery strategy and an understanding of the factors influencing implementation of options and selection of a strategy (Section 3).

Short-term tie-down options have already been identified as a potential strategy for preventing resuspension of radioactive material. In this scenario, there is pressure to remove ^{239}Pu from the contaminated environment and therefore permanent fixing options may not be acceptable to the public. In the longer term, consideration would need to be given to the selection of management options that remove contamination from the surfaces in this commercial district as well as fixing options. It will be extremely important to involve all stakeholders in the decisions.

The development of a recovery strategy for external building surfaces using the accident scenario for ^{239}Pu is described in Table 6.10 below, based on the eight generic steps described in Section 5.1. The numbers in brackets in Tables 6.11 - 6.17 refer to the datasheet number.

Table 6.10 Steps involved in selecting and combining options for external building surfaces contaminated with ^{239}Pu

Step	Action
1	**Identify one or more surfaces that are likely to be/have been contaminated**
	Using Table B5, it is possible to estimate the likely levels of contamination on other surfaces in the area. This provides an indication of the surfaces that are likely to have received the most contamination. Using this information, contaminated soil/grass areas, trees and roofs and streets could be expected to contribute most to resuspension doses. Exactly how much each of these surface types would contribute depends on the sizes and locations of the surfaces in relation to the location where people spend time. To assess this, a detailed model would be required. For this scenario (described in Section 6.2), external building surfaces, particularly roofs have been identified as being of concern. Management options may be required to reduce resuspension doses from these contaminated surfaces; however, doses from this exposure pathway have been estimated to be low. The scenario also indicates that there is pressure to remove plutonium contamination from the area so it is likely that all surfaces will need to be considered, particularly those that are considered as sensitive.
2	**Refer to selection tables for specific surfaces (Table 5.2 - Table 5.7). These selection tables provide a list of all of the applicable management options for the surfaces selected.**
	The relevant selection table is Table 5.2 which lists all applicable management options for buildings. For ease of reference it is reproduced here in Table 6.11. However some of these 16 options are not relevant to the scenario. Snow/ice will not be present in September. Also, as the contaminated area is not residential, temporary and permanent relocation do not need to be considered. Access to the public can be restricted and restrictions can be imposed on transport. At the predicted level of dose (< 10 mSv in the first year), demolition of the buildings would not be justified, and neither would surface removal. Whilst the area remains empty, security will need to be maintained. Empty premises may become a target for looters and thieves. A revised selection table (Table 6.12) has been produced to reflect the 11 options that might be appropriate for external building surfaces. Subsequent steps will investigate whether any further options can be eliminated.

Table 6.10 Steps involved in selecting and combining options for external building surfaces contaminated with ^{239}Pu

Step	Action
3	**Refer to look-up Table 5.9 showing applicability of management options for ^{239}Pu**
	The relevant data for ^{239}Pu are summarised in Table 6.13. These data have been used to eliminate options from the selection tables that are not applicable to ^{239}Pu. Two of the management option listed could be eliminated on the basis of either being targeted at radiocaesium (treat walls with ammonium nitrate) or inappropriate for such a long-lived radionuclide (natural attenuation with monitoring).
4	**Refer to look-up table Table 5.10 showing a checklist of key constraints for each management option**
	The key constraints for the remaining 9 management options are summarised in Table 6.14. Rainfall at the time of deposition will affect the application of fix and strip coatings making this option unsuitable.
5	**Refer to look-up Table 5.12 showing effectiveness of management options**
	Table 6.15 presents information on effectiveness for the 8 remaining management options. Restricting public access to the area and controlling workforce access are effective in keeping doses low. The remaining remediation options have the potential to remove contamination from different surfaces according to surface type, smoothness and degree to which the contamination is fixed. None of the options can be eliminated on the basis of their effectiveness.
6	**Refer to look-up Table 5.13 which shows quantities and types of waste produced from implementation of management options**
	Table 6.16 shows the quantities and types of waste produced from the decontamination options. The implementation of these options would require an agreed waste management strategy. The option to treat waste water in situ could reduce the quantities of waste requiring disposal by concentrating the contaminants on ion exchange resins.
7	**Refer to individual datasheets (Section 7) for all options remaining in the selection table and note the relevant constraints.**
	The final selection table for the 8 remaining management options is presented in Table 6.17. A detailed analysis of all remaining options by careful consideration of the relevant datasheets is required. It can only be done on a site specific basis and in close consultation with the affected local population and other stakeholders to take into account local circumstances.
8	**Based on Steps 1-7, select and combine options that should be considered as part of the recovery strategy.**
	The following options could be considered to reduce doses from external building surfaces contaminated with ^{239}Pu. However, it is known that building surfaces do not make a major contribution to the doses received, which largely arise from inhalation of resuspended material. If selected, these options would be carried out for reasons other than radiological protection (ie public perception, political pressure). It is important that the workers implementing these options are adequately protected (Section 3.3) and that measures are put in place to prevent the further spread of contamination in the environment.

Option	Comments
Control workforce access (1)	Important for keeping doses to those carrying out remediation as low as possible. Also for any workforce required to remain on site.
Restrict public access (4)	Essential to restrict public access while clean-up of external surfaces is being carried out
Pressure and fire hosing (15)	High pressure hosing can be used if firehosing proves ineffective. Both produce large quantities of liquid waste
Reactive liquids (16)	Reactive liquids can be used on specialised surfaces (eg metal, plastic and coated surfaces)
Roof cleaning including gutters and downpipes (17)	If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable
Tie-down (23)	Only likely to be only used prior to implementation of other recovery options in order to protect workers from the resuspension hazard.
Treatment of waste water (26)	Useful for removing contamination of waste water following pressure hosing and roof cleaning.
Water based cleaning (29)	Washing and wiping/scrubbing of building surfaces has been found to produce similar levels of decontamination as achieved using high-pressure water jet washing but with less waste for disposal.

Go to greyscale table

Table 6.11 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)	Amber	Dark red
Permanent relocation from residential areas (3)	Dark red	Dark red
Restrict public access (4)	Amber	Dark red
Temporary relocation from residential areas (5)	Amber	Dark red
Remediation		
Demolish/dismantle and dispose (8)	Dark red	Dark red
Fix and strip coatings (9)	Amber	Red
Natural attenuation (with monitoring) (13)	Amber	Dark red
Pressure and fire hosing (15)	Amber	Red
Reactive liquids (16)	Amber	Red
Roof cleaning including gutters and downpipes (17)	Amber	Amber
Snow/ice removal (18)	Amber	Red
Surface removal (buildings) (20)	Dark red	Dark red
Tie-down - bitumen (permanent) (23)	Amber	Dark red
Tie-down - water or sand (temporary) (23)	Green	Red
Treatment of walls with ammonium nitrate (25)	Amber	Red
Treatment of waste water (26)	Amber	Amber
Water based cleaning (29)	Green	Red

Key:

Green	Recommended with few constraints
Amber	Recommended but requires further evaluation to overcome some constraints
Dark red	Economic or social constraints exist, requiring full analysis and consultation period.
Red	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to greyscale table

Table 6.12 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Restrict public access (4)		
Remediation		
Fix and strip coatings (9)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Roof cleaning including gutters and downpipes (17)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of walls with ammonium nitrate (25)		
Treatment of waste water (26)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Table 6.13 Step 3 - Applicability of remaining management options* for ^{239}Pu

Restrict access	
Control workforce access (1)	a
Restrict public access (4)	✓
Remediation	
Fix and strip coatings (9)	✓
Natural attenuation (with monitoring) (13)	a, b
Pressure and fire hosing (15)	✓
Reactive liquids (16)	✓
Roof cleaning including gutters and downpipes (14)	✓
Tie-down (23)	✓
Treatment of walls with ammonium nitrate (25)	c
Treatment of waste water (26)	✓
Water based cleaning (29)	✓

Key:

✓: Selected as target radionuclide (ie known or probable applicability, see Section 5.3)

a. Comparatively long physical half-life of radionuclide relative to timescale that the management option can be left in place

b. No/low photon energy of radionuclide makes detection difficult

c. This management option is targeted specifically at radiocaesium

*****: Only options listed in selection table are for buildings

Table 6.14 Step 4 - Checklist of key constraints to consider when selecting management options

Restrict access	Key constraints
Control workforce access (1)	**Time:** this option should be implemented as soon as a contaminated area is identified with cordons and signage to prevent access. These measures will need to be in place until the doses have been assessed and management of the area agreed **Technical:** availability of system to monitor and control doses
Restrict public access (4)	**Time:** this option should be implemented as soon as a contaminated area is identified with cordons and signage to prevent access. These measures will need to be in place until the doses have been assessed and management of the area agreed
Remediation	
Fix and strip coatings (9)	**Technical:** technique may be affected by severe cold weather and wet weather
Pressure and fire hosing (15)	**Waste:** pressure washers may produce large volumes of effluent and waste water. To prevent run off on to other sensitive surfaces such as soil and ground water, the effluent needs to be effectively collected and may require disposal and/ or storage under a waste transfer licence **Technical:** walls and roofs must be resistant to water at high pressure cannot be carried out in severe cold weather **Time:** needs to be implemented quickly and preferably before rain
Reactive liquids (16)	None
Roof cleaning including gutters and downpipes (17)	**Technical:** roof construction must resist water at high pressure cannot be carried out in severe cold weather
Tie-down (23)	**Technical:** technique may be affected by severe cold weather and wet weather
Treatment of waste water (26)	**Technical:** availability of ion exchange resins and other media for removing radionuclides from waste water
Water based cleaning (29)	**Waste:** produces water based wash solutions that are likely to be contaminated which may require disposal and/ or storage under a waste transfer licence

Table 6.15 Step 5 - Effectiveness of management options for ^{239}Pu

Management option	Effectiveness in reducing resuspension doses and/or contamination on surface	Comments
Restrict access		
Control workforce access (1)	See comment	Effective in controlling doses to an essential workforce as long as people comply and controls are enforced. This option does not reduce contamination levels in the environment. Particularly useful for short-lived radionuclides.
Restrict public access (4)	Up to 100% reduction in dose (all pathways) from areas where access is prohibited	Particularly useful for short-lived radionuclides. Effectiveness depends on individuals complying. It does not reduce contamination levels in the environment
Remediation		
Pressure and fire hosing (15)	Buildings: DF of 1.3-5 can be achieved if implemented within 1 week of deposition and before significant rain. High pressure hosing gives greater effectiveness (1.5-5%) than fire hosing.	Repeated application is unlikely to provide any significant increase in DF. A higher DF can be achieved following dry deposition rather than wet deposition.
Reactive liquids (16)	For metal surfaces: DF 2-30 (soft techniques) and DF 30-100 for hard techniques For plastic and coated surfaces: DF 10-100	The effectiveness depends on the reactive liquid used, the radionuclide and the surface that is being decontaminated
Roof cleaning including gutters and downpipes (17)	DF of 2-7 could be achieved if implemented soon after deposition (DF of 2-4 after 10 years).	Repeated application is unlikely to provide any significant increase in DF. If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
Tie-down (23)	Up to 100% reduction in resuspension dose from surface while integrity of covering is maintained. Reductions in external beta dose rates above roads and paved surfaces: 90% for sand, 70% for bitumen and 45% for water. Small reductions in external beta dose rates above soil surfaces could be expected.	This option may be effective at reducing external beta dose rates above the surface (for low energy beta emissions) while the tie-down remains intact, but is not effective at reducing external gamma dose rates. Sand (2 mm) would be the most effective at reducing beta dose rates, typical thicknesses of bitumen (1 mm) and water (1 mm) will give less protection. Applying water to soil surfaces will aid the bonding of activity to soil particles and can wash contamination below the surface, both of which will reduce resuspension in the longer term.
Treatment of waste water (26)	See comments	Removal efficiencies can be > 70% for some radionuclide cation/anion exchange media.

Table 6.15 Step 5 - Effectiveness of management options for ^{239}Pu

Management option	Effectiveness in reducing resuspension doses and/or contamination on surface	Comments
Water based cleaning (29)	DF up to 10 assuming that this option is implemented within a few weeks of deposition and no previous cleaning has taken place	The highest DFs can be expected from cleaning smooth surfaces (ie wood, tiles, linoleum, glass and painted surfaces). Lower DFs are likely for cleaning rough surfaces (concrete, stone, brick, and for carpets, rugs, tapestries, upholstery, bedding and soft furnishings.

Table 6.16 Quantities and types of waste produced by the management options*

Management option	Waste arising (kg m^{-2} unless otherwise stated) #	Waste material
Restrict access		
Control workforce access (1)	None	
Prohibit public access (4)	None	
Remediation		
Pressure and fire hosing (15)	$1\ 10^{-1}$ - $2\ 10^{-1}$ (fire hosing)	Dust
	$2\ 10^{-1}$ - $4\ 10^{-1}$ (high pressure)	Dust
	$5\ 10^{1}$ litres m^{-2} (fire hosing)	Water
	$2\ 10^{1}$ litres m^{-2} (high pressure)	Water
Reactive liquids (16)	Variable	Various
Roof cleaning including gutters and downpipes (17)	$2\ 10^{-1}$ - $6\ 10^{-1}$	Dust and moss
	$1.5\ 10^{1}$ - $3\ 10^{1}$ litres m^{-2}	Water
Tie-down (23)	$3\ 10^{-1}$ litres m^{-2}	Water and dust
	1 - 2	Sand and dust
	No waste	Bitumen (permanent)
	$4\ 10^{-1}$	Paint
Treatment of waste water (26)	Variable	Water and filters
Water based cleaning (29)	$1\ 10^{-3}$ - 1.3	Dust, water, detergent, filters

* All values are for illustrative purposes to enable the impact of the implementation of the various options to be scoped and a comparison across options to be made.

No collection of waste and segregation assumed unless stated. If waste materials can be segregated into contaminated and exempt waste, quantities of contaminated waste will be much smaller. For example, water can be collected, filtered and re-used.

Go to greyscale table

Table 6.17 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Restrict public access (4)		
Remediation		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Roof cleaning including gutters and downpipes (17)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of waste water (26)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

6.3 Greyscale tables

Go to colour Table 6.2

Table 6.2 Selection table of management options for soils and vegetation (all options)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)	[light grey]	[hatched]
Permanent relocation from residential areas (3)	[hatched]	[hatched]
Restrict public access (4)	[light grey]	[hatched]
Temporary relocation from residential areas (5)	[light grey]	[hatched]
Remediation		
Collection of leaves (6)	[white]	[white]
Cover grass/soil with clean soil/asphalt (7)	[light grey]	[hatched]
Grass cutting and removal (10)	[white]	[black]
Manual and mechanical digging (11)	[light grey]	[light grey]
Natural attenuation (with monitoring) (13)	[light grey]	[hatched]
Ploughing methods (14)	[white]	[white]
Snow/ice removal (18)	[light grey]	[black]
Tie-down (23)	[hatched]	[hatched]
Topsoil and turf removal (24)	[black]	[hatched]
Tree and shrub pruning and removal (27)	[light grey]	[black]

Key:

[white]	Recommended with few constraints
[light grey]	Recommended but requires further evaluation to overcome some constraints
[hatched]	Economic or social constraints exist, requiring full analysis and consultation period.
[black]	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 6.3

Table 6.3 Selection table of management options for soils and vegetation (relevant options)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (5)		
Remediation		
Cover grass/soil with clean soil/asphalt (7)		
Grass cutting and removal (10)		
Manual and mechanical digging (11)		
Natural attenuation (with monitoring) (13)		
Tie-down (23)		
Topsoil and turf removal (24)		
Tree and shrub pruning and removal (27)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 6.6

Table 6.6 Selection table of management options for soils and vegetation (after Step 4)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (5)		
Remediation		
Grass cutting and removal (10)		
Manual and mechanical digging (11)		
Natural attenuation (with monitoring) (13)		
Topsoil and turf removal (24)		
Tree and shrub pruning and removal (27)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 6.9

Table 6.9 Selection table of management options for soils and vegetation (final)

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Temporary relocation from residential areas (5)		
Remediation		
Manual and mechanical digging (11)		
Natural attenuation (with monitoring) (13)		
Topsoil and turf removal (24)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour

Table 6.11 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)	[light grey]	[hatched]
Permanent relocation from residential areas (3)	[hatched]	[hatched]
Restrict public access (4)	[light grey]	[hatched]
Temporary relocation from residential areas (5)	[light grey]	[hatched]
Remediation		
Demolish/dismantle and dispose (8)	[hatched]	[hatched]
Fix and strip coatings (9)	[light grey]	[black]
Natural attenuation (with monitoring) (13)	[light grey]	[hatched]
Pressure and fire hosing (15)	[light grey]	[black]
Reactive liquids (16)	[light grey]	[black]
Roof cleaning including gutters and downpipes (17)	[light grey]	[light grey]
Snow/ice removal (18)	[light grey]	[black]
Surface removal (buildings) (20)	[hatched]	[hatched]
Tie-down - bitumen (permanent) (23)	[light grey]	[hatched]
Tie-down - water or sand (temporary) (23)	[white]	[black]
Treatment of walls with ammonium nitrate (25)	[light grey]	[black]
Treatment of waste water (26)	[light grey]	[light grey]
Water based cleaning (29)	[white]	[black]

Key:

[white]	Recommended with few constraints
[light grey]	Recommended but requires further evaluation to overcome some constraints
[hatched]	Economic or social constraints exist, requiring full analysis and consultation period.
[black]	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 6.12

Table 6.12 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Restrict public access (4)		
Remediation		
Fix and strip coatings (9)		
Natural attenuation (with monitoring) (13)		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Roof cleaning including gutters and downpipes (17)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of walls with ammonium nitrate (25)		
Treatment of waste water (26)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

Go to colour Table 6.17

Table 6.17 Selection table of management options for buildings - external surfaces

When to apply	Early (E) days-weeks	Medium-Long (M/L) (months - years)
Restrict access		
Control workforce access (1)		
Restrict public access (4)		
Remediation		
Pressure and fire hosing (15)		
Reactive liquids (16)		
Roof cleaning including gutters and downpipes (17)		
Tie-down - bitumen (permanent) (23)		
Tie-down - water or sand (temporary) (23)		
Treatment of waste water (26)		
Water based cleaning (29)		

Key:

	Recommended with few constraints
	Recommended but requires further evaluation to overcome some constraints
	Economic or social constraints exist, requiring full analysis and consultation period.
	Technical or logistical constraints may exist, or the option may only be appropriate on a site specific basis

7 Datasheets of Management Options

7.1 Datasheet template

This handbook considers 29 management options that may be implemented in inhabited areas following a radiation incident. Data hs been presented systematically in a standard format to facilitate comparisons between options. The template design is based on that used in the STRATEGY project (Andersson et al, 2003) but has been adapted to make it more appropriate for describing countermeasures for implementation in inhabited areas. The template includes the information that decision makers might want to consider when evaluating different countermeasures. These include:

- the objectives of the option
- a short description of the option
- constraints on its implementation
- effectiveness
- requirements
- waste generated
- doses received by those implementing the option
- costs
- side-effects
- practical experience

Table 7.1 presents the template with a brief summary of the information that appears under each heading.

Values for all data quantities presented in the datasheets should be treated as indicative only. Real values will be dependent on the specific circumstances. The inclusion of these indicative values is purely to allow comparisons to be made between management options.

Table 7.1 Datasheet template (adapted from Brown et al, 2007)

Name of management option	
Objective	Primary aim of the management option (eg reduction of external dose)
Other benefits	Secondary aims of the action (if any). For instance, the primary objective may be reduction of external dose, whereas an additional benefit may be a limited reduction in internal dose from food consumption.
Management option description	Short description of what the management option does and how to implement it.
Target	Type of area or surface where the management options will be implemented.
Targeted radionuclides	Radionuclide(s) or categories of radionuclides (eg alpha emitters) that the management option will protect against.
Scale of application	An indication of whether the option can be applied on a small or large scale (small scale ≤ 300 m^2; large scale > 300 m^2).
Time of application	Time relative to the accident/incident when the option is applied. Can be early phase (days), medium-term phase (weeks-months), or late phase (months-years).
Constraints	Provides information on the various types of restrictions that have to be considered before applying the management option.
Legal constraints	Laws referring to, for example, protection of the environment, cultural heritage protection, liabilities for property damage, protection of workers.
Environmental constraints	Constraints of a physical nature that prevent or restrict implementation (eg frost, soil type, slope and structure of land).
Effectiveness	Provides information on the effectiveness of the management option and factors affecting effectiveness.
Reduction in contamination on the surface	The reduction in activity concentration on the target surface at the time of implementation, ie a decontamination factor (DF).
Reduction in surface dose rates	The reduction in the dose rate above a surface.
Reduction in resuspension	The reduction in the resuspended activity concentration in air above the surface.
Technical factors influencing effectiveness	Technical factors that may influence the effectiveness of the method (eg surface material, evenness or slope of surface, weather conditions, soil type).
Social factors influencing effectiveness	Social factors that may influence the effectiveness of the method (eg reliance on voluntary behaviour, population behaviour).
Feasibility	Provides information on the equipment, infrastructure and skills needed to carry out the management option.
Equipment	Primary equipment for carrying out the management option.
Utilities and infrastructure	Utilities required in connection with implementing the management option (eg water and power supplies, distribution networks including roads).
Consumables	Consumables needed to implement the management option (eg fuel)
Skills	Level of skilled worker required to implement the option.
Safety precautions	Safety precautions necessary before workers can implement the option.
Waste	Some management options create waste, the management of which must be carefully considered at the time the management option is selected.
Amount and type	Nature and volume of waste. Also, indication of whether waste is contaminated and whether contaminated waste can be segregated or minimised.
Doses	Provides information on how the management option leads to changes in the distribution of dose to individuals and populations
Averted doses	Likely reduction in external dose rates that could be received, recognising that any savings in dose are strongly dependent on the scenario.
Additional doses	Additional doses that could be received by workers implementing management options are included here. Potential exposure pathways are identified and a broad indication of dose-rates expressed as a multiplier of public doses is given.
Intervention costs	Provides information on the direct costs that may be incurred from implementing the management option (not including waste disposal).

Table 7.1 Datasheet template (adapted from Brown et al, 2007)

Name of management option	
Operator time	Time required for implementing the option per unit of the target. Operator times are subject to many variables including the environment, weather conditions, the skills and equipment available. It is therefore difficult to give anything more than a rough estimate of the time required. Those estimates given in datasheets are intended to give an indication of the time required, and may not be accurate for the specific situation being considered. It is noted that working with radioactive material is often more time consuming than normal cleaning operations due to the restrictions of working with PPE and other requirements for protection of workers, public and the environment.
Factors influencing costs	Eg size and accessibility of target surface to be treated, availability of equipment and consumables within the contaminated area, requirement for additional manpower, wage level in the area, etc.
Side effects	Provides information on side effects of implementing the management option.
Environmental impact	Impact that a management option may have on the environment (eg with respect to pollution, land use).
Social impact	Impact that an option may have socially (eg cleaned and renewed urban surfaces, affect population behaviour, loss of amenities, etc.)
Practical experience	Experience in carrying out the management option.
Key references	References to key publications leading to other sources of information.
Version	The version number of the datasheet.
Document history	The history of the document

7.2 Datasheets

The datasheets are comprehensive, concise and specific to the UK. The format and content are based largely on similar documents developed initially in the STRATEGY project (Andersson et al, 2003; Eged et al, 2003) and adopted in version 1 of the UK Recovery Handbook (Health Protection Agency, 2005). The datasheets were further developed within the EURANOS project taking into account feedback from European stakeholders (Brown et al, 2007). Additional management options were added in the generic European recovery handbook developed under the EURANOS project, including seven datasheets for specialised surfaces in industrial buildings. All the management options that are appropriate for consideration in the UK have been included in this version of the UK Inhabited Areas Handbook. In accordance with the agreed terminology for the handbook, the term countermeasure has been replaced with management option. Hyperlinks to sections of the handbook or to other datasheets are indicated in the datasheets by blue underlined text.

7.2.1 Key updates to the datasheets

The datasheets presented in this section are based on a combination of those published in the UK Recovery Handbook for Radiation Incidents (HPA, 2009) and those in the UK Recovery Handbook for Chemical Incidents (Wyke-Sanders et al, 2012), with further updates to reflect new data from recovery work in Japan following the accident at Fukushima Daiichi. Several datasheets have been produced by combining options in the previous version of the UK Recovery Handbook, and some new management options have also been included (impose restrictions on transport, cleaning vehicle ventilation systems, natural attenuation with monitoring, and treatment of waste water).

7.2.2 Datasheet history

The history of the development of the datasheets is given in Table 7.2. Any additional relevant information, such as changes to the name of the management option is given in each datasheet in the document history field.

Table 7.2 Datasheet document history

Datasheet number(s)	Document history
1,3,4,5,6,21, 22,25,28	**UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK).
2,13	**UK Recovery Handbook for Chemical Incidents, 2012.** Developers: S Wyke-Sanders, N Brooke, A Dobney, D Baker and V Murray
7,20	**UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK). plus for some material: **STRATEGY, 2006.** Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK) **STRATEGY peer reviewers:** B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK).
8	**UK Recovery Handbook for Chemical Incidents, 2012**. Developers: S Wyke-Sanders, N Brooke, A Dobney, D Baker and V Murray plus for some material: **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK). plus for some material: **STRATEGY, 2006.** Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK) **STRATEGY peer reviewers:** B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). plus for some material: **UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK).

Table 7.2 Datasheet document history

Datasheet number(s)	Document history
9,14	**EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK). plus for some material: **STRATEGY, 2006.** Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK) **STRATEGY peer reviewers:** B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). plus for some material: **UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). Updated for the UK and addition of new material.
10,15,17,23, 24,27	**STRATEGY, 2006**. Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK). **STRATEGY peer reviewers**: B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). **UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). Updated for the UK and addition of new material. **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK).
11	**EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK). plus for some material: **UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). Updated for the UK and addition of new material. plus for some material: **STRATEGY, 2006.** Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK) **STRATEGY peer reviewers:** B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK).

Table 7.2 Datasheet document history

Datasheet number(s)	Document history
12,16	**UK Recovery Handbook for Chemical Incidents, 2012**. Developers: S Wyke-Sanders, N Brooke, A Dobney, D Baker and V Murray plus for some material: **STRATEGY, 2006.** Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK) **STRATEGY peer reviewers:** B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). plus for some material: **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK).
18	**STRATEGY, 2006**. Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK). **STRATEGY peer reviewers**: B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK).
19	**EURANOS Recovery Handbook, 2007.** Originators: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK).
26	New datasheet developed for the UK Recovery Handbook for Radiation incidents, 2015.

Table 7.2 Datasheet document history

Datasheet number(s)	Document history
29	**UK Recovery Handbook 2005.** Originators: J Brown, GR Roberts and K Mortimer (HPA-RPD, UK). **EURANOS Recovery Handbook, 2007.** Developers: J Brown, K Mortimer (HPA-RPD, UK) and KG Andersson and J Roed (Risoe National Laboratory, Denmark). Up-dated and extended datasheets. **UK Recovery Handbook, 2008.** Developers: H Rochford and J Brown (HPA-RPD, UK). Up-dated EURANOS datasheets for the UK. **UK Recovery Handbook, 2009.** Developers:A Nisbet, J Brown, T Cabianca and A Jones (HPA-RPD, UK). plus for some material: **STRATEGY, 2006.** Originators: KG Andersson and J Roed (Risoe National Laboratory, Denmark. Contributors: K Eged, Z Kis, R Meckbach (GSF, Germany), G Voigt (IAEA), DH Oughton (Agricultural University of Norway), J Hunt and R Lee (University of Lancaster, UK), NA Beresford (Centre of Ecology and Hydrology, UK) and FJ Sandalls (UK) **STRATEGY peer reviewers:** B Johnsson (NFI/ISS, Sweden), SC Hoe (DEMA, Denmark), J Barikmo (Directorate for Nature Management, Norway), A Bayer (BfS, Germany), L Brynilsden (Ministry of Agricultur, Norway), O Harbitz (NRPA, Norway), D Humphreys (Cumbria County Council, UK) and K Mondon (FSA, UK). plus for some material: **UK Recovery Handbook for Chemical Incidents, 2012**. Developers: S Wyke-Sanders, N Brooke, A Dobney, D Baker and V Murray

Table 7.3 Index of all management options for inhabited areas with hyperlinks to datasheets

7.3 References

Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical Countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* D. Riso National Laboratory, Riso-R-1396(EN).

Brown J, Mortimer K, Andersson KG, Duranova T, Mrskova A, Hänninen R, Ikäheimonen T, Kirchner G, Bertsch V, Gally F and Reales N (2007). *Generic handbook for assisting in the management of inhabited areas in Europe following a radiological emergency. Parts I-V.* Chilton, UK, EURANOS (CAT-1)-TN(07)-02.

Eged K, Kis Z, Voigt G, Andersson KG, Roed J and Varga K (2003). *Guidelines for planning interventions against external countermeasure application.* GSF, Germany, GSF-Bericht 01/03.

Health Protection Agency (2005). *UK Recovery Handbook for Radiation Incidents.* Chilton, UK, HPA-RPD-002.

HPA (2009). *UK Recovery Handbook for Radiation Incidents 2009 Version 3.* Health Protection Agency, Chilton, HPA-RPD-064.

Wyke-Sanders S, Brooke N, Dobney A, Baker D and Murray V (2012). *UK Recovery Handbook for Chemical Incidents, Version 1.* Health Protection Agency, ISBN 978-0-85951-717-1.

Back to list of options

1 Control workforce access

Objective	To enable a workforce to work/operate in a contaminated area, legally designated controlled radiation area under the supervision of an appointed radiation protection advisor (RPA). This allows essential services and infrastructure to be maintained, enabling the population in the wider area (ie where there are no restrictions due to contamination) to remain in place, and allows necessary recovery operations to be implemented.
Other benefits	Doses to the work force operating the essential services and infrastructure will be controlled in line with the legal requirements in the IRR's. Any necessary recovery options to remove contamination will be implemented more easily whilst only a limited population is present in the contaminated area. The spread of contamination will be limited by controlling access.
Management option description	Work environments can be controlled (both the people who are allowed to enter a workplace and the time that workers spend there). Employers have a legal duty of care for their employees; therefore it will not generally be acceptable for employees to work in a contaminated area where it has been deemed unacceptable for people to live. In this case access is likely to be prohibited. For employees who are providing essential services and recovery operations, restricted access can be used with close control on the doses. Other recovery options, including any required remediation options to remove contamination, may be implemented while controls on workforce access are in place.
Target	People working in contaminated areas.
Targeted radionuclides	All radionuclides. Particularly short-lived radionuclides.
Scale of application	Any size of workplace.
Time of application	Soon after deposition but may continue for some time. May be implemented while recovery options are being implemented.
Constraints	
Legal constraints	Compensation for lack of earnings. Duty of care of employers.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	This option will not reduce contamination levels in the restricted area. However, it will be effective in controlling doses to an essential workforce and limiting the spread of contamination as long as people comply and controls are enforced.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	None.
Social factors influencing effectiveness	Compliance with restricted access. Workers may not be willing to enter or work in a contaminated environment, though appropriate training may counteract this.
Feasibility	
Equipment	Monitoring equipment for workforce going into area.
Utilities and infrastructure	System to control and monitor doses to workforce.
Consumables	None
Skills	Ability to manage radiation protection of the workforce. Staff will need to be trained to use the monitoring equipment
Safety precautions	Monitoring health and safety when there is only a skeleton workforce in an establishment.
Waste	
Amount and type	There is potential for contaminated PPE and equipment, with disposal subject to conditions depending on the activity levels and other properties of the waste.
Doses	
Averted doses	

Back to list of options

1 Control workforce access

Factors influencing averted dose	Compliance with restricted access.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment • resuspension of activity deposited in the environment No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	Labour for implementing option.
Factors influencing costs	Size of area(s) where access is restricted. Level of security required.
Side effects	
Environmental impact	Buildings and outdoor areas may not be maintained.
Social impact	Loss of public amenities. Acceptability of key workers receiving additional doses. Effect on public perception.
Practical experience	None
Key references	N/A
Version	3
Document history	See Table 7.2 Previously called Restrict workforce access (time or personnel) to non-residential areas in version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

2 Impose restrictions on transport

Objective	To prevent the re-suspension of radionuclide contamination by all vehicle types. To prevent the spread of radionuclide contamination on vehicle surfaces. To reduce access to and egress from the affected area. To reduce exposure to passengers and drivers.
Other benefits	Any necessary recovery options related to cleaning or replacing of surfaces on roads may be implemented more easily whilst transport is restricted through the affected area. Reduced traffic allows for easier access and egress of recovery operational equipment.
Management option description	Prohibit members of the public from using their vehicles and /or impose restrictions on bus and train networks in a contaminated area. Closure of roads via the use of barriers/ signs. Some vehicular access may be required to allow for remediation operations and emergency vehicle access should not be restricted. In extreme cases it could also include the prevention of flights to prevent spread of contamination nationally or internationally. Lesser restrictions may include imposing stricter speed limits to minimise the dispersal of contaminated material deposited on the ground. Advice could also be provided to limit car use to essential tasks, and to keep windows closed and air conditioning turned off if driving through an affected area. Another consideration would be to allow public transport (eg buses) but prevent private vehicle use (ie cars). Advice to carry out regular washing of vehicles, with provision of wash stations would also help limit the spread of contamination. This option may not be required if the option (4) Restrict public access has already been implemented. However, in some cases access may be prohibited in heavily contaminated areas whilst transport may be restricted in less contaminated areas. In such cases rules may be determined for discrete areas to help limit contamination of vehicles and spread of contamination by vehicles.
Target	All transport vehicles and networks - emergency vehicles may still be granted access.
Targeted radionuclides	Likely to be more applicable for radionuclides with an inhalation risk - ie where no external risk from contamination on grounds, but wish to avoid resuspension and subsequent inhalation. Beneficial in restricting the spread of any nuclide, including beta and gamma emitters.
Scale of application	Any.
Time of application	Maximum benefits are associated with this option if implemented soon after emergency phase to prevent further spread of contamination.
Constraints	
Legal constraints	Seek specialist advice and guidance.
Environmental constraints	Strong winds may cause distribution and spread of contamination, thereby reducing the effectiveness of this option.
Effectiveness	
Reduction in contamination on the surface	This option **will not reduce** contamination levels in the restricted area, although it will be effective in limiting the spread of contamination and controlling doses. Therefore, unless only short lived radionuclides are involved, this must be used in conjunction with some other remediation in order to minimise duration of transport restriction, particularly if major transport routes are involved.
Reduction in surface dose rates	Surface dose rates will not be reduced as contamination levels will remain the same.
Reduction in resuspension	If restrictions are successfully applied, this will prevent vehicles from resuspending certain radionuclides.
Technical factors influencing effectiveness	Level of contamination in area. Properties of radionuclide(s) involved. The physical and chemical properties of the form.
Social factors influencing effectiveness	Disruption in the affected communities may be extensive and members of public may refuse to adhere to advice. There may be problems for people requiring urgent use of vehicles (eg medical emergency, food supplies), travel to/ from home/ work. Access criteria for emergency vehicles will need to be established.
Feasibility	
Equipment	Road blocks, notices, signs and traffic cameras, monitoring equipment.

Back to list of options

2 Impose restrictions on transport

Utilities and infrastructure	Roads and transport networks
Consumables	Notices, signs amongst others
Skills	Operator time and personnel requirements will vary depending on the size and scale of the incident where restrictions on transport are required.
Safety precautions	None.
Waste	
Amount and type	If cleaning of vehicles takes place as part of transport restrictions then waste will occur. Waste water could be collected and treated - see Datasheet 26, while disposal of solid waste will be subject to conditions depending on the activity levels and other properties of the waste.
Doses	
Averted doses	Exposure from re-suspended radionuclides would be reduced for people living and working in the affected area. Averted exposure may be influenced by compliance with restrictions on transport; members of public may need to drive through contaminated area to obtain food / medical supplies.
Additional doses	None.
Intervention costs	
Operator time	That of implementing transport restrictions
Factors influencing costs	Duration of restrictions.
Side effects	
Environmental impact	Restrictions on transport could improve local air quality (due to reduction in car exhaust emissions). In an agricultural area there may be animal welfare issues (ie provision of feed) that should be considered - seek specialist advice and guidance.
Social impact	Transport restrictions will cause some level of disruption, particularly if roads are closed, trains and flights are cancelled, or if restrictions are imposed for an extended period of time. The level of disruption and the impact on society must be balanced against the benefits gained from imposing restrictions.
Practical experience	Restrictions on transport were implemented during the remediation of the dioxin incident in Seveso, Italy. Fukushima, Chernobyl and US accidents where roads were contaminated.
Key references	UK Recovery Handbook for Chemical Incidents Japan Decontamination Guidelines 2nd Ed 2013. III Decontamination and other measures for roads. Table 2-24 Measures to reduce public exposure in connection with decontamination and other works for roads. Page 2.54
Version	1
Document history	See Table 7.2 Adapted from datasheet of same name from the UK Recovery Handbook for Chemical Incidents.

Back to list of options

3 Permanent relocation from residential areas

Objective	To reduce external gamma and beta doses from material deposited on surfaces and inhalation doses from material resuspended within contaminated inhabited areas.
Other benefits	Any necessary management options will be implemented more easily while the population are absent from the area.
Management option description	The removal of people from a contaminated area on a permanent basis. Resettlement may occur in the future. This option may be required if it has been determined that it is not practicable to decontaminate structures and open areas to levels that are protective of human health without the imposition of unreasonable restrictions (eg the prohibition of severe restriction of children playing outdoors.) Permanent relocation might be considered if the alternative option of temporary relocation (see Datasheet 5) is expected to last for more than 1 year, as such a lengthy temporary relocation may not be acceptable to the community. There is a high social and economic impact associated with this option.
Target	People living in contaminated residential areas.
Targeted radionuclides	Only long-lived radionuclides.
Scale of application	Any. This option is likely to be complex for very heavily populated areas.
Time of application	Maximum benefit soon after deposition or during the emergency phase
Constraints	
Legal constraints	Compensation for homes, possessions and possible loss of earnings. Building new residential areas and waste facilities will need to meet legislation and authorisation may need to be granted.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	This option will not reduce contamination in the restricted area. However, if people comply, this option is fully effective at removing all doses during the period of relocation.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	Time of implementation.
Social factors influencing effectiveness	Compliance: people cannot be forced to leave their homes. Trust in the scientific community and authorities seen to be providing advice. Ability to prevent subsequent unauthorised access.
Feasibility	
Equipment	Transport vehicles for moving people and possessions
Utilities and infrastructure	New housing. Infrastructure to support relocated populations: schools, doctors, social services, support for those seeking employment etc.
Consumables	Fuel and parts for vehicles and other transport
Skills	Drivers. Security personnel may be required to support drivers. Removal personnel. Supportive administration at new site.
Safety precautions	None
Waste	
Amount and type	Any waste arisings would depend on future use of the area. There will be no waste to be disposed of urgently.
Doses	
Averted doses	Doses will be reduced by 100% for the people relocated if they are moved away from the affected area.
Factors influencing averted dose	Time of implementation.

Back to list of options

3 Permanent relocation from residential areas

	Level of exposure at new location. Compliance with relocation as people cannot be forced to leave their homes. People re-entering area.
Additional doses	People implementing permanent relocation could be exposed to: • external exposure from deposited radioactive material • inhalation of resuspended radioactivity No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	Assuming people are moved about 1 hour away to a 'holding' location, it is estimated that 1 person can relocate about 60 people every 4 hours. Further effort will be required to relocate people and their possessions to a new area.
Factors influencing costs	Weather. Type of vehicles used. Number of vehicles available. Ease of access and transport route. Distance people have to be moved. Numbers of people being relocated.
Side effects	
Environmental impact	Building new residential areas will impact on the environment, eg need to build new infrastructure, changes of land use, generation of waste, etc. If it is decided not to remediate the affected area then there may be associated environmental impact.
Social impact	Disruption in affected communities will be very large (those moved and those in receiving communities). Fragmentation of communities. Need for accommodation and infrastructure, with additional burden on schools, medical and recreational services, in the receiving community. There may be psychological impacts on members of the public who are required to relocate permanently from their homes. If workers are unable to undertake their usual jobs, or children require new schools, they may lose their sense of community. Relocation can lead to lifestyle changes that cause health effects that are unrelated to radiation. Can lead to a deep sense of injustice in the resettlers, even when compensated for their losses, offered free houses and given a choice of resettlement location. Some older resettlers may never adjust. Studies have also shown that those who remain behind in or close to an affected area also suffer psychological impacts linked to stigma associated with the area, evacuated buildings and worries over potential health effects, though may cope better psychologically with the accident's aftermath than have those who were resettled to less affected areas.
Practical experience	Relocation after the Chernobyl accident. Relocation in the Marshall islands. Relocation in Japan following the Fukushima accident. Relocation following the Kyshtym accident.
Key references	IAEA (1991). The international Chernobyl project: an overview. Report by an International Advisory Committee, IAEA, Vienna. IAEA (2006) Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine. The Chernobyl Forum: 2003-2005. IAEA (2011) Final Report of the International mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Dai-ichi NPP 7-15 October 2011, Japan, IAEA NE/NEFW/2011, 15/11/2011 Niedenthal J (1997) A History of the People of Bikini Following Nuclear Weapons Testing in the

Back to list of options

3 Permanent relocation from residential areas

	Marshall Islands: with Recollections and Views of Elders of Bikini Atoll, Health Physics 73(1) Reuther C (1997) Atomic Legacy in the Marshall Islands, Environmental Health perspectives, Vol 105, No 9 Simon S (1997) A Brief History of People and Events Related to Atomic Weapons Testing in the Marshall Islands, Health Physics 73(1) UNSCEAR (2013) Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Sixtieth session (27-31 May 2013). General Assembly official records sixth-eighth session, supplement No 46. A/68/46 More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	3
Document history	See Table 7.2

Back to list of options

4 Restrict public access

Objective	To reduce external gamma and beta doses from material deposited on surfaces and inhalation dose from material resuspended from surfaces within contaminated non-residential areas.
Other benefits	Any necessary recovery options will be implemented more easily whilst the population are absent from the area. Reduction in ingestion doses from consuming wild foods collected from recreational areas, eg woods, countryside. Restricted public access will limit the spread of contamination.
Management option description	For non-residential areas accessed by the public (eg parks, recreational areas), only a total prohibition on access will be enforceable. Any partial restriction cannot be controlled and it will not be possible to control the doses received by members of the public. Could be implemented in the short or long term. Recreational areas are unlikely to have a high priority for clean-up and so restricting access may be necessary prior to any clean-up being implemented. Land is only likely to be fenced-off in the long term if it is privately owned. Public land would be controlled with notices and barriers on main access routes (if practicable). Temporary prohibition of access to non-residential areas may be enforced while clean-up is being implemented.
Target	People living in and visiting contaminated areas.
Targeted radionuclides	All radionuclides. Particularly short-lived radionuclides.
Scale of application	Any scale.
Time of application	Maximum benefit if carried out soon after deposition. Can be applied at any time and for any duration of time. May be implemented while other management options are implemented.
Constraints	
Legal constraints	May require legislation to restrict access to land, depending on ownership.
Environmental / technical constraints	None.
Effectiveness	
Reduction in contamination on the surface	If people comply, this option is fully effective at reducing doses from the areas where access is prohibited. This option will not reduce contamination levels in the restricted area, however the spread of contamination will be limited.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	Effective exclusion of people from an area may be difficult to demonstrate. Success of barriers and fences (if used).
Social factors influencing effectiveness	Compliance: an effective public information strategy will be essential.
Feasibility	
Equipment	None.
Utilities and infrastructure	None.
Consumables	Notices, signs, barriers etc.
Skills	None.
Safety precautions	None.
Waste	
Amount and type	None.
Doses	
Averted doses	Doses that would have been received from the prohibited areas will be reduced by 100% if access is effectively stopped.

Back to list of options

4 Restrict public access

Factors influencing averted dose	Compliance with access prohibition. Population habits - for example, if people didn't spend time in areas where access is prohibited, this option will not reduce their overall doses. Success of cordons (if used).
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment • resuspension of activity deposited in the environment No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	Labour for implementing option.
Factors influencing costs	Size of areas(s) where access is restricted. Type of area(s) where access is restricted - the costs of restricting access to a highly populated or business area will be different to restricting access to a rural area or recreational land. Possible need to regulate access prohibition in some areas.
Side effects	
Environmental impact	Prohibition of access to countryside may benefit fauna and flora.
Social impact	Loss of public amenities. Changed perception of the countryside / other recreational areas. Living adjacent to areas that are known to be contaminated, even if access is restricted, can be psychologically harmful. Can result in significant negative social consequences, potentially leading to advice from the authorities to the general public being ignored. Temporary access, for example if residents are allowed to enter the area temporarily for a few hours and carry the minimum necessary goods out from there while ensuring safety, may help reduce this.
Practical experience	In the former Soviet Union after the Chernobyl incident. In Japan after the Fukushima accident. In the UK as a consequence of foot and mouth disease.
Key references	N/A
Version	3
Document history	See Table 7.2 Previously called Prohibit public access to non-residential areas in version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

5 Temporary relocation from residential areas

Objective	To reduce external gamma and beta doses from material deposited on surfaces and inhalation doses from material resuspended from surfaces within contaminated inhabited areas.
Other benefits	Management options will be more easily implemented whilst the population are absent.
Management option description	The removal of individuals from a contaminated area on a temporary basis. It is likely that people would be moved to an area that is sufficiently far outside the contaminated area that doses are minimal but is near enough for people to commute to their normal places of work. Should be time bound. A temporary relocation of over a year is unlikely to be acceptable to residents, in which case permanent relocation (see Datasheet 3) could be considered. May also be considered whilst recovery options are underway.
Target	People living in contaminated areas.
Targeted radionuclides	All radionuclides. Particularly useful for short-lived radionuclides.
Scale of application	Any number of people. Easier to implement on a small scale.
Time of application	Maximum benefit if people are moved out soon after deposition or are evacuated during the emergency phase and do not return.
Constraints	
Legal constraints	Compensation for people moved and possible lack of earnings. Provision of security for empty buildings.
Environmental constraints	Maintenance of buildings and environment for longer term temporary relocation.
Effectiveness	
Reduction in contamination on the surface	This option will not reduce contamination in the restricted area. However, if people comply, this option is fully effective at removing all doses during the period of relocation.
Reduction in surface dose rates	
Reduction in resuspension	
Technical factors influencing effectiveness	Time of implementation. Clear communication of need to relocate and related instructions.
Social factors influencing effectiveness	Compliance: people cannot be forced to leave their homes. Trust in the scientific community and authorities seen to be providing advice. Ability to prevent subsequent unauthorised access. Ability to commute to work. Affects on pets and animals. Theft from properties.
Feasibility	
Equipment	Transport for moving people and possessions.
Utilities and infrastructure	Alternative accommodation / housing. Infrastructure to support relocated populations: schools, doctors, social services etc. Security services for area that has been relocated.
Consumables	Fuel and parts for vehicles and other transport.
Skills	Drivers. Security personnel may be required to support drivers.
Safety precautions	None
Waste	
Amount and type	No waste produced
Doses	
Averted doses	Doses will be reduced by 100% during the period of relocation if people are moved fully away from the affected area.

Back to list of options

5 Temporary relocation from residential areas

Factors influencing averted dose	Time of implementation. Level of exposure at new location. Compliance with relocation.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment • enhanced resuspension of activity deposited in the environment No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	Assuming people are moved about 1 hour away, it is estimated that one person can relocate 60 people every 4 hours.
Factors influencing costs	Weather. Type of vehicle used. Number of vehicles available. Ease of access and transport route. Distance people have to be moved. Numbers of people being move. Availability of appropriate accommodation.
Side effects	
Environmental impact	Increasing the size of the population in the area where people are temporarily relocated may impact on the environment, eg amount of general waste generated, increased traffic.
Social impact	Disruption in the affected communities (those moved and those in the receiving communities). Fragmentation of communities. Need for accommodation and infrastructure, with additional burden on schools, medical and recreational services, in the receiving community. Enforced evacuation and entry restrictions can force livestock owners to slaughter valuable animals. Prolonged evacuation can lead to an increase in domestic strife, alcoholism and illnesses such as deep vein thrombosis from lack of exercise. Criminals may take advantage evacuations to steal property and money left behind, adding to the emotional distress of those in evacuation centres. This has been known to occur, despite efforts of law enforcement agencies. When temporary evacuation orders are lifted residents may have mixed feelings of relief and worry and may choose not to return, even if they know decontamination work has lowered radiation levels.
Practical experience	Some experience of temporary relocation for other incidents at a local level. Relocation after the accidents at Chernobyl and Fukushima. Relocation after the incident in Goiania. Relocation in the Marshall Islands.
Key references	Akabayashi A and Hayashi Y (2012) Mandatory evacuation of residents during the Fukushima nuclear disaster: an ethical analysis, Journal of Public Health vol 34, no 3, pp 348 - 351 Becker S (2013) The Fukushima Dai-ici Accident: Additional Lessons from a Radiological Emergency Assistance Mission, Health Physics Volume 105, Number 5, pp455-461 IAEA (1988) The Radiological Accident in Goiania. STI/PUB/815 ISBN 92-0-129088-8, IAEA, Vienna Japan NGO Centre for International Cooperation (2014) Miyakoji residents showed mixed feelings toward full open of no-go zone - See more at: http://fukushimaontheglobe.com/the_earthquake_and_the_nuclear_accident/3431.html#sthash.ouYt38UA.dpuf http://fukushimaontheglobe.com/the_earthquake_and_the_nuclear_accident/3431.html

Back to list of options

5 Temporary relocation from residential areas

	Knight S and Slodkowski A (2013) For many Fukushima evacuees, the truth is they won't be going home http://in.reuters.com/article/2013/11/11/us-japan-fukushima-idINBRE9AA03Z20131111 Morrey M and Allen P (1996). The role of social and psychological factors in radiation protection after accidents. *Radiation Protection Dosimetry*, 68**,** (3/4), 267-271. Oughton DH, Bay I, Forsberg E-M, Hunt J, Kaiser M and Littlewood D (2003). Social and ethical aspects of countermeasure evaluation and selection - using an ethical matrix in participatory decision making. Deliverable 4 of the STRATEGY project. Agricultural University of Norway, Norway. UNSCEAR (2013) Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Sixtieth session (27-31 May 2013). General Assembly official records sixth-eighth session, supplement No 46. A/68/46 More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	3
Document history	See Table 7.2

Back to list of options

6 Collection of leaves

Objective	To reduce inhalation and external doses from fallen leaves within inhabited areas. Mainly for use when deposition has occurred under dry conditions and when trees and shrubs are in leaf. After wet deposition, consideration should be given to decontaminating the ground under trees as most of the contamination washes straight off the trees.
Other benefits	None
Management option description	Collection of leaves (deciduous trees and shrubs), needles and pinecones (coniferous trees). Leaves that have fallen from trees are collected and disposed of or composted. Additional decontamination may also be necessary for surfaces under trees/shrubs. Leaf fall may be induced by the application of chemical sprays subject to there being no environmental restrictions on the chemicals used. As conifers will shed needles over a number of years (2 - 7), repeated application may be beneficial after the first leaf fall material has been collected. If leaf fall is expected soon, it may be beneficial to use polythene sheeting/netting under trees to isolate falling leaves from the ground and aid in collection of leaves. Alternatively, trees and shrubs may be pruned (see Datasheet 27) in order to avoid waiting for leaf fall or repeated collection from coniferous trees. If contamination is present in forest areas adjacent to inhabited areas, a significant reduction in dose rates in the inhabited area can be seen by decontamination of the first 10 m wide strip of forest nearest to the inhabited area. There may be a need for large numbers of vehicles to collect and transport leaves. Care should be taken with vehicle access as this could damage the ground, causing mud and embedding leaf litter into the soil. There is a potential to generate large volumes of putrescible waste, which may lead to problems with disposal. Incineration (using HEPA filter on exhaust stack) or compaction may be required. If leaves are stored, the management of liquid waste generated during decomposition should be considered.
Target	Trees and shrubs in inhabited areas that are in leaf at the time of deposition.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if the time between deposition and leaf drop is short.
Scale of application	Removing leaf litter can generate huge quantities of wastes, which may limit the area that can be treated.
Time of application	If there is a significant time period between deposition and leaf fall there is an increased likelihood that weathering will wash contamination from leaves to the ground. **Deciduous trees:** Collection must be carried out soon after leaf fall before weathering moves activity from leaves to underlying soil, leaves blow to contaminate adjacent areas or compost into soil. **Coniferous trees:** Maximum benefit if collection of pine cones is in the autumn when the needle fall for the year has finished.
Constraints	
Legal constraints	Ownership and access to property. Waste disposal of collected leaves, Organic material may not meet criteria set by the LLWR, therefore authorisation for waste disposal may be required.
Environmental constraints	Slope of land (if extreme).
Effectiveness	
Reduction in contamination on the surface	Most contamination on trees and shrubs is associated with the leaves. So, the decontamination factor (DF) is likely to be similar to that for tree removal (DF up to 50) if leaves are on the trees at the time of deposition and all the leaves are collected (see Datasheet 27). This option will be less effective for coniferous trees, even if collection is repeated several times. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by trees, bushes and shrubs and the time spent by individuals on or close to these areas.
Reduction in surface dose rates	External gamma and beta dose rates surrounding shrubs and trees will be significantly reduced if leaves are collected. An average dose rate reduction of up to 90% were seen, with an average reduction of about 30% following Japanese tests removing litter/ground cover.

Back to list of options

6 Collection of leaves

Reduction in resuspension	Resuspended activity in air adjacent to the shrubs and trees will be significantly reduced if leaves are collected.
Technical factors influencing effectiveness	Weather conditions eg windy conditions will hamper attempts to collect all contaminated leaves. Collection of all contaminated leaves; once they disperse or begin to compost, the technique will become less effective. Some contamination may transfer from leaves to the underlying surfaces. Consistency in effective implementation of option over a large area. Number of trees/shrubs in the area and tree species - the foliage level at time of deposition will affect contamination levels on the leaves and will be different between deciduous and evergreen plants/trees. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Additionally, if leaf collection is delayed such that a second fall of uncontaminated leaves occurs, this may act as shielding to underlying contamination, so that when collection is eventually made there is an increase in dose rate.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Garden vacuum equipment. Rakes. Shovels. Wheelbarrows. Polythene sheeting/netting to collect falling leaves. Municipal vehicles for slurry collection would also be very efficient in sucking up leaves and could be applied on a large scale in the autumn. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads (transport of equipment, materials and waste).
Consumables	Fuel and parts for equipment and vehicles.
Skills	Only a little instruction is likely to be required. The method could be implemented by inhabitants of the affected area as a self-help measure, after instruction from authorities. Provision of safety and other required equipment may be required.
Safety precautions	Gloves and overalls. Respiratory protection, especially in dusty conditions.
Waste	
Amount and type	*Amount*: $5\ 10^{-1}$ kg m^{-2}. Experience in Japan found that removing leaves and humus generated 0.2 - 0.9 m^3 waste per m^2 *Type:* leaves / pine needles / pinecones. This is putrescent material which may generate liquid waste generated during decomposition. Therefore, as well as considering potentially large volumes of leaves, the management of liquid waste should be considered.
Doses	
Averted doses	Most contamination is associated with leaves. Figure 1.4 gives an indication of the likely importance of trees in contributing to long-term external doses. Reductions in external gamma dose rate received by a member of the public living in an inhabited area shortly after leaf collection could be expected to be similar to those given for tree removal (see Datasheet 27) if the trees were predominantly deciduous.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Number of trees/shrubs in the area ie environment type/land use. Time of implementation. The impact of removing leaves on the overall doses will be reduced with time as there will be less contamination on the leaves due to natural weathering.
Additional doses	Exposure pathways workers could be exposed to are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may

Back to list of options

6 Collection of leaves

	be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	2 10^2 m^2/team.h (team size: 1 person). If underlying humus is collected with the leaf litter then the removal rate will be considerably slower. Depending on the PPE used individuals may need to work restricted shifts.
Factors influencing costs	Weather. Access. Size of area. Underlying surface. Type of equipment used. Access.
Side effects	
Environmental impact	Possible adverse effect on ecology and plant health. Removal of leaf litter from broad swathes of forest could lead to erosion and poor tree health. Replacement nutrients may be required. Possible soil erosion. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Collection of fallen leaves will make the area look tidier. Temporary restriction of access to public areas. Waste disposal may not be acceptable. Trees remain in place (positive benefit for wildlife and the area). While it has been shown that decontamination of the first 10 m wide strip of forest nearest to inhabited areas leads to a significant reduction in dose rates, public opinion may require a wider strip to be decontaminated. Decontamination of forest areas can lead to stress in the local population, while reassurance may not follow if decontamination is considered unnecessary.
Practical experience	Removal of leaf litter used as a decontamination technique in forest areas in Japan following the Fukushima accident.
Key references	Hardie SML and McKinley IG (2014) Fukushima remediation: status and overview of future plans. J Environ Radioact 2014; 133:17-85. IAEA (2011) Final Report of the International mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Dai-ichi NPP 7-15 October 2011, Japan, IAEA NE/NEFW/2011, 15/11/2011 Kihara S (2012) Report of the Results of the Contamination Model projects, Overview of the Results of Decontamination Demonstration Tests Conducted in Date City and Minami Soma City, presentation at meeting held on March 26, 2012 at Fukushima City Public Hall Little and Bird (2013) - Little J and Bird W, A Tale of Two Forests. Addressing Postnuclear Radiation at Chernobyl and Fukushima, Environmental Health Perspectives, Volume 121, Number 3, March 2013 Ministry of the Environment, Japan (2013) Progress on Off-Site Cleanup Efforts in Japan, presentation by Ministry of the Environment on Oct 7th 2013 Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Miyahara K., Tokizawa T., Nakayama S (2012) Decontamination pilot projects: building a

Back to list of options

6 Collection of leaves

	knowledge base for Fukushima environmental remediation. Mater Res Soc Symp Proc 2012; 1518:245-256. Morgan CJ (1987). Methods and cost of decontamination and site restoration following dispersion of plutonium in a weapon accident. Aldermaston, AWE, SCT Laboratory. Yasutaka T, Naito W, Nakanishi J (2013) Cost and effectiveness of decontamination strategies in radiation contaminated areas in Fukushima in regard to external radiation dose. PLoS One 2013; 8(9):e75308 Yoshihara T, Matsumara H, Hashida S and Nagaoka T (2013) Radiocesium contaminations of 20 wood species and the corresponding gamma-ray dose rates around the canopies at 5 months after the Fukushima nuclear power plant accident, Journal of Environmental Radioactivity, 115 (2013) 60-68 More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	3
Document history	See Table 7.2

Back to list of options

7 Cover grass/soil surfaces with clean soil/asphalt

Objective	To reduce inhalation and external doses from contamination on areas of grass or soil within inhabited areas.
Other benefits	The spread of contamination will be limited. Shielding of contamination with soil effectively ties-down the underlying contamination that could otherwise be resuspended. This is therefore an effective tie-down option. If asphalt is used as the covering material, or if geomembranes and/or clay are incorporated into a covering soil layer, water infiltration will be restricted. This will reduce leaching of radioactive material into drinking water sources.
Management option description	A layer of soil or a hard surface such as asphalt may be used to cover contaminated grass or soil to provide shielding from contamination on the ground area. May also be applied to reduce the external dose rate from residual contamination on a soil surface after removal of a topsoil layer (see Datasheet 24). Can also be used for tie-down of contaminated soil to reduce the resuspension hazard to members of the public. (See Datasheet 23 for more information on tie-down options) When planning to cover contaminated grass/soil, the need for vehicle access, and the control of such access so as not to turn the underlying ground to mud (that cannot be easily covered) must be considered. This option severely complicates subsequent removal of the contamination and restricts future development of the area. **Soil:** A 5 - 10 cm layer of radiologically clean soil can be applied in areas where people spend time. Use of sprays to dampen soil would help reduce resuspension and help with bedding in until plants are growing through the new soil layer to anchor it. A multi-layered cap may be constructed using compacted filler underneath a geomembrane, a layer of compacted clay, another geomembrane and a layer of topsoil. **Asphalt:** A layer of asphalt (or alternatives, eg concrete or paving stones) can be applied over small areas adjacent to buildings, particularly as soil very close to a building may, in some cases, be contaminated to a greater depth, due to run-off from the building. Generally, the procedure would involve applying a layer of stabilising gravel, then asphalt (using shovels and other hand-tools) and finally to use a roller to consolidate. Resurfacing using asphalt may also be carried out by applying a thick layer of gravel, on to which is sprayed a thin sealing asphalt emulsion layer, and finishing with a thin layer of gravel. Dust creation during implementation is unlikely to be a problem therefore management options to reduce resuspension hazard to workers will not be necessary (unless the resuspension hazard in the area is deemed significant).
Target	Grass/soil surfaces in inhabited areas. Typically coverage with clean soil will be targeted at gardens, parks, playing fields and other open spaces, while use of asphalt will be targeted at small to medium sized open areas, often around residential buildings, schools etc, where people generally spend much of their time while outdoors.
Targeted radionuclides	All long-lived radionuclides. Typically not short-lived radionuclides alone, though covering with soil may be used to reduce external doses from short-lived radionuclides if implemented quickly. Tie-down usage targets alpha emitting radionuclides that give rise to inhalation doses from resuspended material.
Scale of application	Covering with soil: Best suited to smaller areas, though larger areas may be possible. Covering with asphalt: Small - medium sized areas with boundaries around buildings.
Time of application	**Tie-down:** maximum benefit is achieved if carried out soon after deposition when most of the contamination remains on the ground surface and resuspension is likely to be high. **Shielding:** likely to be effective for a long time after deposition. It may be beneficial to wait until after the first rain so that most contamination has washed off other outdoor surfaces and buildings on to ground areas to avoid re-contamination of clean surfaces following early implementation.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Cultural heritage protection, eg use on listed and other historically important sites and in conservation areas.

Back to list of options

7 Cover grass/soil surfaces with clean soil/asphalt

Environmental constraints	Cold weather (temperature must be > 5 °C). In extreme cases, the slope of the area may be a concern. There may be issues with the acceptability of smothering flora and fauna, if covering with asphalt. The condition of the underlying area may affect the ability to cover, eg mud cannot easily be covered with asphalt or soil.
Effectiveness	
Reduction in contamination on the surface	The decontamination factor (DF) for this option is 1, as no contamination is removed. Subsequent disturbance of the clean layer, by whatever means, will reduce the effectiveness of the option.
Reduction in surface dose rates	**Soil:** A reduction in gamma dose-rate above the clean soil of 30-80% could be expected depending on the energy of the radionuclide. This option will be 100% effective in reducing external beta dose-rates. **Asphalt:** While the asphalt remains undisturbed, the external gamma dose rate above the surface will be reduced by a factor which is dependent on the energy of the gamma rays emitted and the depth of the asphalt layer used. This option will effectively reduce external beta dose rates above the surface by 100%.
Reduction in resuspension	Resuspended activity in air above the soil (or grass) surface will be effectively reduced to 100%.
Technical factors influencing effectiveness	Design of the cover - this may need to be adjusted to the specific features of a site eg amount of rainfall Thickness of layer used Density of material used - compaction may be required depending on the density of the material Availability of required quantities of material - may be an issue with soil. Traces of contamination in the cover material. Size of treated area. Evenness of ground surface. Correct implementation of option. Time of implementation - if done too early, more contamination washes on to clean surface. Number of plants, shrubs and trees left in area.
Social factors influencing effectiveness	If soil is used as the covering medium, there may be restrictions on digging the soil that has been used to cover contamination.
Feasibility	
Equipment	Soil: Spades. Bobcat mini-bulldozer. Rake. Plywood for surface compaction Sprinkling equipment Transport vehicles for equipment and soil. Asphalt: Small asphalt roller. Shovels. Special rakes for planing gravel / asphalt layers. Trucks for transport of roller, asphalt and stabilising gravel.
Utilities and infrastructure	Roads for transport of equipment and materials.
Consumables	Soil and possibly geomembrane/clay material, or asphalt and stabilising gravel. Fuel and parts for equipment and vehicles.
Skills	On a small scale, using spades, covering with soil can be implemented by unskilled workers. This option could be implemented as a self-help measure. Instruction and provision of safety and other required equipment should be ensured. Requires hard physical work, which not all persons would be capable of. If covering a larger area with soil, or if covering with asphalt, skilled workers will be required to operate equipment.
Safety precautions	Asphalt workers will require safety helmets, gloves and safety shoes. All workers may require respiratory protection, particularly in dry and dusty conditions.

Back to list of options

7 Cover grass/soil surfaces with clean soil/asphalt

Waste	
Amount and type	None
Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Amount of grass/soil in the area ie environment type/land use. Size of the area resurfaced. Time of implementation. The impact on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	Depends on access and openness of area and equipment used. Soil, small areas: 20 m^2/team.h (team size: 1 person). Soil, larger areas: 400 m^2/team.h (team size: 2 people). Asphalt: 15 m^2/team.h (team size: 4 people). Depending on the PPE used individuals may need to work restricted shifts.
Factors influencing costs	Type of equipment and covering medium used. Thickness of covering layer used. Quality of the asphalt or soil type and condition Operator skill. Amount of vegetation to be removed. Evenness of surface. Weather. Topography. Size of area. Access. Use of personal protective equipment (PPE). Need to take into account drainage/sewerage pipes etc.
Side effects	
Environmental impact	Possible adverse impact on bio-diversity. In particular, use of asphalt will result in total loss of biodiversity in the treated area. Possible impact on fertility. In particular, use of asphalt will result in total loss of fertility in the treated area. Aesthetic consequences of landscape changes, particularly from soil to asphalt. Loss of plants. Possible soil erosion risk due to increased soil depth, although reseeding of grass or replanting would reduce the risk of soil erosion. There will also be an impact in areas from where soil is obtained, potentially affecting the quality or quantity of arable land available. Possible flooding risk in areas where large scale application of asphalt is used to cover

Back to list of options

7 Cover grass/soil surfaces with clean soil/asphalt

	contaminated land. As contamination is not removed over time some radionuclides may leach deeper into the soil.
Social impact	Acceptability of leaving some contamination in-situ. Aesthetic consequences of landscape /amenity changes. Future development of the site may be limited in order not to re-exposure contamination. Possibility of radionuclides leaching deeper into the soil may preclude use of land for food production. Access to public areas may need to be restricted temporarily before clean surface is applied. Potential loss of public amenity if used to cover grass areas.
Practical experience	The method has been widely applied in the Former Soviet Union after the Chernobyl accident. Following the Fukushima accident, soil dressing was implemented in those areas with contaminated spots with high activity concentration of radioactive caesium in the subsoil layer to mitigate radiation hazard.
Key references	Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Gjørup H, Jensen NO, Hedemann Jensen P, Kristensen L, Nielson OJ, Petersen EL, Petersen T, Roed J, Thykier-Nielsen S, Heikel Vinther F, Warming L and Aarkrog A (1982). *Radioactive contamination of Danish terrirory after coremelt accidents at the Barsebäck power plant.* Risø National Laboratory, Risø-R-462. Hedemann Jensen P, Lundtang Petersen E, Thykier-Nielsen S and Heikel Vinther F (1977). Calculation of the individual and population doses on Danish terrirory resulting from hypothetical core-melt accidents at the Barsebäck reactor. Risø National Laboratory, Risø-R-356. Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Roed J (1999). Decontamination in a Russian settlement. *Health Physics*, **76**, (4), 421-430. Roed J, Andersson KG, Varkovsky AN, Fogh CL, Mishine AS, Olsen SK, Ponomarjov AV, Prip H, Ramzaev VP, Vorobiev VF (1998). *Mechanical decontamination tests in areas affected by the Chernobyl accident.* Risø-R-1029, Risø National Laboratory, Roskilde, Denmark. Roed J, Lange C, Andersson KG, Prip H, Olsen S, Ramzaev VP, Ponomarjov AV, Varkovsky AN, Mishine AS, Vorobiev BF, Chesnokov AV, Potapov VN and Shcherbak SB (1996). *Decontamination in a Russian settlement.* Risø National Laboratory, Risø-R-870, ISBN 87-550-2152-2. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheets Cover grassed and soil surfaces (eg with asphalt) (datasheet 27) and Cover with clean soil (datasheet 28) from version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

8 Demolish/dismantle and dispose of contaminated material

Objective	To remove contamination, including hotspots or more widespread material, associated with external and internal building surfaces and other contaminated items ranging from cars, street furnishings, indoor objects, personal items, furnishing and fixtures.
Other benefits	To reduce inhalation and external doses arising from contamination. To minimise the overall volume of waste requiring disposal, and the associated level of traffic required, by selectively removing contaminated materials.
Management option description	Depending on the level of contamination on surfaces/objects, and the ease of decontamination, it may be decided to dismantle or remove objects and dispose of them, rather than carrying out decontamination (see datasheets 20, 21 and 22) to an acceptable level. A variety of equipment will be required, together with regular vehicular access to remove items and rubble. Consideration should be given to monitoring of equipment and vehicles to prevent the spread of contamination. Dismantling/demolition may generate large volumes of wastes. It is important to apply best practise techniques for minimising the waste produced, with efficient and effective management of waste through a planned waste management strategy being essential to ensuring the success of the recovery process. It will therefore be important to • establish clearance levels to help manage the volume of waste being disposed of as radioactive material. Cleared material should be considered for recycling where possible • establish appropriate disposal routes for each of the waste types generated - some negotiation with the regulators may be necessary • bag waste items where possible to contain contamination and segregate material collected, using a suitable area for sorting, based on its radioactivity content. Consider size reduction, if possible • establish an inventory of materials to keep track of the activity and amounts generated **Dismantling** refers to the physical removal of selected components (such as contaminated environmental control systems) from equipment. Dismantling could be the sole activity of decontamination efforts or removal of substructures prior to other cleanup techniques, or to expose inaccessible areas of contamination. **Disposal** refers to the complete destruction and or disposal of equipment, parts of equipment or any other parts of the infrastructure by an appropriate disposal route. Significant preparation activities may be required, for example all surfaces may need to be washed down to minimise dust. **Selective/partial dismantling** involves removing components of the building (doors, windows, wooden panels, etc.) or outside objects such as street furnishings (items such as street signs, bus shelters) to remove contamination. **Roof removal**, including replacing contaminated roof covering with new or cleaned slates/tiles and removal of contaminated gutters and drains, could be implemented as a more extreme example of partial dismantling. **Building demolition** may be required in more extreme circumstances. Techniques used could include using a ball and crane, pneumatic chisel, or hydraulic shears, crushers or puliverisers. In all cases emissions (ie dust and particulate matter) will need to be monitored and controlled. This may be achieved by use of a dust suppression system such as a water spray during demolition, with suitable management of any liquid waste arising. For more specialist demolition, buildings could be encapsulated in a scaffolding structure, faced with panels, equipped with a HEPA filtered ventilation system to control dust and particulate emissions. Although it is unlikely that foundations would be significantly contaminated, unless contamination has leeched deep into the ground, they may be removed (by jack hammers or other means) depending on the size of the building, if required. Building demolition will only be acceptable if the surrounding environment is also contaminated. Surrounding ground surfaces must also be decontaminated or removed. Checks for asbestos must take place before buildings are demolished. **Internal objects**, fixtures and furnishings in buildings can be removed, or it may be possible to remove and replace part of an object. Contamination should be fixed to the surface prior to removal if there is a risk of dust further spreading contamination during the removal process. For upholstery, unfixed carpets and linen, a spray fixative of 10% glycerol in water can be used; wax polish can be sprayed on to smooth finished furniture to prevent dust spreading during removal. **Vehicle disposal** any vehicles severely contaminated on external and/or interior contaminated would be stripped down and disposed of accordingly. This may involve towing

Back to list of options

8 Demolish/dismantle and dispose of contaminated material

	the vehicle (possibly combined with fixing of contamination) to appropriate site for disposal. Another option could be to dismantle vehicles on site (hand deconstruction). **Decontamination prior to disposal** If a decision is made to dispose of contaminated material / objects the implementation of other recovery options to reduce the amount of contamination in the final waste generated should also be considered.
Target	Highly contaminated buildings or items, including vehicles, street furnishings, indoor objects, personal items, furnishing and fixtures, within areas (external, internal and semi-enclosed) where exposure concentrations are too high for people to live or work.
Targeted radionuclides	This recovery option is applicable for all long-lived radionuclides, especially on material that is otherwise difficult to decontaminate. Unlikely to be suitable for short-lived radionuclides alone, especially for more extreme techniques such as roof replacement or building demolition.
Scale of application	Any.
Time of application	Dismantling, and particularly demolition, can cause significant resuspension of radioactive material. Therefore if other decontamination options are also being implemented, it is important to consider the sequencing of techniques so as to avoid recontamination of previously treated areas. Otherwise, this recovery option is not time limited and can be implemented at any stage, though there is maximum benefit if carried out within a few weeks of deposition when maximum contamination is on the surfaces.
Constraints	
Legal constraints	The dismantling or demolition of non-residential properties does not require planning permission or prior approval. However, the dismantling or demolition of residential buildings may require approval from the local planning authority, which may impose conditions on the way dismantling or demolition is carried out. Compensation may be required for demolition of buildings. Responsibility for relocating residents or users where this is required. Ownership and access to property. Liabilities for possible damage to property. Use on listed and other historically important buildings and on precious objects. Solid waste treatment and disposal legislation.
Environmental constraints	The dismantling process (eg demolishment of buildings) can result in release of contamination into environment. Control of dust is required, and the use of fix and strip coatings (see Datasheet 9) should be considered to limit this. High winds will complicate matters, making control of dust and other particles more difficult. High winds and wet weather may also make implementation of building demolition or roof replacement more difficult because of danger to workers. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. If wet weather is present the potential of contaminants leaching into groundwater should be considered.
Effectiveness	
Reduction in contamination on the surface	Option will be virtually 100% effective in removing contamination on surfaces if all debris is removed and contamination is not spread during demolition process. The amount of contamination re-distributed will depend on the extent to which contamination is contained prior to the removal. Roof replacement may leave a fraction of the contamination (usually small) that may have penetrated into underlying wooden construction materials, depending on the nature of the roofing material.
Reduction in surface dose rates	Dose rates from contamination on surfaces will be eliminated. However, it should be noted that demolition of buildings may reduce shielding provided by the buildings against radiation from other sources in the environment. Therefore in order to reduce overall dose rates from the surrounding land, this will also need to be decontaminated.
Reduction in resuspension	None.
Technical factors influencing effectiveness	The materials and radionuclides involved. The techniques used. Type and condition of surface as this will affect the amount of dust that is likely to be produced and hence spreading of contamination - though dust suppression technologies can

Back to list of options

8 Demolish/dismantle and dispose of contaminated material

	be used where necessary. The amount of contamination (including dust and particulate matter) released into the environment, and the level of control of such contamination. Weather at time of deposition; much less material is deposited indoors during wet deposition. Consistency in effective implementation of option over entire area. Time of implementation: quick implementation will improve effectiveness and chance of contamination spread. Reduction of dose contributions from surrounding ground surfaces. Construction of new buildings. Amount of dust on indoor surfaces at the time of deposition. Whether any cleaning has already been undertaken. Collection of all removed surface material. Amount of furniture and furnishings and ventilation rates in indoor environments.
Social factors influencing effectiveness	There may be issues with regard to the public acceptability of this option (ie people's homes, items, vehicles being dismantled or demolished, distress caused by loss of homes or amenities, aesthetic changes to area). Public acceptability of waste treatment and storage routes. This option may not be appropriate for us on listed and other historically important buildings. Temporary relocation of residents in areas immediately surrounding the building in question may be essential during demolition. It is essential that clear communication strategies are developed and implemented. Any communication strategy must consider and define the information that is suitable to be given to the public at the scene and in the local (affected) area. This information must be developed in partnership with other experts, government agencies and departments. The probability that the event may not only be the focus of local, regional, national and international media scrutiny, but that is may also attract government interest at local, regional, national and international level should be addressed.
Feasibility	
Equipment	Specific equipment may vary (dependent on the technique and surface involved) but the following may be required: Monitoring equipment; Tools for dismantling/disposing of contaminated material eg pneumatic chisels, machine (long reach scaler) to remove tiles stuck to concrete floors, saws etc; Equipment for control of dust and particulate matter; Appropriate containers for temporary storage of waste products; Transport vehicles for equipment and waste. Hire of equipment may not be possible as contamination of the equipment may occur, potentially making it unsuitable for return to the hire company.
Utilities and infrastructure	Roads for transport of equipment, materials and waste. Access and sufficient operational space is required for equipment, possibly including large and heavy equipment such bulldozers, cranes, diggers and forklifts. Power supply. Water supply. Infrastructure for management of very large volumes of generated material. Storage for waste.
Consumables	Water. Fixative coatings such as acrylic paint (to prevent dust). Bags for containing items and wastes. Fuel and parts for equipment and vehicles.
Skills	Depending on the techniques used skilled personnel may be required to undertake this recovery option, and will be essential for more complex tasks such as replacement of roofs or demolition of buildings. For less complex tasks, where only a little instruction is required, it may be possible for at least partial implementation by the population as a self-help measure,

Back to list of options

8 Demolish/dismantle and dispose of contaminated material

	after instruction from authorities on technique and radiation safety and provision of safety and other required equipment. Operator time and personnel requirements will vary depending on the size and scale of the incident and types of contaminated surfaces.
Safety precautions	Employers have a duty of care to protect employees from hazards and risks in the workplace and to ensure that safety procedures and processes are in place to reduce hazards and risks. Structural engineering reports may be required to assess safety of work. Additionally, a risk assessment would need to be undertaken to determine safety measures required for the radionuclide involved. Recovery workers must use appropriate PPE (eg hat, boots, goggles, gloves, overalls; respiratory protection if dust and particulate matter would be generated or if asbestos is present; additional safety equipment if working at height) and follow Standard Operating Procedures (SOPs).
Waste	
Amount and type	Likely to generate large amounts of contaminated rubble, tiles, slates, roofing felt and other building fragments, or solid waste such as furniture, soft furnishings, electrical goods, fixtures and objects from inside a building. Materials should be segregated by type (wood, concrete, metal etc) and ideally by activity, though Japanese experience found this not to be practical. It is estimated that up to 50% of waste may be combustible. Volume reduction (eg processing of woody materials such as small trees and pruned branches with a chipper or shredder) can be important, though there may be issues with where the processing will take place. Building demolition can be expected to generate 70 kg m^{-2} Roof replacement can be expected to generate 20 - 50 kg m^{-2} Removal of furniture, soft furnishings, and objects from inside a building can be expected to generate 20 - 30 kg m^{-2} floor area, while removal of fixtures may generate 50 kg m^{-2} floor area. An amount of this waste may be cleared, based on its radioactive content, and be considered for recycling or reuse or managed as municipal solid waste. This amount may be quite sizeable. Therefore, it will be important to have an infrastructure set up to manage additional quantities of unconditionally cleared material from clean-up campaigns, and to clarify the extent to which municipal solid waste landfills can accommodate such waste. Waste that is not cleared is likely to be designated as Low Level radioactive Waste or Very LLW and would be required to meet the corresponding requirements for transportation, adequate processing, packaging, and facilities for interim storage and disposal in licensed near surface facilities. It is likely that some negotiation with the regulators will be required, especially if large volumes of waste are generated.
Doses	
Averted doses	It is likely that individuals would not inhabit areas where dismantling or disposal is being implemented, due to high contamination levels. Therefore, there may not be an immediate reduction in doses to individuals. If option is carried out effectively and waste disposed of accordingly it should prevent further public exposure and enable resettlement in the area in the future. If only removal of fixtures, furniture etc from inside a building is required, it should be noted that will only reduce doses to people while they are indoors and will be very dependent on the specific situation and the surfaces cleaned. Shortly after replacement of a roof surface, reductions of approx. 9 - 11% in external gamma dose rate received by a member of the public living in an inhabited area could be expected. Figure 1.4 gives some indication of the likely importance of roofs in contributing to long term external gamma doses.
Factors influencing averted dose	Consistency in effective implementation of option over entire area. Care of application. Need to remove contamination from the building and not just move it on to another surface. Control of dust produced. Application of appropriate decontamination to other surrounding surfaces and objects. Weather at time of deposition; less material is deposited indoors during wet deposition. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering and cleaning. Amount of time spent inside buildings.

Back to list of options

8 Demolish/dismantle and dispose of contaminated material

Additional doses	Monitoring of recovery workers may be required to ensure that exposure limits are not exceeded, and to confirm that the remediation is having the desired effect. Due to the specific nature of tasks it is not possible to estimate likely recovery worker exposure. This would need to be assessed on a case-by-case basis as it will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE. Exposure pathways recovery workers could be exposed to are: • external exposure from contamination in environment and equipment • inhalation exposure from contamination in environment and equipment (may be enhanced over normal levels due to enhanced resuspension of activity deposited in the environment) • dermal (skin) exposure from contamination on skin • *inadvertent ingestion of contamination from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. The potential for additional doses to workers should be considered when planning working procedures. For example, while use of containers to contain wastes may be recommended, if workers are expected to be highly exposed to contaminated dust and radiation when they engage in packaging wastes, then use of containers may not be required, providing efforts are made to stop scattering and leakage of contaminated materials.
Intervention costs	
Operator time	Costs for operator time and personnel requirements will vary depending on the size and scale of the incident and types of contaminated surfaces (ie buildings, roads, paved areas, vehicles). Skilled personnel may be required to undertake this recovery option. Depending on the PPE used individuals may need to work restricted shifts. The work rates given below are indications of what may be achieved - these rates will become slower once access and monitoring time are taken into account. **Roof replacement** work rate estimated at 1 - 3 m^2/team.h (team size: 2 people) - depending on type of roof and material (excludes setting up of scaffolding). **Building demolition** work rate (with a team size of 4 people) estimated at 5 m^2/team.h for crane and ball method, or 0.5 m^2/team.h for secondary containment and pneumatic chisels. **Removal of internal objects** work rate (with a team of 2 people) estimated at 20 - 30 m^2/team.h.
Factors influencing costs	Costs and equipment required will vary according to the scale of contamination and size and construction of structure or objects that requires dismantling or disposal. Other factors influencing costs include: • property type and use (ie residential or commercial) • compensation for damage to building/property or loss of items • weather • size of structure that requires disposal • type of equipment used • access • use of personal protective equipment (PPE) • use of scaffolding The costs associated with demolition/dismantling could vary considerably depending on the situation and would need to be carefully balanced with the costs of decontamination.
Side effects	
Environmental impact	The dismantling process (eg demolishment of buildings) can result in release of contamination into environment, and the use of fix and strip coatings (see Datasheet 9) should be considered in conjunction to limit this. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. If wet weather is present the potential of contaminants leaching into groundwater should be considered. The large quantity of waste produced may lead to this option not being feasible if

Back to list of options

8 Demolish/dismantle and dispose of contaminated material

	implemented on anything more than a small scale.
Social impact	Destruction of inhabited area. Distress caused by loss of homes or amenities, or loss of personal items. Acceptability of aesthetic changes to area. Damage may be caused to buildings by partial dismantling or roof replacement. Acceptability of production and disposal of large amounts of waste. Disposal of contaminated material may lead to the opportunity for redevelopment and revitalisation of city centre or residential areas. There may a positive benefit of cleaning houses. There may be a positive impact on associated trades such as the roofing industry.
Practical experience	Tested on selected houses in the Former Soviet Union (eg, in Gomel, Belarus) after the Chernobyl accident. Used following the polonium poisoning incident in London. Used following the incident in Goiania, including the demolition of seven residences and the replacement of two roofs. Used in Japan following the Fukushima accident.
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. IAEA (1988) The Radiological Accident in Goiania. STI/PUB/815 ISBN 92-0-129088-8, IAEA, Vienna IAEA (2011) Final Report of the International mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Dai-ichi NPP 7-15 October 2011, Japan, IAEA NE/NEFW/2011, 15/11/2011 Miyahara K., Tokizawa T., Nakayama S (2012) Decontamination pilot projects: building a knowledge base for Fukushima environmental remediation. Mater Res Soc Symp Proc 2012; 1518:245-256. Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Yasui S (2014) New Regulations for Radiation Protection for Work involving Radioactive Fallout Emitted by the TEPCO Fukushima Daiichi APP Accident: Application Expansion to Recovery and Reconstruction Work. Journal of Occupational and Environmental Hygiene, 11:D105-D114, August 2014 More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheet Dismantle and Disposal of Contaminated Material from version 1 of the UK Recovery Handbook for Chemical Incidents and datasheets Demolish Buildings(datasheet 5), Roof Replacement (datasheet 10) and Removal of Furniture, Soft Furnishings and Other Objects (datasheet 16) from version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

9 Fix and strip coatings

Objective	To reduce inhalation and external doses from contamination on external walls and roofs of building, roads/paved areas, semi-enclosed surfaces and vehicles within inhabited areas, and on metal surfaces in industrial buildings.
Other benefits	Will remove contamination from treated surfaces and therefore prevent redistribution of contamination. While they are in place, peelable coatings will also provide a tie-down effect and reduce exposure to workers implementing other recovery options, and also to members of the public.
Management option description	The application of peelable coatings, to a surface can fix contamination to the coating such that when the coating is peeled off the contamination is stripped away from the surface. As well as contamination adhering to the coating, there may also be chelating agent properties in the coating, that bind organic chemicals to a metal ion, bringing them into solution and increasing removal from the surface. Peelable coatings have the additional benefit of providing a tie-down effect, but this only temporary while the coating is in place (though subsequent applications may be applied to extend the tie-down effect for a longer duration) and the primary use is to remove contamination from the surface. Detex and Pelableau are examples of peelable coatings though other materials, including polymer pastes, may be appropriate (eg PVA). A sharp knife can be used to score a surface into large sections to facilitate peeling of cured coatings. The coating can be rolled as it is removed for ease of handling and to further entrap any contamination on the surface of the coating. Removed coatings should be incinerated where possible. Coatings can be reapplied to a surface in order to sandwich in layers of contamination. **Detex**: On buildings, Detex is applied by brush because it is difficult to use in a spray gun. Brushing will also force the liquid into surface areas and crevices, which is better for decontamination. On flat surfaces, it can be poured manually and spread using metal rakes. After curing (typically up to 2 hours, though will depend on factors such as application, temperature and humidity) the rubber film is removed with a knife or by peeling. The contamination adheres to the peeled film, which is then disposed of as solid active waste. **Pelableau**: Pelableau is sprayed on to the surface using an airless pump. After curing it is peeled off. It is not widely available and not suitable for use on roofs, thereby reducing its usefulness. **Polymer pastes:** based on PVA, these can be used for the removal of contamination from metal surfaces. In particular they can be used for machinery and ventilation systems. The detachable coatings are liquids or gels. When the dry intact film has formed on the surface, the coating is peeled off by hand, removing any loose contamination. The technique can be applied easily and quickly and requires minimum equipment and personnel.
Target	Any robust surface such as building surfaces, paved surfaces, hard surfaces in semi-enclosed areas, vehicles, metal surfaces in buildings and special parts of machinery, handtools and other equipment. Contamination should be loose, removeable particulates or loose contaminant-harbouring debris.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone. As a tie-down option: alpha emitting radionuclides that give rise to inhalation doses from resuspended material.
Scale of application	Suitable for small areas (eg houses, pavements, playgrounds). Unlikely to be suitable for large areas as the coatings can be very difficult to remove intact when used on large surface areas.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surface. The peelable coating will be effective in stopping resuspension over the period that it remains intact.
Constraints	
Legal constraints	Liabilities for possible damage to property. Use on listed buildings, historically important sites and conservation areas. Solid waste disposal legislation. Ownership and access to property.
Environmental constraints	Severe cold weather. Cannot be applied in wet weather.

Back to list of options

9 Fix and strip coatings

Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of up to 5 can be achieved if this removal option is implemented within a few weeks of deposition. This option is likely to be most effective when used on smooth surfaces. Later application is likely to give a lower DF, particularly on porous building materials such as bricks and tiles. Decontamination work in Japan, applying a stripping agent to roof tiles and slates gave DFs of around 1.5. Use of polymer pastes on metal surfaces has been tested on stainless steel, cast iron and brass. Based on small-scale laboratory and field experiments, 75 - 97% reduction (DF range of 4 to 33) in contamination can be achieved. Repeated application may provide additional benefit, ie an increase in the contamination removed.
Reduction in surface dose rates	External gamma and beta dose rates dose rates from external walls and roofs will be reduced by approximately the value of the DF.
Reduction in resuspension	While the peelable coating is in place, resuspended activity in air will be reduced by almost 100%. In the long term, resuspended activity in air adjacent to surfaces will be reduced by the value of the DF.
Technical factors influencing effectiveness	Weather conditions and temperature: temperature will affect curing time and on outdoor surfaces curing may not be possible in bad weather conditions. Type, evenness and condition of surface. . With increasing surface roughness/complexity, strippable coatings before more difficult to remove easily, loading to reduced effectiveness. If metal surfaces are rusty or peeling, decontamination is reduced by about 4 - 7 times. Time of operation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface. Care of operation - careful removal is required to be effective. Removal should be done by hand. Consistent application of peelable coating over the contaminated area. Viscosity of applied liquids. Amount of buildings and paved surfaces in the area. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Ladders. Scaffolding. Brushes. Paint rollers and telescopic poles Metal rake. Airless spray pump and compressor. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment, materials and waste.
Consumables	Proprietary strippable coatings are recommended, or otherwise a paste made from PVA, EDTA, sodium carbonate and glycerine. Fuel and parts for equipment and transport vehicles.
Skills	Skilled personnel essential to apply (and remove) coating. Industrial cleaning companies will have the required skills.
Safety precautions	Protective clothing, including respiratory protection. For tall buildings lifelines and safety helmets will be required.
Waste	
Amount and type	Around 1 kg m^{-2} (range 0.2 - 1.8 kg m^{-2}) solid, rubber like material. There may be disposal issues if the waste produced does not meet the LLWR criteria for disposal.

Back to list of options

9 Fix and strip coatings

Doses	
Averted doses	Not estimated.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Amount of buildings in the area ie environment type/land use. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE. Because of potentially high concentration levels, it is important to fully assess external dose rates in these areas prior to cleaning. Coatings are removed by hand so doses to workers may be significant.
Intervention costs	
Operator time	7 - 5 10^1 m^2/team.h (with a team of 2 people), with slower speeds (2 - 6 m^2/team.h) possible when working with polymer pastes. If time is required to set up scaffolding, this will be variable. Japanese experience estimated decontamination speeds of 10 m^2 per day from application of stripping agent to roofs of residential houses. Assuming a 7 hour working day, this suggest around 1.5 m^2 per team.h.
Factors influencing costs	Weather. Building size / height / pitch of roof. Type of equipment used. Need for scaffolding /mobile lifts. Access. Evenness of surface. Size of area to be treated. Cost of specialist labour. Cost of chemicals.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Acceptability of disposal of contaminated waste. Reassurance of employees and users and maintaining continuity of work. Use of peelable coatings may have a positive effect on the appearance of surfaces. Application is slow so may impact upon business continuity and lead to financial losses.
Practical experience	The use of polymer pastes on metal surfaces was tested on a small-scale in Gomel province of Belarus after the Chernobyl accident. Two strippable coatings that were developed in the 1980's are waterborne vinyl resin and polybutyl dispersion, both of which are non-flammable, non-toxic and abrasion resistant (IAEA, 1989; Andersson and Roed, 1994). Use of stripping agent on residential houses following the Fukushima accident.
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315 Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited

Back to list of options

9 Fix and strip coatings

	areas. Environment Agency R&D Technical Report P3-072/TR Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Masayuki I (2012) Report of the Results of the Decontamination Model projects. Analysis and Evaluation of the Results of the Decontamination Model Projects - Decontamination Technologies. Presentation to meeting held on March 26, 2012 at Fukushima City Public Hall More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheets Peelable Coatings (datasheet 41) and Application of Detachable Polymer Paste on metal Surfaces (datasheet 45) in version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

10 Grass cutting and removal

Objective	To reduce inhalation and external beta and gamma doses from contamination on outdoor grassed areas within inhabited areas.
Other benefits	Removal of contamination from grassed areas. Prevention of contamination reaching underlying soil if deposition occurred under dry conditions.
Management option description	Grass area is mown and grass cuttings are collected. The grass cutting height should be as low as possible ie to remove the maximum length of grass. This option is likely to give rise to dust. It will not be possible to apply water to dampen the surface without moving contamination from the grass on to the underlying soil, thereby jeopardising the objective of the grass cutting. The use of personal protective equipment by workers is therefore recommended to limit the resuspension hazard. It may also be possible to set up some screening around areas being mown to prevent release of contamination into surrounding areas. There is anecdotal evidence that if grassed areas that require cutting are covered with standing water, 'blotter' machines such as those used to quickly dry cricket pitches, could be used to dry the grassed area sufficiently to allow cutting to take place.
Target	Grass surfaces in gardens, parks, playing fields and other open spaces.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Potentially any size, depending on the equipment used. If long grass is to be mown, specialised heavier machinery may be required, which may not be suitable for smaller areas.
Time of application	Maximum benefit if carried out within 1 week of deposition when maximum contamination is on grass. Effectiveness is significantly reduced after rain has occurred or if grass has already been cut post deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Waste disposal of collected grass cuttings. Organic material may not meet criteria set by the LLWR, therefore authorisation for waste disposal may be required.
Environmental constraints	Severe cold weather.
Effectiveness	
Reduction in contamination on the surface	Decontamination factor (DF) of 3 following dry deposition and DF of 1.3 following wet deposition can be achieved if this option is implemented within one week of deposition and before significant rain occurs.
Reduction in surface dose rates	External gamma and beta dose rates immediately above grass surfaces arising from contamination on the grass will be reduced by approximately the value of the DF. However, In some cases the shielding effect for the beta rays by grass may be reduced by the grass cutting, and so the reduction rate may drop.
Reduction in resuspension	Resuspended activity in air immediately above a grass surface will be reduced by approximately the value of the DF.
Technical factors influencing effectiveness	Weather conditions, particularly those at the time of deposition, and the amount of rain post deposition. Correct implementation of option (all grass cuttings must be collected to achieve the DF values quoted). Time of implementation - weathering will reduce contamination over time so quick implementation will improve effectiveness. Evenness of ground surface. Length of the grass at time of deposition - if the grass is short at time of deposition then contamination will reach the soil surface more readily, therefore cutting of short grass will be less effective than cutting of long grass Consistency in effective implementation of option over a large area. Whether recovery options have been applied to adjacent ground surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.

Back to list of options

10 Grass cutting and removal

Feasibility	
Equipment	Grass mowers (various sizes, depending on size of area), preferably fitted with collection boxes to ensure total collection of grass cuttings. A tractor may be required for large areas. Rakes or other collection equipment if grass cutting equipment is not equipped with collection boxes. Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment and waste.
Consumables	Fuel and parts for grass mowers and vehicles.
Skills	For small gardens, grass cutting could be implemented by land owners as a self-help measure with instruction from authorities and provision of safety equipment. Skilled personnel may be desirable if large scale equipment is used, ie for larger area grass mowing.
Safety precautions	Respiratory protection and protective clothes/gloves are recommended to reduce the hazard from resuspended activity, particularly under very dry conditions.
Waste	
Amount and type	Amount: $1\ 10^{-4}$ - $7\ 10^{-4}$ $m^3\ m^{-2}$ (<150 g m^{-2}) (depends on height of grass cut and density of grass cover). Type: Grass. It is noted that waste amounts generated can be large. However methods exist which can substantially reduce the volume of organic waste by up to a factor of about 100. Some of these methods (eg composting) could be practised locally and could be very significant in reducing any waste transport and storage problems. There is also the potential for contaminated equipment to be classed as waste if it cannot be decontaminated sufficiently.
Doses	

Averted doses

^{137}Cs (% reduction in external dose)				^{239}Pu (% reduction in resuspension dose)			
Over 1st year		Over 50 years		Over 1st year		Over 50 years	
Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
20-25	10-15	25-30	15-20	5-10	5-10	10-15	10-15

The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.

Factors influencing averted dose	Consistency in effective implementation of option over a large area. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas. Time of implementation. The impact of decontamination on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Whether adjacent soil surfaces are also decontaminated.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	$2\ 10^2$ - $1\ 10^4$ m^2/team.h depending on scale of equipment used. Team size: 1 person.
Factors influencing costs	Weather. Topography. Size of area. Type of equipment used and whether grass has to be collected manually. Access. Use of personal protective equipment (PPE).

Back to list of options

10 Grass cutting and removal

Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Mowing grass can make an area look 'tidy'. Implementation may give public reassurance. Access to public areas may need to be restricted temporarily before grass mowing is implemented. Waste disposal may not be acceptable.
Practical experience	Tested on a small scale in Europe. Used in Japan following the Fukushima accident.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. IAEA (2014) The follow-up IAEA International Mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Daiichi Nuclear Power Plant. Tokyo and Fukushima Prefecture, Japan. 14-21 October 2013. Final report 23/01/2014. Maubert H, Vovk I, Roed J, Arapis G and Jouve A (1993). Reduction of soil-plant transfer factors: mechanical aspects. *Science of the total Environment*, **137**, 163-167. Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	3
Document history	See Table 7.2

Back to list of options

11 Manual and mechanical digging

Objective	To reduce inhalation and external doses from contamination in outdoor areas covered in grass or soil within inhabited areas.
Other benefits	If applied to vegetable plots, may reduce contamination in the soil depth used for growing crops due to the redistribution of contamination. This in turn may reduce uptake of radionuclides from the soil to food crops grown.
Management option description	Most of the initial deposition remains in the top 50 mm of soil for many years (certainly the case for clay and brown earth soils). Therefore, if the top layers of soil are dug to attempt to bury the top layer of soil or turf a significant shielding from the contamination can be obtained. There are a number of techniques which can be used: • manual digging to a depth of about 150 - 300 mm to bury the top layer to the bottom of this vertical profile • manual double digging, in which the top 150 mm of soil is inverted. This is a traditional method for digging vegetable gardens, particularly for potato crops. The top spade depth of soil is removed; the second spade depth is broken up, effectively mixing the soil to improve it. The top layer is then inverted and replaced. If the area is covered with turf, the top layer should be placed turf down if possible • manual triple digging to change the order of three vertical layers of soil. The thin top layer of soil and vegetation (about. 50 mm thick - optimised according to contamination depth) is inverted and buried at the bottom. The bottom layer (about 150 - 200 mm thick) is placed on top of this; and the intermediate layer (about. 50 - 150 mm thick), which should not be inverted in order to maintain fertility, is placed on the top. Contamination that was on the surface, or within the topmost few centimetres, is thereby well shielded • mechanical digging (rotovating) using power driven machines (rotovators) under manual control. The machines till to a depth of about 150 mm. Rotovating mixes the upper soil layers fairly uniformly within a relatively shallow depth After digging, levelling /compaction may be required to restore the area to about the same height and compactness as before. Large plants and shrubs may need to be removed before digging and the area may need to be subsequently replanted and reseeded with grass or re-turfed. The mixing of contamination by digging is irreversible and will severely complicate subsequent removal of contamination. Digging may be used to treat hotspots of contamination, such as may occur below rainwater guttering. In dry conditions, this option may give rise to dust, so application of water to dampen the surface is recommended prior to implementation to limit the resuspension hazard in these conditions (see tie-down Datasheet 23). Digging must not be repeated, as this could bring contamination back to the surface, or at best will lead to a more uniform mixing of the contamination which will reduce the effectiveness of the option as less of the surface contamination will remain buried.
Target	Grass and soil surfaces in gardens, and other small open spaces. When considering larger areas consider ploughing methods, see Datasheet 14. This option is not appropriate for areas that have already been tilled since deposition occurred.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides.
Scale of application	Suitable for small soil/grass areas only (eg gardens).
Time of application	Maximum effectiveness will be achieved for several years after contamination has occurred, as most contaminants migrate only very slowly down the soil profile. Will continue to be effective up to 10 year after deposition, although effectiveness will reduce with time. It may be beneficial to wait until after the first rain so that most of the dust has washed off other outdoor surfaces and buildings on to grass/soil.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Cultural heritage protection - use on listed and historic sites and conservation areas
Environmental constraints	Severe cold weather - if the ground is snow-covered or frozen down to the digging depth, this method is not practicable. Soil texture.

Back to list of options

11 Manual and mechanical digging

	In extreme cases, the slope of the area maybe a constraint.
Effectiveness	
Reduction in contamination on the surface	This option has a decontamination factor (DF) of 1 as no contamination is removed
Reduction in surface dose rates	Manual digging techniques can be expected to give higher dose rate reductions than mechanical digging as rotovation does not bury contamination under a clean soil layer but mixes (dilutes) it homogeneously over the treated depth. External gamma dose rates above the surface could be reduced by up to 80 - 90% by manual digging (the higher results achieved with triple digging technique), with reductions of 50 - 70% likely from mechanical digging. Beta dose rate reduction is likely to be 100% if the technique is implemented effectively.
Reduction in resuspension	Manual digging techniques can be expected to give higher reduction in resuspension than mechanical digging as rotovation. By effectively burying activity with well implemented manual digging, resuspended concentrations in air above a grass surface will be reduced to zero. Mechanical rotovating can achieve a resuspension reduction factor of 15 for implementation up to several years after deposition.
Technical factors influencing effectiveness	Weather and soil conditions: a very dry or loose consistency soil may make digging ineffective. Flooding will make technique less effective. Method/depth of digging The soil contamination profile with depth at the time of implementation The radionuclides involved, ie their gamma energies Correct implementation of option: all the surface contamination must be buried to achieve the quoted resuspension reduction. Consistency in effective implementation of option over a large area. Soil texture (does the soil contain stones? etc). Current use of land: whether soil is covered with grass/herbage with dense roots or soil is sparsely covered Size of area. Larger dose rate reductions seen if a large area is dug. Any previous tilling since deposition. Repeated tilling may bring more contamination back to the soil surface. Time of implementation. Weathering will reduce contamination over time so quick implementation will improve effectiveness. Also, downwards migration of contamination may make the technique be less effective. Whether recovery options have been applied to other nearby ground surfaces. High groundwater level may impede deep digging.
Social factors influencing effectiveness	None
Feasibility	
Equipment	Spades, rotovators, or larger agricultural equipment, depending on scale of area. Transport vehicles for equipment.
Utilities and infrastructure	Roads for transport of equipment.
Consumables	Fuel and parts for transport vehicles. Plants and turf / grass seed, as required.
Skills	Depending on the equipment used, trained workers may be required. Only a little instruction is likely to be required for manual digging. This option could, to some extent, be implemented by inhabitants of the affected area as a self-help measure, after instruction from authorities and provision of safety and other required equipment. However, digging is a strenuous activity and people would need to be fit.
Safety precautions	Under very dusty conditions, respiratory protection and protective clothes/gloves (PPE) may be recommended to reduce the hazard from resuspended radioactivity.
Waste	
Amount and type	None

Back to list of options

11 Manual and mechanical digging

Doses

Averted doses

^{137}Cs (% reduction in external dose)				^{239}Pu (% reduction in resuspension dose)			
Over 1st year		Over 50 years		Over 1st year		Over 50 years	
Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
10-25	15-30	10-30	20-40	5-10	10-25	10-15	20-30

The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area. Manual digging is likely to give greater reductions in external dose from ^{137}Cs than those seen from rotovating. However, rotovating is likely to give greater reductions in resuspention dose from ^{239}Pu.

Factors influencing averted dose

Consistency of effective implementation of option over a large area.
Population behaviour in area. - reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by grass and the time spent by individuals on or close to grassed areas.
Amount of grass/soil in the area ie environment type/land use.
Time of implementation. The impact of digging on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
If only soil areas are dug, need to consider other options for grass areas.

Additional doses

Relevant exposure pathways for workers are:

- external exposure from radionuclides in the environment and contaminated equipment
- inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Inhalation of dust generated
- *inadvertent ingestion of dust from workers' hands*

Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE.

No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.

Exposure routes from transport and disposal of waste are not included.

Intervention costs

Operator time

Manual digging	4 - 6 m^2/team.h (team size: 1 person).
Triple digging	2 - 3 m^2/team.h (team size: 1 person).
Rotovating	1 10^2 m^2/team.h (team size: 1 person).

Depending on the PPE used individuals may need to work restricted shifts.

Factors influencing costs

Soil type and condition (eg moisture, season).

Weather.

Topography.

Evenness of ground surface and level of vegetation.

Access to gardens and other areas.

Use of personal protective equipment (PPE).

Fitness of workers (heavy manual task).

Need to replant etc.

Side effects

Environmental impact

Soil erosion risk (reseeding and replanting may minimise this).

Digging may reduce soil fertility, though triple digging is likely to minimise fertility loss.

Possible destruction of plants/partial loss of biodiversity.

Acceptability of smothering flora and fauna and destruction of garden planting and amenity areas.

May bring contamination closer to groundwater.

Severely complicates subsequent removal of contamination as more waste will be generated and mixing will make segregation of contaminated waste more difficult.

Social impact

Adverse aesthetic effect of digging gardens (especially for grassed areas).

Destruction of gardens and loss of plants leading to temporary loss of garden function.

Back to list of options

11 Manual and mechanical digging

	Contamination is not removed. Restriction of some future gardening activities (eg banning digging to depths of 200 mm or greater; crop selection may be restricted).
Practical experience	Manual digging has been tested on a small scale in Europe. Triple digging has been tested several times after the Chernobyl accident, in ca. 100-200 m^2 plots in the Former Soviet Union. Mechanical diggers were used to interchange topsoil nd subsoil following the Fukushima accident.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Masayuki I (2012) Report of the Results of the Decontamination Model projects. Analysis and Evaluation of the Results of the Decontamination Model Projects - Decontamination Technologies. Presentation to meeting held on March 26, 2012 at Fukushima City Public Hall Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Roed J (1990). *Deposition and removal of radioactive substances in an urban area.* Final report of the NKA Project AKTU-245, Nordic Liaison Committee for Atomic Energy, ISBN 87-7303-514-9. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Roed J, Andersson KG, Fogh CL, Barkovski AN, Vorobiev BF, Potapov VN, Chesnokov AV (1999). Triple Digging - a simple method for restoration of radioactively contaminatined urban soil areas. *Journal of Environmental Radioactivity*, **45**, (2), 173-183. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheets Manual Digging (datasheet 31), Rotovating (Mechanical Digging) (datasheet 34), and Triple Digging (datasheet 39) from version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

12 Modify operation/cleaning of ventilation systems

Objective	To remove contamination from the area and prevent redistribution of contamination in buildings, and thus reduce exposure from contaminated ventilation systems in commercial, industrial and public buildings, or within semi-enclosed areas.
Other benefits	Reassurance of employees and users of the building that radionuclide contamination has been removed, and maintaining continuity of work.
Management option description	Reduce spread of contamination - interior release Strategies for reducing the spread of contamination through building conditioning systems may include rapidly isolating all air handling unit (AHU) fans and closing all heating ventilation air conditioning (HVAC) dampers, including exhaust dampers. This could be implemented in the response (emergency) phase of a radiation incident to reduce the spread of contamination if an incident occurred inside a building. Reduce spread of contamination - exterior release Significant contamination of building interiors following an exterior airborne release may be relatively unlikely, except for large-scale events. HVAC systems can be shut down if an exterior release is identified, but some ingress can potentially occur through 'leaks' in the building envelope including the main and ancillary entrances. Ventilation HVAC system operation can be maintained and flushed with fresh air to dilute the internal contamination. Gases and volatile liquids mainly contaminate building air and may be removed by appropriate ventilation within a few hours. Would need to consider installing filters in HVAC system to limit spread of contamination outside building. **Underground transport networks -** Disabling ventilation systems may need to be considered if contamination has occurred on an underground transport network (ie London underground). Once evacuation has taken place, shutting down ventilation systems, or stopping movement of trains, may prevent the spread of contamination to the outdoor environment (eg streets). **Cleaning -** Ventilation systems may become heavily contaminated and are not very easy to decontaminate or clean, especially as they are often greasy and grease tends to trap contamination. Ductwork is often in difficult to access areas, such as above ceilings. Cleaning may involve industrial vacuum cleaning (with the system running and working from back of system towards the fan to ensure that loose contamination is drawn towards the filters rather than contaminating operatives), washing with chemical solutions, ice pigging (pumping of ice slurry through a pipe to remove sediment and other unwanted deposits) and possibly the use of an electrical rotating brush in narrow ventilation ducts. Potential cleaning options will vary dependant on the radionuclide involved. In channels with larger diameters (> 50 cm) it may be possible to open the ventilation system and hose it at high pressure with water, or vacuum through holes cut into ductwork, though sometimes it may be necessary for a person to enter the duct with a 'NORCLEAN' type industrial vacuum cleaner. There may be problems disposing of liquid wastes, though treatment of waste water may be possible (see Datasheet 26). Use of gaseous cleaning (for example using hydrogen peroxide or chlorine dioxide) may be possible, but tests suggest that flow patterns can be very complex within ventilation systems, making gaseous decontamination difficult at some locations. Replacement of inlet filters, or removal of the ventilation system, or part of the system, may be an option, particularly if cleaning would be more expensive than replacement. **Filter removal -** A significant quantity of contamination may be removed by replacing the air filters from industrial buildings, mainly from ventilation systems and heaters.
Target	Contaminated air handling unit (AHU) and heating ventilation air conditioning (HVAC) units within buildings or semi-enclosed areas.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Could be carried out on a medium scale in highly contaminated industrial areas.
Time of application	Maximum benefit if carried out shortly after deposition, but can be applicable in the longer term for longer lived radionuclides, when there can be a significant effect on reducing contamination levels even if applied a decade after contamination occurred.
Constraints	
Legal constraints	Liabilities for possible damage to property. Possible regulations on chemical use.
Environmental constraints	Electronic parts may be damaged by water if not dismounted,

Back to list of options

12 Modify operation/cleaning of ventilation systems

Effectiveness	
Reduction in contamination on the surface	**High pressure hosing:** 80 - 97% reduction in contamination. **Vacuuming/brushing:** 80 - 90% reduction in contamination. **Filter removal:** Can expect to remove 100% of the contamination associated with the filter. The effectiveness will depend on the specification of the individual air ventilation system, and on whether the ventilation system is used to introduce fresh air into a building or to expel contaminated air out of a building.
Reduction in surface dose rates	Not estimated
Reduction in resuspension	
Technical factors influencing effectiveness	**Modification of systems:** HVAC systems can be shut down if an exterior release is identified, but some ingress is then likely to occur through 'leaks' in the building envelope including the main and ancillary entrances. **Cleaning:** Technical difficulties in accessing and cleaning contaminated areas Pressure and amount of water for high pressure water treatment. Water temperature: because the air outlet channels, in particular may be greasy and contain dust; a high water temperature (>60 ºC) is required to ensure a high reduction in contamination levels. However, it should be noted that the inlet channels are usually the most contaminated. **Filter removal:** Design of filter and filter housing, position of filter, and amount of contamination on the filter **General:** Operator skills / knowledge of specific ventilation system. The physico-chemical form of the aerosol (eg size, solubility). Need to be aware of potential build-up of flammable natural gases (eg methane) and radioactive radon in poorly ventilated underground spaces.
Social factors influencing effectiveness	The need to avoid causing panic among the population may interfere with the ability to quickly alert people to turn off ventilation systems within the urban environment.
Feasibility	
Equipment	Equipment that is likely to be required may include: Brushes, vacuum device 'Dust trap' filter and/or industrial vacuum cleaner and/or high pressure water washer Grinding machines Other hand tools as required, depending on the exact techniques used and the type of ventilation/filter system. Monitoring equipment. Appropriate containers for temporary storage of waste products.
Utilities and infrastructure	Transport vehicles for equipment and waste. Scaffolding or mobile lifts for tall buildings, where channels may be mounted under the ceiling. Power supply.
Consumables	Water supply. Pressurised air supply.
Skills	Operator time and personnel requirements will vary depending on the size and scale of the incident and types of contaminated buildings or ventilation systems that require remediation. Skilled personnel are likely to be required to undertake this recovery option.
Safety precautions	Will depend on the radionuclide and strategy involved. Appropriate safety equipment likely to include hat, lifelines, waterproof safety clothing, and boots. Respiratory protection would be important if there is a risk that dust and particulate matter would be generated. Appropriate safety measures and respiratory protection will be required if asbestos is present. Monitoring of recovery workers may be required to ensure that exposure limits are not exceeded.

Back to list of options

12 Modify operation/cleaning of ventilation systems

Waste	
Amount and type	**Cleaning ventilation systems** is likely to generate moderate amounts of contaminated waste material: **Solid waste:** 50 - 100 g m^{-2}. Expected contamination level of ~ 10-20 kBq m^{-3} per Bq m^{-2} contamination. **Dry waste:** is collected in vacuuming filters that are relatively easy to dispose. **Liquid waste:** from pressure washing can mostly be collected and filtered with the industrial vacuum cleaner, so that the water is cleaned and sludge is left. **Filter replacement** will generate solid waste in the form of filters. Disposal will be subject to conditions depending on the activity levels and other properties of the waste.
Doses	
Averted doses	Averted doses have not been estimated. Factors influencing averted exposure include: Consistency in effective implementation of option throughout the affected ventilation system; Appropriate decontamination of surrounding surfaces (ie walls, floors and ceilings); Amount of time spent in the vicinity of ventilation ducts.
Additional doses	Due to the specific nature of tasks and the variation of possible radionuclides involved, it is not possible to estimate likely recovery worker exposure. They would, however, need to be assessed on a case-by-case basis in the event of any incident involving the modification/ cleaning of ventilation systems as a remediation technique. Dose rates must be assessed prior to any time-consuming action. Exposure pathways recovery workers could be exposed to are: • External exposure from contamination in the environment and contaminated equipment • Dermal contamination and exposure from contamination • Inhalation exposure from contamination in environment and equipment. Note that resuspension may be enhanced over normal levels. • Inadvertent ingestion of contamination from workers' hands (unlikely to be significant) Exposure routes from transport and disposal of waste are not included. The dose over a day to a worker implementing decontamination of ventilation ducts may be significantly higher than that to an individual living or working in the contaminated area. This is due to the very high contamination levels that can build up in ventilation systems (especially in filters). The level of contamination depends on the size of filter and filter system (ie requirement to climb into system or possibility for external handling). Dose rates must be assessed prior to any time-consuming action.
Intervention costs	
Operator time	**Cleaning small channels:** (<20 cm in diameter): 6 m^2 per hour. **Cleaning larger channels:** 2 - 3 m^2 per hour. If there are valves, these must be dismounted. Each valve takes about 1.5 h to dismount. **Replacing filters:** takes between a few minutes and a few hours per filter, depending on filter type. Depending on the PPE used individuals may need to work restricted shifts.
Factors influencing costs	Need for scaffolds/ mobile lifts, and potential need for different types of treatment (dependant on eg, channel sizes and other ventilation system characteristics). Different types of filter and access for replacement, depending on the ventilation system. Costs of specialist labour.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. Electronic parts may be damaged by water if not dismounted.
Social impact	Acceptability of disposal of contaminated waste. Removal of the corrosion products from the surface; ventilation system can be expected to run better when clean.

Back to list of options

12 Modify operation/cleaning of ventilation systems

	Reassurance of employees and users and maintaining continuity of work.
Practical experience	Tested in a number of industrial buildings in the Former Soviet Union and Europe after the Chernobyl accident.
Key references	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2000). *Compendium of measures to reduce radiation exposure following events with not insignificant radiological consequences.* Bonn: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, vols 1 and 2. Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3.
Version	1
Document history	See Table 7.2 Based on datasheet of same name in version 1 of the UK Recovery Handbook for Chemical Incidents and datasheets Cleaning of Contaminated (Industrial) Ventilation Systems (datasheet 48) and Filter Removal (datasheet 50) from version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

13 Natural attenuation (with monitoring)

Objective	To allow the natural decay, degradation or dispersal of a radionuclide within the environment (eg internal building structure or external building surface), with no intervention, until it poses little or no hazard to inhabitants.
Other benefits	No active implementation required, although this option involves monitoring to reassure the affected population and to ensure there is no spread of contamination.
Management option description	Natural decay of radionuclides will occur with time. When the contamination involves a radionuclide that has short half-life, then simply allowing sufficient time for the contamination to decay with time can be sufficient. Natural attenuation processes such as weathering may act without human intervention to reduce the concentration of contaminants in the environment. Monitoring of affected areas is required to confirm whether natural attenuation processes are acting at a sufficient rate to ensure that the wider environment is unaffected and that remedial objectives will be achieved within a reasonable timescale. Monitoring may include airborne and vehicle based surveys, handheld dosimeter surveys or soil samples. Population/stakeholder involvement likely to be necessary to ensure that the public do not think that they have been forgotten.
Target	Potentially all surfaces but more effective in outdoor environments. Natural attenuation could be used, perhaps in conjunction with restricted access, in areas with little public access or where access to carry out decontamination is difficult (eg roof areas, forests, external building walls above a certain height) as long as contamination will not spread from within those areas. Natural attenuation may also be used in lower priority areas, while other higher priority areas are first tackled.
Targeted radionuclides	**Probable applicability**: Short-lived radionuclides such as ^{131}I. **Not applicable**: Long-lived radionuclides where no significant reduction in activity level will be seen before a prolonged period of time has passed.
Scale of application	Any.
Time of application	This recovery option can be implemented from the early to late phase (hours - years) of a radiation incident. This recovery option may take several decades to arrive at a satisfactory outcome.
Constraints	
Legal constraints	Need to consider implications if spread of contamination occurs as a result of no active remediation being implemented. The restrict public access option (see Datasheet 4) may be required in conjunction with natural attenuation.
Environmental constraints	Decay may lead to the generation of daughter products with greater toxicity/ mobility than the parent radionuclide. Potential for spread of contamination in environment.
Effectiveness	
Reduction in contamination on the surface	The effectiveness of this option is linked to the half-life of the radionuclide and its behaviour in different environments and surfaces.
Reduction in surface dose rates	Not applicable
Reduction in resuspension	Not applicable
Technical factors influencing effectiveness	Properties of radionuclide Weather conditions Ability to monitor Working temperature range of monitors - recalibration may be required for certain weather conditions eg temperatures below 0°C Need to know the background level of contamination
Social factors influencing effectiveness	Acceptance of monitored natural attenuation. Public may perceive this option as ‘doing nothing’ which can have negative implications. The environment into which a radionuclide is released can also determine how feasible this recovery option would be. For instance, it may be more acceptable to let a radionuclide naturally decay in a rural area that is rarely used whereas an important commercial district or

Back to list of options

13 Natural attenuation (with monitoring)

	critical facility may require more urgent remediation strategy due to social pressures.
Feasibility	
Equipment	Monitoring equipment
Utilities and infrastructure	Capacity to analyse samples (ie laboratory facilities).
Consumables	Any consumables required for sampling, monitoring and analysis work.
Skills	Skilled personnel may be required to undertake monitoring and analysis.
Safety precautions	Monitoring team should carry out a risk assessment and may wear PPE
Waste	
Amount and type	None
Doses	
Averted doses	If radionuclide decays reasonably quickly, exposure may be reduced but maybe not as quickly as if cleaning techniques were used.
Additional doses	Exposure pathways that workers carrying out monitoring could be exposed to are: • external exposure from contamination in environment and equipment • inhalation exposure from contamination in environment and equipment • dermal exposure from contamination on skin • inadvertent ingestion of contamination from workers' hands (unlikely to be significant) Incremental exposure to the public will be influenced by their knowledge, understanding and compliance of associated advisory notices, warning about the incident.
Intervention costs	
Operator time	Costs of staff for monitoring and analysis work. Costs of public/stakeholder engagement meetings. Monitoring and engagement may be ongoing over some extended periods of time, leading to potentially high resource requirements.
Factors influencing costs	There is the potential for the long-term monitoring for many years (decades), which will require significant financial provision.
Side effects	
Environmental impact	Potential for spread of contamination in environment.
Social impact	It is essential that prior to, during and after the response to a radiation incident or event, clear communication strategies are developed and implemented. Acceptance of monitored natural attenuation requires liaison and agreement with various stakeholders (landowners, insurers, financiers and prospective purchasers) and the relevant regulators. Regular consultation is recommended throughout. If monitoring team are wearing PPE in an area with unrestricted public access this may damage public relations. Communication of monitoring data is of key importance.
Practical experience	Option implemented in Japan following the Fukushima accident.
Key references	IAEA (2014). The follow-up IAEA International Mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Daiichi Nuclear Power Plant. Tokyo and Fukushima Prefecture, Japan. 14-21 October 2013. Final report 23/01/2014. Miyahara K., Tokizawa T., Nakayama S (2012) Decontamination pilot projects: building a knowledge base for Fukushima environmental remediation. Mater Res Soc Symp Proc 2012; 1518:245-256.
Version	1
Document history	See Table 7.2 Based on datasheet of same name from version 1 of the UK Recovery Handbook for Chemical Incidents

Back to list of options

14 Ploughing methods

Objective	To reduce inhalation and external doses from contamination in outdoor areas covered in grass or soil within inhabited areas.
Other benefits	Ploughing (particularly deep ploughing or skim and burial ploughing) may reduce contamination in the surface soil layer (reduction of 90 - 95% of contamination in upper 20 cm of soil) in which food may subsequently be grown and so reduce uptake into food crops.
Management option description	Ploughing can be carried out at a range of depths, depending on the equipment used. A standard single-furrow mouldboard plough can be used to a depth of 250 - 300 mm, or to a deeper depth of 450 mm. Both techniques bury contamination in the top few cms of the soil, removing most of the contamination from the root uptake zone of plants - the increased ploughing depth doing this more effectively - while also mixing contamination throughout the ploughed depth of soil. A special deep plough that tills the soil to a depth of 900 mm may also be available. Such ploughs require a more powerful tractor than is commonly available. An alternative technique, skim and burial ploughing, can also be used. This uses a specialist plough with two ploughshares: a skim coulter and the main plough. The coulter skims off the upper 50 mm of soil and places it in the trench made by the main plough in the previous run. Simultaneously, the main plough digs a new trench and places the lifted subsoil on top of the thin layer of topsoil now in the bottom of previous trench. This results in the top 50 mm of soil being buried at 450 mm and the 50 - 450 mm layer not being inverted. The effect on soil fertility is minimised, although it may be necessary to fertilise soil after implementation. The contamination is largely buried below the rooting zone for crops. Removal of plants, shrubs and trees may be necessary before ploughing. Afterwards, replanting, replacing grass and fertilising and rolling the land may be required. The mixing of contamination by ploughing is irreversible and will severely complicate subsequent removal of contamination. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard (see tie-down Datasheet 23). Ploughing must not be repeated, as this could bring contamination back to the surface. However, shallow ploughing of land that has been previously deep ploughed may be permissible as long as the contamination remains buried below the depth of the shallow plough.
Target	Grass and soil surfaces in large, parks, playing fields and other open spaces, which have not been tilled since deposition occurred.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Suitable for large surface areas only (eg parks). When considering smaller areas consider digging, see Datasheet 11.
Time of application	Maximum benefit is obtained if ploughing is carried out soon after deposition, ie before soil migration occurs. However, it will continue to be significantly effective for many years after deposition has occurred because in most cases, the contamination will remain in the top 5 cm for many years (this is certainly the case for caesium in clay and brown earth soils). The effectiveness will gradually decrease with time.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed and historic sites or in conservation areas.
Environmental constraints	Severe cold weather. Soil texture (must not be too loose/sandy). In extreme cases, the slope of the area maybe a constraint. Soil depth must be greater than 0.3 m for shallow ploughing, 0.45 m for deep ploughing, and 0.5 m for skim and burial ploughing. High ground water level may be a constraint on deep ploughing.
Effectiveness	
Reduction in contamination on the surface	This option has a decontamination factor (DF) of 1 because it removes no contamination.
Reduction in surface dose rates	Reductions in external gamma dose rate above the surface depend on:

Back to list of options

14 Ploughing methods

- radionuclides involved, ie their gamma energies
- ploughing depth - an external gamma dose rate reduction factor of between 2 and 7 can be expected for shallow ploughing, between 5 and 10 for deep ploughing and a factor of 10 for skim and burial ploughing
- soil contamination profile with depth at the time of implementation
- success of the implementation

Beta dose rate reduction is likely to be significantly higher, effectively stopping beta emitters, if the technique is implemented effectively.

Reduction in resuspension

By effectively burying most of the contamination, resuspended activity in air above the surface will be reduced by a factor significantly larger than the external gamma dose rate reduction.

Technical factors influencing effectiveness

Weather conditions.

Correct implementation of option.

Soil texture - does the soil contain stones etc.

Whether area has been tilled since deposition.

Time of implementation: if contamination has migrated below the ploughing depth, the technique will be much less effective. Also, weathering will reduce contamination over time so quick implementation will improve effectiveness.

Consistency in effective implementation of option over a large area.

Contamination profile in soil.

Amount of the area covered by grass/soil.

Whether recovery options have been applied to other nearby ground surfaces.

Social factors influencing effectiveness

None

Feasibility

Equipment

Suitable plough for required depth - note that Skim and burial ploughing equipment is not readily available throughout Europe at the present time. As this procedure remains effective over several years, one piece of equipment could be used for a large area.

Suitable tractor to pull the plough - deep or skim and burial ploughing will require a powerful tractor.

Transport vehicles for equipment and waste.

Utilities and infrastructure

Roads for transport of equipment.

Consumables

Fuel and parts for transport vehicles and tractor. Fuel: around 15 litres ha^{-1} for ploughing.

Plants and replacement grass.

Skills

Personnel skilled in ploughing can be used but must be instructed carefully about the objective.

Safety precautions

Very dusty conditions: respiratory protection and protective clothes may be recommended to reduce the hazard from resuspended activity.

Waste

Amount and type

There is the potential for contaminated equipment to be classed as waste if it cannot be decontaminated sufficiently.

Doses

Averted doses

	^{137}Cs (% reduction in external dose)				^{239}Pu (% reduction in resuspension dose)			
	Over 1st year		Over 50 years		Over 1st year		Over 50 years	
Technique	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Deep	15-20	15-20	20-25	25-30	<5	5-10	5-10	10-15
Shallow	10-15	15-20	15-20	20-25	<5	10-15	5-10	15-20
S&B	15-20	15-20	20-25	25-30	<5	5-10	5-10	10-15

The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.

Back to list of options

14 Ploughing methods

Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Amount of grass/soil in the area ie environment type/land use. Time of implementation. The impact of ploughing on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Whether recovery options have been applied to other nearby ground surfaces.	
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) (can be controlled with the use of air-conditioned tractors) • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE. Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Deep	$7\ 10^3$ m^2/team.h (team size: 1 person).
	Shallow	$6\ 10^3$ - $8\ 10^3$ m^2/team.h (team size: 1 person).
	Skim and burial	$2\ 10^3$ - $3\ 10^3$ m^2/team.h (team size: 1 person).
	Depending on the PPE used individuals may need to work restricted shifts.	
Factors influencing costs	Soil type and condition. Amount of vegetation. Weather. Use of personal protective equipment (PPE). Topography. Size of area. Evenness of ground surface. Access. Need to replant.	
Side effects		
Environmental impact	Soil erosion risk (may be reduced by reseeding of grass). May bring contamination closer to groundwater. Acceptability of smothering flora and fauna and loss of plants and shrubs. Loss of soil fertility. Severely complicates subsequent removal of contamination. Soil may need to be rolled afterwards before use. The impact on farming depends on the time of year and land use prior to deposition.	
Social impact	Adverse aesthetic effect. Loss of public amenity. Leaving contamination in-situ. Temporary restriction of access to public areas. Restrictions on subsequent tilling of the land may not be practicable or acceptable.	
Practical experience	Tested widely in the Former Soviet Union after Chernobyl and on limited scale in Denmark. Used in Japan following the Fukushima accident.	
Key references	Andersson KG, Rantavaara A, Roed J, Rosén K, Salbu B and Skipperud L (2000). *A guide to countermeasures for implementation in the event of a nuclear accident affecting Nordic food-producing areas.* NKS/BOK 1.4 project report NKS-16, ISBN 87-7893-066-9, 76p. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R,	

Back to list of options

14 Ploughing methods

	Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. IAEA (2011) Final Report of the International mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Dai-ichi NPP 7-15 October 2011, Japan, IAEA NE/NEFW/2011, 15/11/2011 Masayuki I (2012) Report of the Results of the Decontamination Model projects. Analysis and Evaluation of the Results of the Decontamination Model Projects - Decontamination Technologies. Presentation to meeting held on March 26, 2012 at Fukushima City Public Hall Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Roed J, Andersson KG and Prip H (1996). The skim and burial plough: a new implement for reclamation of radioactively contaminated land. *Journal of Environmental Radioactivity*, **33**, (2), 117-128. Vovk IF, Blagoyev VV, Lyashenko AN and Kovalev IS (1993). Technical approaches to decontamiantion of terrestrial environments in the CIS (former USSR). *Science of the Total Environment*, **137**, 49-64. More information may become available after the publication of this handbook from the work following the Fukushima accident.

Version	Draft 1
Document history	See Table 7.2 Based on datasheets Deep Ploughing (datasheet 29), Ploughing (datasheet 33), and Skim and Burial Ploughing (datasheet 35) from version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

15 Pressure and fire hosing

Objective	To reduce external gamma and beta doses from contamination on surfaces within inhabited areas, and reduce inhalation dose from material resuspended from these surfaces.
Other benefits	Will remove contamination from surfaces (external walls and roofs of buildings (also see Datasheet 17 for more information on roof cleaning), outdoor hard surfaces such as roads and paved area, surfaces in semi enclosed areas, and vehicles) within inhabited areas.
Management option description	High pressure-washing or fire hosing equipment can be used to loosen contamination from a surface and wash it off. The pressure and flow rate is usually chosen to be optimal for a given situation. To prevent dispersion of contamination by water pressure, cleaning shall be performed at low pressure initially and the pressure shall be raised gradually while checking the flow of cleaning water and the dispersion conditions. Washing must start at the top of walls and roofs. A distance of 20 cm or less should be maintained between the nozzle head and the surface being decontaminated. Attention must be paid to the fact that there is the possibility of damaging property, such as by potentially peeling off the surface of objects. Any possibility of breakage or damage from high pressure water cleaning shall be checked in advance - obtaining advice from a specialist is recommended. **Fire hosing:** Ordinary fire hosing equipment is used to hose contaminated material from hard surfaces. For normal sized residential housing, a hydraulic platform can be used to provide access to the front and rear walls and roofs of buildings. Dust creation during implementation is unlikely to be a problem and so methods are not required to reduce the resuspension hazard to workers. Recontamination of surfaces by resuspended contaminants will be insignificant, so repeated application is not required. **High pressure hosing:** Pressure washing equipment supplies a continuous water flow at high pressure of about 150 bar (2000 psi). When treating buildings a pump is mounted on the ground and hoses are fed to a platform or scaffolding. It is particularly important to avoid lifting roof tiles by forcing water upwards. It may be necessary to apply a surface treatment to roofs after high pressure washing to ensure protection against future water penetration. If treating a large area of flooring, equipment may be mounted on a heavy trolley. Ultra-high pressure washing with pressures of over 20000 psi can also be used, although this is not suitable for corner sections of buildings, is difficult on vertical surfaces, and use of high pressure jets at pressures significantly above 150 -200 bar is not advisable on roofs as this may lead to lifting of the tiles. Pressure washing can be implemented in conjunction with rotating wire brushes, or with nano-bubble water or with hydrogen peroxide added to the water. An ultra-high pressure water cleaner of 1500 bar (~22000 psi) or higher may be used for scraping material away on paved surfaces, with material being collected by a powerful vacuum truck. High pressure sweepers: Road sweepers with high pressure (or ultra high pressure) jet nozzles can be used to clean roads or paved surfaces, blasting contamination from cracks. These systems can include filtered water collection. Waste water: This option generates a large volume of waste water. Where possible, measures shall be taken to prevent the dispersion of the cleaning water. If collection of waste water is possible, it may be possible to use bunding with an inbuilt absorber for caesium, to act as a filter and treat the water, otherwise refer to Datasheet 26 for other water treatment options. **Walls:** it is unlikely to be practicable to collect the waste water and associated contamination, although this may be done using PVC sheets draped between scaffolding and the wall. The bottom of the sheet hangs in a metal trough sealed to the wall with pitch. Water flows into the trough and a pump delivers the water to collection tanks where it is then filtered and pumped to delay tanks. **Roofs:** If high pressure hosing is used, it should be practicable to collect the water. This is unlikely to be practicable for firehosing. Collection of water from roofs can be aided by modifying guttering and drainpipes, so that the collected waste is fed into collection tanks, where it may be filtered (most of radioactivity will be associated with the solid phase). If no active means are adopted to collect the water, some of the waste water may soak into the ground and the rest will pass directly into the drains (public sewers or highway drainage) or to soak-aways via gutters and drainpipes. **Roads and paved areas:** It is probably not practicable to collect water from fire hosing or pressure hosing, though collection may be possible through the use of bunds, ie constraining the water within an area thus allowing it to be subsequently pumped to tankers, or with

Back to list of options

15 Pressure and fire hosing

	specialised road sweeping equipment. Without collection, contamination, dirt/dust and water are washed directly down drains (public sewers or highway drainage) or on to grass and soil verges.
Target	Highly contaminated external walls and roofs of buildings, outdoor hard surfaces such as roads and paved areas, surfaces in semi enclosed areas, and vehicles. Some internal floors and walls with large area hard surfaces (eg within public buildings such as railway stations) may be robust enough to withstand high pressure hosing. It may be beneficial to give particular focus to schools, nurseries, hospitals and other buildings frequented by large numbers of people. High pressure water jets can also be used to decontaminate train tracks and gravel/pebbles.
Targeted radionuclides	All long-lived radionuclides. Short lived radionuclides only if implemented quickly.
Scale of application	Any size.
Time of application	Maximum benefit if carried out soon after deposition (within one week) when maximum contamination is still on the surfaces. Fire hosing is unlikely to have a significant effect at later times, though high pressure hosing can be effective up to several years after deposition, depending on the cleaning and weathering that has occurred before decontamination takes place. If run-off to ground surfaces occurs, the implementation of options to the surrounding ground surfaces should also be considered after fire hosing or high pressure hosing has been implemented. If the implementation of any other options to the surrounding ground surfaces is planned, high pressure hosing of walls and roofs should be implemented first.
Constraints	
Legal constraints	Liabilities for possible damage to property (eg flooding). Ownership and access to property. Disposal of contaminated water via public sewer system. Use on listed and other historical buildings, or in conservation areas.
Environmental constraints	Severe cold weather (snow and ice may cause problems and water would need to be heated). Surfaces must be waterproof, and must resist water at high pressure if necessary. Nearby drains are required, unless waste water can be collected. This option generates a large volume of water to be treated and therefore consideration should also be given to water based cleaning, Datasheet 29.
Effectiveness	
Reduction in contamination on the surface	The decontamination factor (DF) achieved depends on time of application. A higher DF will be achieved if there is no rainfall before implemention. The DFs shown below can be achieved if the option is implemented soon (within a week) after deposition and no significant rainfall. When considering roads and paved surfaces it is also assumed that there has been no significant 'traffic' before implementation.

	Fire hosing	High pressure hosing
Building surfaces (walls and roofs)	1.3	1.5 - 5
Roads and paved areas	2 - 5	3 - 7

Japanese experience has given the following reductions in surface contamination using high pressure jet washing:

Surface	Reduction in surface contamination
Building surfaces (roofs/walls/floors)	Up to 70% (DF=3.3)
Concrete roof surfaces	39% (DF=1.6) - 77% (DF=4.3) (May be higher with treated concrete)
Pavement	2% (DF=1) - 90% (DF=10)
Roads	Up to 55% (DF=2.2)

Back to list of options

15 Pressure and fire hosing

	Where a range of DFs is given, higher DFs tend to be achieved following dry deposition then after wet deposition. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be same for almost all radionuclides. Exceptions are that: • for elemental iodine and tritium, thorough hosing of impermeable surfaces will lead to virtually full removal • in the case of high pressure hosing of external buildings, a DF of between of 2 and 10 can be achieved for plutionium More information may become available after the publication of this handbook from the work following the Fukushima accident.
Reduction in surface dose rates	External gamma and beta dose rates from decontaminated surfaces will be reduced by a factor similar to the DF. Experience of pressure hosing in Goiania gave about 20% reduction in dose rates. Reductions in external doses received by a member of public living in the area will depend on the surfaces in the area and the time spent by individuals close to these surfaces (see below).
Reduction in resuspension	Resuspended activity in air following decontamination will be reduced by the value of the DF.
Technical factors influencing effectiveness	Method used - water pressure, duration of wash, angle of water jet, use of brushes, additions to the water. Consistent application of water over the contaminated area (ie operator skill). When carried out over a wide area, attention must be paid to ensure that no variance occurs between the work methods at different points (height of the nozzle over the ground, work time per unit of surface area, etc). Care in application: care needed to wash contamination from surfaces and not just move the contamination around; lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building; special care needed to clean roof gutters and drain pipes; road gutters must be hosed carefully because contamination tends to accumulate there. Amount of dust on surface at time of contamination. Type, evenness and condition of surface: rough surfaces, eg roof tiles, may trap contamination which is harder to remove. The amount of moss on roofs will have an effect. Time of implementation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface. Weathering will reduce contamination over time so quick implementation will improve effectiveness. Rainfall increases the penetration of contamination into the surface, though studies (US EPA, 2014) show that the increased penetration is less on asphalt than on brick or limestone. Therefore a delay in cleaning roads may not be as significant. Number of buildings or amount of hard outdoor surfaces in the area. Number of windows in buildings (windows easier to clean). Whether the surrounding ground areas on to which run-off may have occurred have been decontaminated after treating the building (if waste was not collected).
Social factors influencing effectiveness	N/A
Feasibility	
Equipment	The equipment used will depend on the exact method used and whether the waste water is filtered prior to disposal. High pressure hosing: ≥ 2000 psi pressure washer; 7.5kW generator; gully sucker. Fire hosing: Fire-tender or hydrant with pump if required; fire hose; PVC sheets, hydraulic platform with mounted hoses if required for reaching buildings. Both: Transportation vehicles for equipment and waste; filter; spate pump; scaffolding with roof ladders or mobile lift for roof access if required for buildings. Possible extras: high pressure road sweepers, brushes; trough, tanks or other water collection equipment.

Back to list of options

15 Pressure and fire hosing	
Utilities and infrastructure	Roads for transport of equipment and waste. Water and power supplies. Public sewer or highway drainage system.
Consumables	Fuel and parts for generators and transport vehicles. Water. Hydrogen peroxide if used as additive to water. Surface treatment if required for roofs. Sand, if required, for high pressure hosing of roads.
Skills	Skilled personnel essential to operate high pressure or hoses and gully suckers or fire engines and hoses.
Safety precautions	Water-resistant clothing will be required, particularly in highly contaminated areas. Personal protective equipment (PPE) will be required, including respiratory protection, to protect workers from contaminated water spray. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, eg by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system. For tall buildings: lifeline and safety helmets.
Waste	
Amount	High pressure hosing: 2 10^{-1} - 4 10^{-1} kg m^{-2} solid and 20 l m^{-2} water. Fire hosing: 1 10^{-1} - 2 10^{-1} kg m^{-2} solid and 50 l m^{-2} water. Disposal will be subject to conditions depending on the activity levels and other properties of the waste.
Type	Dust and water.
Doses	
Averted dose	Estimated dose reductions are typically up to 5-10% reduction, not including any potential future doses that may arise if contaminated water enters the drainage system and subsequently the wider environment.
Factors influencing averted dose	Consistency in effective implementation of option over a large area Care in application. Care needed to wash contamination from surfaces and not just move the contamination around the surface; lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building; special care needed to clean roof gutters and drain pipes; road gutters must be hosed carefully because contamination tends to accumulate there. Population behaviour in the area. Whether the ground areas surrounding the surfaces on to which run-off (if waste water was not collected) may have occurred have been decontaminated after treatment. Number of buildings and amount of hard surfaces in the area, ie environment type/land use. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • inhalation of dust and water spray generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.

Back to list of options

15 Pressure and fire hosing

Intervention costs		
Operator time	Work rate (m^2/team.h) (excludes setting up scaffolding, if required)	High pressure hosing: 30 - 60 Japanese experience indicates that high pressure washing can be performed at 100-300 m^2 per day, with a higher rate on roads than for buildings. Fire hosing: 70 for roofs, 600-700 for walls, 1000 for roads Depending on the PPE used individuals may need to work restricted shifts.
	Team size (people)	Typically 2-3, possibly up to 5, will depend on equipment used and access to buildings. May have more people in a fire hosing team than for high pressure hosing. May have more people working when treating walls than roofs. More people needed if water is collected and filtered prior to disposal.
Factors influencing costs	Weather. Size of areas to be treated. Topography of area when treating roads and paved areas. Type of equipment used. Access. Proximity of water supplies. Use of personal protective equipment (PPE).	
Side effects		
Environmental impact	Fire hosing or high pressure hosing will create contaminated waste water. If waste water is not collected, some of it will run on to other surfaces (possibly pooling in some areas) or directly down drains into public sewer or highway drainage systems. Run off on to other surfaces results in a transfer of contamination which may require subsequent clean-up, generating more waste. It is important that hosing of buildings is implemented before the implementation of any recovery options to surrounding ground surfaces. It may be preferable to use the wipe/wash method (refer to Datasheet 29) to avoid splatter risk if the impact of secondary contamination is substantial. Disposal of waste water to drains may have an environmental impact. Some water will enter the public sewers and be treated at the sewage treatment plant (STP). Monitoring and control, through relevant authorisations, of any subsequent disposal of sludge and water from the STP will minimise the environmental impact. Surface water that enters a highway drainage system may be drained through a Sustainable Urban Drainage (SUD) system, which will offer some control. Some highway drainage systems will however direct to a local water course. Interaction with the regulators is necessary to establish the best disposal route and discharge limits. Where waste water can be disposed via a STP or SUD, the environmental impact may be easier to control and monitor than long term run-off produced by rainfall. It is possible that restrictions on the use of sludge containing radioactive materials and problems with disposal of such material may lead to accumulation of sludge at wastewater treatment plants. The of disposal of waste water from hosing directly to drains in the sewage treatment plant There may be environmental impact if hydrogen peroxide is added to the water. If waste water is collected treatment may be possible. Refer to Datasheet 26 for further information.	
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. Hosing of buildings or roads will make an area look clean; implementation may give public reassurance. Repair work on some walls and roofs may be required.	
Practical experience	Treatment of walls and roofs have been tested on realistic scale in the Former Soviet Union and Europe after the Chernobyl accident. Small-scale test on the treatment of roads and paved areas have been conducted in Denmark and the USA under varying conditions. Used following the incident in Goiania. Used in Japan following the Fukushima accident to clean roofs and outer walls; eaves, roof	

Back to list of options

15 Pressure and fire hosing

	gutters, storm water catch basins and street gutters (after removing deposited material); parking lots, roads and other paved surfaces (in combination with washing and surface removal).
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, 46, (2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315 Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR Hardie SML and McKinley IG (2014) Fukushima remediation: status and overview of future plans. J Environ Radioact 2014; 133:17-85. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996*). Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. IAEA (1988) The Radiological Accident in Goiania. STI/PUB/815 ISBN 92-0-129088-8, IAEA, Vienna IAEA (2014). The follow-up IAEA International Mission on Remediation of Large Contaminated Areas Off-Site the Fukushima Daiichi Nuclear Power Plant. Tokyo and Fukushima Prefecture, Japan. 14-21 October 2013. Final report 23/01/2014. Masayuki I (2012) Report of the Results of the Decontamination Model projects. Analysis and Evaluation of the Results of the Decontamination Model Projects - Decontamination Technologies. Presentation to meeting held on March 26, 2012 at Fukushima City Public Hall Ministry of the Environment, Japan (2013) Progress on Off-Site Cleanup Efforts in Japan, presentation by Ministry of the Environment on Oct 7th 2013 Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, 33 (2), 107-116. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. US EPA (2014) Fate and Transport of Cesium RDD Contamination - Implications for Cleanup Operations. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/250, 2014. Warming L (1984). Weathering and decontamination of radioactivity deposited on concrete surfaces. Risø-M-2473, Risø National Laboratory, Roskilde, Denmark. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheets Firehosing (datasheets 6 and 21) and High Pressure Hosing (datasheets 7 and 22) and Aggressive Cleaning of Indoor Contaminated Surfaces (datasheet14) from version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

16 Reactive liquids

Objective	To reduce external doses from contamination on a variety of surfaces (internal and external)
Other benefits	Removal of contamination from the area and prevent redistribution of contamination in buildings. May reduce resuspension doses in dusty environments.
Management option description	A number of reactive liquids are available - see below. Depending on the chemicals applied, procedures are termed soft (non-corrosive reagents such as detergents (including household cleaners), chelating agents, diluted acids or alkalis, can be used when the object has to be treated without attacking the base material) or hard (concentrated strong acids or alkalis and other corrosive reagents). The choice of agent will depend on the surface being treated. For example, a plastic surface may need a soft procedure using a mild detergent or chemical, while metals surfaces may withstand more aggressive, hard treatment. Procedures can be static (without flow) or dynamic (with flow). The dynamic method is useful for removing radionuclides from both internal and otherwise inaccessible surfaces. Otherwise spray bottles, wipes, paper towels or tack cloths may be used. Chemical decontamination is usually carried out by circulating the selected reagents through a filter system. The chemical solution is contained in a tank in which a spraying system, placed near to or below the surface being cleaned, circulates the solution. Decontamination can also be carried out by immersion of the contaminated item (hand tools, special parts of machinery) in a bath. It may be beneficial to start with a degreasing agent to remove easily removable surface grease or dust prior to final decontamination. Treatment can be followed with passivation, the preparation of a corrosion-resistant, thermodynamically stable surface after removing the contaminated surface layer. **Chelating (complexing) agents:** Chelation (also known as complexation or sequestration) binds an organic chemical, the chelating agent, to a metal ion so as to bring it into solution and hence remove it from the surface. Chelation is normally used against fixed contamination. Common chelating agents are organic acids which also cause decontamination by an oxidation-reduction mechanism as well. Acids are also more effective chelators for radioactive contamination. Chelation can be carried out as a stand-alone technique, but is often part of a more complex process. **Strong mineral acids:** These release bound contaminants by dissolving metal oxide films that contain contamination. Acids used are hydrochloric acid (HCl), nitric acid (HNO_3), sulphuric acid (H_2SO_4) and phosphoric acid (H_2PO_4), which can be used on all metal surfaces except more reactive metals such as zinc. **Oxidising and Reducing agents:** Oxidising and Reducing (redox) reactions can be used to aid decontamination by increasing the solubility of metal ions, or the degree to which a metal ion will bond with a chelating agent. Agents may be used stand-alone, though they have limited effectiveness on their own, or in more complex processes with chelating agents or acids. Bleach, nitric acid and alkaline-permanganate solutions are the most commonly used oxidising agents. **Chemical foams and gels:** These are commonly used as carrier agents for other reactive agents such as chelators or acids. Foam is produced using water, detergent and the decontamination agent(s) using and industrial foam generator, which is cheap, simple and reliable. Foams have little decontamination ability on their own, although the detergent part may have some minor decontamination effect. Foams allow increased contact time compared with aqueous solutions, although repeated applications may be necessary as the amount of agent in contact with the surface is small compared to with the aqueous solution. Foams and gels are good for complex shapes.
Target	Indoor and outdoor surfaces and objects, including semi-enclosed surfaces and vehicles.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Small scale.
Time of application	Maximum benefit if carried out soon after an incident when maximum contamination is still on the surfaces and before natural processes can disperse contamination.
Constraints	
Legal constraints	Liability issues regarding possible damage to property. Issues with ownership and access to property or affected site. Cultural heritage protection of listed and other historically important buildings. Possible regulations on use of chemicals.

Back to list of options

16 Reactive liquids

Environmental constraints	Chemical incompatibility. For example, if the system to be decontaminated previously contained special chemicals, this material can produce some explosive gases when put together with the decontamination chemical. Depending on the reactive liquid used and the type of contaminant(s) involved, the toxicity of waste products would need to be considered. Contaminated waste products from treatment (ie effluent) could run on to other surfaces (roads, soil, grass etc) if not controlled effectively, resulting in a transfer of contamination which may require subsequent clean-up thus generating more waste. There may be issues with disposal (eg lack of compliance with LLWR criteria) and handling of some chemicals which may prevent their use.
Effectiveness	
Reduction in contamination on the surface	This depends on the exact technique and agents used. **Soft techniques:** typically 50 - 90% reduction. **Hard techniques:** typically > 90% (up to 100%) reduction. Effectiveness may be lower on non-metallic surfaces.
Reduction in surface dose rates **Reduction in resuspension**	If the surface is decontaminated effectively, there should be a significant reduction in both dose rates and resuspension, similar to the reduction in contamination on the surface, and hence in potential exposure.
Technical factors influencing effectiveness	Treatment temperature. Chemical concentration. Flow rate of the applied chemical solution. Contact time. Time between contamination and clean up. Surface type (less effective on porous surfaces or if contamination has penetrated into inaccessible surfaces (ie under a screw). Chemical incompatibility. Consistency in procedure application. Cleanliness of surface (heavily grimed surfaces could have a high concentration of metals in the grime that interfere with the decontamination process and reduce efficiency) The bottom part of the building should be cleaned particularly well, as this will often be the closest to people working in the building. This option may need to be repeatedly implemented to effectively decontaminate the affected surface.
Social factors influencing effectiveness	None
Feasibility	
Equipment	High pressure water washer. Spray machines. Other hand tools (sponge, brush, cloths). Liquid tanks.
Utilities and infrastructure	Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings. Water and power supplies. Pressurised air supply.
Consumables	Depends on the target surfaces and hence the chemical agents used ie soft or hard treatment. Soft (mild) chemical decontamination will typically require Step 1 attack and dissolve metal oxide films: potassium permanganate ($KMnO_4$) (one of the best for Cs) or potassium hydroxide (KOH) or sodium hydroxide (NaOH) or trisodium phosphate (Na_3PO_4). Step 2 bind and remove the radionuclides: detergent - any hydrophobic materials eg dodecyl benzene sulphuric acid - and chelating (complexing) agent such as EDTA (one of the best for Cs) or oxalic acid ($C_2H_2O_4$) or citric acid ($C_6H_8O_6$) (one of the best for Cs).

Back to list of options

16 Reactive liquids

	Step 3 passivation: nitric acid (HNO_3) or phosphoric acid (H_3PO_4) or sulphuric acid (H_2SO_4) or hydrogen peroxide (H_2O_2). Hard (strong) chemical decontamination will typically require Step 1: as for soft decontamination, but at higher concentration. Step 2: detergent - any hydrophobic materials eg dodecyl benzene sulphuric acid and chelating (complexing) agent such as sodium bisulphate ($NaHSO_4$) or sodium sulphate (Na_2SO_4) or ammonium oxalate ($NH_4C_2O_4$) or ammonium citrate [$(NH_4)_2HC_6H_5O_7$] or EDTA. Step 3: as for soft decontamination, but at higher concentration.
Skills	Skilled personnel required. Knowledge and experience in corrosion technology, waste generation/removal techniques and chemical cleaning is needed. Industrial cleaning companies will have the required skills.
Safety precautions	PPE and safety equipment should consider the hazards arising from the use of chemicals (corrosive, toxic or oxidising materials, gases, fires and explosion hazards) as well as radiological protection. Safety helmets and lifelines. Water proof safety clothing. Respiratory protection. Proper ventilation (because the tanks are usually open to the air).
Waste	
Amount and type	5 - 30 l m^{-2} liquid waste (applying a recycling system). Efficient recycling of reactive chemicals will help to keep waste levels low. There may be limitations on disposal routes available based on the agents used.
Doses	
Averted dose	Not estimated.
Factors influencing averted dose	Amount of time spent in or close to the buildings. Amount of the building that is covered in metal surfaces. Extent of decontamination of nearby surfaces.
Additional doses	Relevant exposure pathways for workers are: external exposure from radionuclides in the environment and contaminated equipment enhanced resuspension leading to inhalation of dust Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	2 - 6 m^2/team.h. Depending on the PPE used individuals may need to work restricted shifts. Variable time for setting up scaffolds/transport.
Factors influencing costs	Need for scaffolding /mobile lifts. Different types of treatment of surfaces and waste chemicals. Cost of specialist labour. Cost of chemicals.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. Electronic parts may be damaged by water if not dismounted. Damage to equipment due to the mechanical impact or the chemical used (eg the basic material will be thinner and rough). If strong chemicals are used they may lead to corrosive and toxic reagents being produced which will need to be handled and disposed of.
Social impact	Acceptability of disposal of contaminated waste and chemicals. Removal of the corrosion products from the surface; the metal surfaces are cleaned.

Back to list of options

16 Reactive liquids

	Reassurance of employees and users and maintaining continuity of work.
Practical experience	Chemical decontamination is very effective at NPPs in normal practice and is used in decommissioning. Acidic and caustic solutions are used in industry for decontamination. Decon 75 and Decon 90 are commonly used in industry, though there are limitations to their use eg Decon 90 is alkaline and therefore not suitable for use on non-ferrous metals or on polycarbonate. Tested in a number of industrial buildings in the Former Soviet Union and Europe after the Chernobyl accident.
Key references	Barkatt A, Spring S and Olzsovka SA (1995). *Removal of radioactive or heavy metal contaminanats by means of non-persistant complexing agents.* United States Patent and Trademark Office: United States Patent; No. 5435331. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2000). *Compendium of measures to reduce radiation exposure following events with not insignificant radiological consequences.* Bonn: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, vols 1 and 2. Desrosiers, M., T. Cousins, K. Volchek, D. Velicogna, A. Obenauf, L. Boudreau, M. Hornof, A. Dumouchel, A. Somers, T. Jones, A. Mastilovich, and M. Vijay, 'Radiological Decontamination - Laboratory Research Study', Manuscript Report EE-180, Science and Technology Branch, Environment Canada, ON, 2006. Eged K, Kis Z, Andersson KG, Roed J and Varga K (2003). Guidelines for planning interventions against external exposure in industrial area after a nuclear accident. Part 1: a holostic approach to countermeasure application. GSF-Bericht 01/03, Germany. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. International Atomic Energy Agency (IAEA) (1989). *Cleanup of large areas contaminated as a result of a nuclear accident.* Vienna: International Atomic Energy Agency, Technical Report Series No. 300. Magyar Szabvány (1983). *Testing of painted coatings in the laboratory, determination for ease of decontamination.* Hungarian Patent Office: Hungarian Patent, No. MSZ-05 22.7662-83. Murray AP (1989). *Method of decontaminating metal surfaces.* European Patent Office: European Patent Specification; No. 04164988 B1. Nuclear Energy Agency (NEA) (1999). *Decontamination techniques used in decommissioning activities.* NEA Report-1707. Available online at: http://www.nea.fr/html/rwm/reports/1999/decontec.pdf [Accessed 16/10/08] US Department of Energy (1994). *Decommissioning technology descriptions: decontamination.* USDoE, Office of Environmental Management.
Version	1
Document history	See Table 7.2 Based on Reactive liquids (bleaches, detergents, foams and gels) datasheet from version 1 of the UK Recovery Handbook for Chemical incidents and Chemical Cleaning of Metal Surfaces (datasheet 46) and Chemical Cleaning of Plastic and Coated Surfaces (datasheet 47) from version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

17 Roof cleaning including gutters and downpipes

Objective	To reduce external gamma and beta doses and inhalation doses from contamination on roofs, guttering and downpipes of buildings within inhabited areas.
Other benefits	Will remove contamination from roofs, guttering and downpipes of buildings.
Management option description	Roof cleaning, including gutters and downpipes, can be carried out using either pressurised hot water and/or rotating brushes, or with simple wiping of surfaces. See sections below for information on these options. Roof cleaning shall be implemented prior to decontamination of ground and surrounding surfaces, using the hierarchy of procedures as follows: • removal of leaf litter, moss and silts from gutters • cleaning of roof into gutter, working from higher areas to lower ones • removal of additional leaf litter, moss, silts etc washed from rook into gutter • cleaning of gutter Special attention shall be paid to cleaning the overlapping sections of roofs, places where the metal is corroded, and around the drain for rooftops, because these are places where there are comparatively large amounts of sediments. After manual removal of leaf litter etc, it may be advisable to install a fitting at the top of downpipes to catch additional leaf litter being washed off the roof to prevent solids being washed down the pipe. Cutting of downpipes near to ground level will allow pipes to be fitted to divert water for collection and treatment. Attention must be paid to the fact that there is the possibility of damaging property, such as by potentially peeling off the surface of objects. Any possibility of breakage or damage from high pressure water cleaning shall be checked in advance - obtaining advice from a specialist is recommended. **Pressurised hot water:** Rotating nozzles are driven by hot water at high pressure. Cleaning is performed in a closed (shielded) 'box' system. The device is mounted on a trolley that can be drawn across the roof. It is operated from the top of the roof, lowered down the roof using the pressure water hose. It should be noted that the use of hotter water (ca. 80 °C) and detergent can considerably increase the effectiveness of the procedure. High pressure water cleaners with a water pressure of 50 bar (725 psi) or less, can be used to ensure that rainwater guttering is not destroyed. This is primarily for narrow places where people cannot reach and other sections where it is difficult to perform wiping work. See Datasheet 15 for further information on hosing. **Rotating brushes:** The roof is cleaned using commercially available rotating brushes driven by compressed air. Cleaning is carried out in a closed (shielded) 'box' system. The device is mounted on an extendable rod that allows operation from the top of the roof or, in the case of single-storey buildings, from the ground. Dust creation is unlikely to be a problem during implementation. Waste is largely solids (eg moss) that are collected. **Pressurised hot water and/or rotating brushes** Contaminated waste should be segregated, with care taken not to block drains with moss, etc. Waste water can be easily collected via downpipes, then filtered and recycled. See Datasheet 26 for information on treating waste water. However, water may be allowed to pass into drains or to soak-aways via gutters and drainpipes. Cleaning of these should be considered after implementation. The implementation of options to the surrounding ground surfaces should also be considered following roof cleaning if contaminated water is drained on to the ground surrounding the buildings. If the implementation of any other options to the surrounding ground surfaces is planned, roof cleaning should be implemented first. **Wiping and brushing:** Manual removal of leaves, moss and sediments, followed by washing or wiping gutters with water has been found to produce similar levels of decontamination as achieved using high-pressure water jet washing, but with minimal risk of spread of contamination to other surfaces. Sediment in downspouts (especially bend sections) tends to get overlooked, so these should be cleaned with a wire brush. See Datasheet 29 for further information on water based cleaning.
Target	Contaminated roofs, guttering and downpipes of buildings, both residential and industrial. Although roofing is made from diverse materials, with some exceptions (eg flat roof covered with gravel, or weathered cement roof tiles) techniques are generally suitable for all types.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Any size building
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surfaces. However roof cleaning can be effective up to 10 years after deposition depending on the roof material and removable debris/growth.

Back to list of options

17 Roof cleaning including gutters and downpipes

	Roof cleaning should be implemented prior to decontamination of ground and surrounding surfaces.
Constraints	
Legal constraints	Ownership and access to property. Liabilities for possible damage to property. Use on listed and other important buildings. Disposal of contaminated water via the public sewer system, if required Solid waste disposal.
Environmental constraints	Severe cold weather (may require heating of water, even if not using hot water method). Roof construction must resist water at high pressure.
Effectiveness	
Reduction in contamination on the surface	Most work cleaning roofs using pressurised water and/or rotating brushes has achieved a decontamination factor (DF) of between 1 and 7, though occasionally higher DFs of up to 15 have been seen. Japanese experience following Fukushima found that pressure washing of concrete roofs gave DFs of between 2 and 4. Wiping roofs can achieve a DF of between 1 and 4. Cleaning guttering with high pressure water jets can achieve a DF of between 1 and 4, while wiping guttering can achieve a DF of between 1 and 10. These DFs are if implemented soon after deposition. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be the same for all radionuclides, with the exception of elemental iodine and tritium, for which thorough washing of impermeable surfaces will lead to virtually full removal. Even after 10 years, a DF of 2 - 4 can be achieved. The DF will be lowest for slate, clay and concrete roofs, and highest for silicon-treated slate, and possibly even higher for aluminium/ iron. If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
Reduction in surface dose rates	External gamma and beta dose rate contributions from roofs of buildings will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air above the roof surface can also be assumed to be reduced by the value of the DF.
Technical factors influencing effectiveness	Material from which roof/guttering is constructed. Amount of removable debris on roof, eg moss, pine needles. Evenness, condition of the surface Time of implementation: weathering will reduce contamination over time. However, the longer the time between deposition and implementation of the option, the more fixing of the contamination to the surface can occur. Therefore quick implementation will improve effectiveness. Consistency in effective implementation of option over entire area. Care taken to wash contamination to the roof gutter and not just transfer it on to other parts of the roof. Special care must be taken to clean roof gutters and drain pipes thoroughly after implementation. Water pressure, amount of water, water temperature (hotter water is more effective), use of detergent. Number of buildings in the area. Care should be taken that water does not penetrate through roofs.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Scaffolding and roof-ladders or fire-tender with hydraulic platform or other mobile lift for operation from the roof. If pressure cleaning: Pressure washer with hot water generator and/or rotating brush attachment if required.

Back to list of options

17 Roof cleaning including gutters and downpipes

	Roof cleaning trolley. If wiping: Shovel for removal of leaves, moss etc. Washcloths and water. Filters and collection tanks for waste water and solid wastes. Transportation vehicles for equipment and waste.
Utilities and infrastructure	Water and power supplies. Public sewer system if water is not collected. Roads for transport of equipment and waste.
Consumables	Water. Wash cloths if required. Fuel and parts for generators and transport vehicles.
Skills	Skilled personnel essential for working at heights. Otherwise can be carried out with little instruction - one person on the rooftop and one on the ground administering supplies.
Safety precautions	For tall buildings: lifeline and safety helmet. Water-resistant clothing will be required, particularly in highly contaminated areas. If pressure washing is implemented, personal protective equipment (PPE) will be required, including respiratory protection, to protect workers from contaminated water spray. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, eg by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.
Waste	
Amount and type	The amount of waste depends on the amount of moss and other debris on the roof. 15 - 30 l m^{-2} waste water. 0.2 - 0.6 kg m^{-2} solid waste (dust and moss sludge). If washing/wiping if carried out then the wash cloths used for this will also require disposal as solid waste, though the volume of this waste is unlikely to be large. Disposal will be subject to conditions depending on the activity levels and other properties of the waste. Waste may be toxic (asbestos). Water can be collected via down-pipes and filtered using a simple filter prior to disposal via the drains or can be recycled. Where possible, measures shall be taken to prevent the dispersion of the cleaning water. If water is collected, see Datasheet 26 for information on treatment of waste water. Care must be taken not to block drains with moss etc.
Doses	
Averted doses	Reductions in external gamma dose rate shortly after decontamination of the roof surface received by a member of the public living in an inhabited area could be expected to be up to about 8%. This is an illustrative value and should only be used to provide an indication of the likely effectiveness of this option and to compare across options. The estimated dose reductions do not include any potential future doses that may arise if contaminated water enters the drainage system and subsequently the wider environment.
Factors influencing averted dose	Consistency in effective implementation of option over entire area. Careful implementation. Special care must be taken to clean roof gutters and drain pipes. Care should be taken to wash contamination to the roof gutter and not just move it around the roof. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Whether the ground surfaces below the roof (on to which run-off may have occurred) have been decontaminated after treating the roof (especially if there is no gutter and waste water is not collected). Number of buildings in the area, ie environment type / land use. Type of building - Industrial buildings often have shallow sloping roofs resulting in high contamination levels and high dose rates.

Back to list of options

17 Roof cleaning including gutters and downpipes

	Population behaviour in area, including time spent by individuals close to buildings.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • inhalation of dust generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	3 - 8 m^2/team.h (team size: 1 - 2 people). Work rate excludes setting up scaffolding. Decontamination speeds of 120 m^2 per day brushing or wiping roofs of residential houses are estimated from Japanese projects.
Factors influencing costs	Weather. Type of equipment used. Building height and pitch of roof - determines size of scaffolds, mobile lifts etc. Type of surface, numbers of gutters etc. Amount of debris on roof. Access. Proximity of water supplies. Operator skill.
Side effects	
Environmental impact	Disposal of waste water to drains may have an environmental impact. Water may enter the public sewers and be treated at the sewage treatment plant (STP), or may be discharge directly to a local water course, or via a Sustainable Urban Drainage (SUD) system. If water is disposed via a STP or SUD, the environmental impact can be minimised by monitoring, and control through relevant authorisations, of any subsequent disposal of sludge and water. If water cannot be collected for treatment, interaction with the regulators is necessary to establish the best disposal route and discharge limits. It is possible that restrictions on the use of sludge containing radioactive materials and problems with disposal of such material may lead to accumulation of sludge at wastewater treatment plants. If waste water is not collected, some of it will run on to other surfaces (roads, soil, grass etc). These may require subsequent clean-up, generating more waste. If waste water is collected, see Datasheet 26 on treatment of waste water.
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. Cleaning roofs will make buildings look cleaner; implementation may give public reassurance. Repair work on roof etc may be required but this is unlikely.
Practical experience	Tested on realistic scale on selected roofs of different types in the Former Soviet Union after the Chernobyl accident. Carried out in Japan following the Fukushima accident
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315

Back to list of options

17 Roof cleaning including gutters and downpipes

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Tsushima I, Ogoshi M and Harada I (2013) Leachate tests with sewage sludge contaminated by radioactive cesium, Journal of Environmental Science and Health, Part A (2013) 48, 1717-1722

More information may become available after the publication of this handbook from the work following the Fukushima accident.

Version	1
Document history	See Table 7.2 Based on datasheets for Roof Brushing (datasheet 8) and Roof Cleaning with Pressurised Hot Water (datasheet 9) from version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

18 Snow/ice removal

Objective	To reduce inhalation and external doses from contamination on external walls and roofs of buildings, roads and paved areas, vehicles and areas of soil and vegetation within inhabited areas.
Other benefits	Will remove contamination from outdoor surfaces.
Management option description	If the snow cloud was contaminated, all the snow should be removed. If deposition occurs in open areas already covered by a thick layer of snow, the removal of the snow layer before the first thaw will prevent the contaminants from reaching the underlying ground surface. Generally, soil areas will be most important to treat, with trees/shrubs removed / pruned as described in Datasheet 27. The management option could also be applied on roads and paved surfaces, external building surfaces (removal from roofs should also be considered, though walls would very seldom be sufficiently contaminated by snow to require special action) and vehicles. If snowfall occurs after deposition, this could provide shielding and reduce dose rates while the snow remains in place. But there would be an increased spread of contamination when thawing occurs. Therefore is may be beneficial to leave snow in place while short lived radionuclides decay, but then remove the snow and consider other options for managing the contamination on the ground. Where applicable, removal can be carried out by 'Bobcat' mini-bulldozers (easy to manoeuvre in small areas) or similar available equipment. Alternatively removal can be undertaken with spades, shovels, pokers or manual scrapers. However, these alternatives are much slower. Snow blowers should not be used as they can spread contamination and cause an airborne hazard.
Target	Snow covered open areas, particularly grassed areas and other areas of soil, eg parks, playing fields and gardens. Additionally, roads/paved areas, external building surfaces and vehicles.
Targeted radionuclides	All radionuclides. Short-lived radionuclides if implemented quickly.
Scale of application	Any size. Suitable for small areas (eg gardens) and large areas (eg parks, playing fields etc).
Time of application	Maximum benefit if carried out as soon as possible after deposition. Must be carried out before the first thaw following the contamination. This means that implementation must be relatively prompt under normal UK conditions.
Constraints	
Legal constraints	Ownership and access to property. Liabilities for possible damage to property. Waste disposal legislation.
Environmental constraints	Snow storms can make it very difficult, or possibly hazardous, to carry out the work. In extreme cases, the slope of the area may be a constraint (depends on operator skill). Obstacles eg trees / shrubs. The disposal of the waste water from the implementation of this option will have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. It is important to note that a pile of contaminated snow becomes a major contamination source when it melts.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 10 and 30 can be achieved if this option is carried out prior to the snow melting and as long as snow is removed to a depth to include the contamination.
Reduction in surface dose rates	External dose rates above the snow covered surfaces will be reduced by a value similar to the DF. If further snow fall occurs post deposition, external beta dose rates above the snow surface are likely to be negligible prior to removal.
Reduction in resuspension	Resuspension from a snow-covered surface will be generally low. If further snow falls after deposition, the resuspended air concentrations above the snow surface will be zero prior to removal.
Technical factors influencing effectiveness	Effective and consistent application of option over a large area. Time of implementation. The impact of snow removal will be reduced with time as snow melt starts. Over time, snow may form drifts leading to areas of enhanced contamination.

Back to list of options

18 Snow/ice removal

	The snow layer must be sufficiently thick to allow complete removal of the snow surface. If, for example, human activity has compressed the snow, complete removal will be more difficult. Watertight storage areas to store contaminated snow would be required.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Bobcat mini-bulldozer or similar equipment (eg tractor with scraper), or spades, shovels, pokers or manual scrapers. Containers for collecting snow/ice. Vehicles for transporting equipment and waste.
Utilities and infrastructure	Roads for transporting equipment and waste. Storage or facilities to dispose of contaminated snow/ice off-site.
Consumables	Fuel and parts for vehicles.
Skills	Little instruction is required. On a local scale, snow removal from the ground could be done by the inhabitants of the affected area as a self-help measure, after instruction from authorities and provision of safety and other required equipment eg shovels, containers. However, the manual work requires hard physical work, which not all people would be able to do.
Safety precautions	Waterproof clothing, boots and gloves. In case of dry frost / storm weather, respiratory protection should be considered if carrying out the procedure soon after contamination.
Waste	
Amount and type	Depends on thickness of the snow layer. 5 cm snow = 0.5 kg m^{-2} waste.
Doses	
Averted doses	Snow removal may be expected to achieve immediate reductions in external gamma dose rate of around 40-50% in urban areas contaminated by a dry deposition of ^{137}Cs. Reductions in dose rates are likely to be higher following wet deposition, with approximately 55-85% reduction possible. These values assume that deposition occurs to a wintry, snow-covered landscape.
Factors influencing averted dose	Population behaviour in area: the time spent by individuals on or close to snow covered surfaces. Amount of the area containing snow covered surfaces.
Additional doses	Relevant exposure pathways for workers are: • external exposures from radionuclides in the environment Exposure routes from transport and disposal of waste are not included.
Intervention costs	

Operator time	Work rate (m^2/team.h)	$2.5\ 10^2$ - $5\ 10^2$ (Manual removal would be about a factor of 5 slower). Includes loading to waste transport truck. Note that available working hours likely to be restricted as daylight hours are shorter in winter.
	Team size (people)	1
Factors influencing costs	Weather. Topography. Size of area. Thickness of snow layer to be removed. Type of equipment used. Access. Use of personal protective equipment (PPE).	

Back to list of options

18 Snow/ice removal

Side effects	
Environmental impact	The disposal of the waste water from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Public reassurance. Limited adverse aesthetical effect, due to the use of relatively heavy machinery in garden areas.
Practical experience	Successfully tested on relatively small scale in Norway.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson, K. G. and Roed, J. (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Qvenild C and Tveten U (1984). *Decontamination and winter conditions*. Institute for Energy Technology, Kjeller, Norway, ISBN 82-7017-067-4, 1984.
Version	3
Document history	See Table 7.2 Previously called Snow Removal in version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

19 Storage, covering, gentle cleaning of precious objects

Objective	To reduce inhalation and external doses arising from contamination on personal and precious objects within inhabited areas. This option is likely to be implemented primarily for public reassurance as exposure from personal and precious objects is unlikely to be a significant contribution to an individual's dose.
Other benefits	Gentle cleaning will remove contamination from precious objects within buildings or otherwise within inhabited areas.
Management option description	It may not be possible or appropriate to carry out decontamination of precious objects, such as museum artefacts, tapestries, jewellery, paintings etc because of the risk of damaging the objects during the cleaning process. Several alternative options are available for such objects. If objects are placed within rooms or storage facilities to which people do not have general access, significant reductions in dose rates to persons in adjoining rooms and buildings can be achieved. Such storage could be done as a temporary measure, while other higher priority decontamination is undertaken, or to protect precious objects from inadvertent exposure to more aggressive decontamination techniques. Some objects, which do not require handling, could be shielded or covered. For instance, museum artefacts could be placed behind leaded glass or Perspex; they can remain on display, but the public will be shielded from the contamination. Depending on the radionuclide, this shielding may have to remain in place for some considerable time. Material encapsulation technology, including embedding into acrylic blocks is readily available but this would best be considered as a last option as removal of items from acrylic may be more difficult than decontamination. Specialist, gentle cleaning techniques (such as ultrasonic bath cleaning) could be carried out on objects. Gentle, water based cleaning (see Datasheet 29) or use of wipes may also be suitable for some objects if carried out with care.
Target	Precious and personal objects, such as museum artefacts, tapestries, jewellery, paintings etc, within buildings.
Targeted radionuclides	All radionuclides. The storage option will be particularly suitable for short-lived radionuclides. Shielding and covering will be particularly effective for beta emitters.
Scale of application	Small objects.
Time of application	Maximum benefit if carried out soon after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to objects. Ownership and access to objects. Use in listed or other historic buildings.
Environmental constraints	None
Effectiveness	
Reduction in contamination on the surface	Contamination on the surface of objects will only be reduced if gentle cleaning is applied.
Reduction in surface dose rates	**Cleaning:** reduces surface doses rates from objects by removing contamination. **Shielding and storage:** reduces external gamma and beta dose rates; the degree of reduction will depend on the thickness of shielding used. Some examples are given below. **Brick or concrete wall**: thicknesses of 10-20 cm will half the dose rate outside a room for medium to high energy gamma emitters. **Lead**: around 10 mm lead will be sufficient to half the gamma dose rate for many radionuclides. A few centimetres could reduce gamma dose-rates by a factor of 10. **Glass**: 1-5 mm will totally absorb beta particles for the range of beta energies likely to be of concern. Plastic (Perspex) would need to be about twice as thick to have the same effect. **Air**: can also be used as a shielding material. 1-2 m of air will reduce dose-rates to very low levels for weak beta emitters: a distance of up to 10 m would be needed to give high reductions in dose rate for high energy beta emitters such as $^{90}Sr/^{90}Y$. For gamma emitters, dose rates will drop off in air in proportion to the square of the distance, eg, if people are kept 5 m away from an object, the dose-rate they receive from that object will be 25 times lower than if they were 1 m away.
Reduction in resuspension	**Removing contamination:** reduces contamination available for resuspension.

Back to list of options

19 Storage, covering, gentle cleaning of precious objects

	Shielding: a closely fitting container will stop all resuspension.
Technical factors influencing effectiveness	Type, condition and fragility of object. Time of operation (contamination migrates elsewhere over time). Consistent application of cleaning over entire object. Amount of dust on the surface of the object at the time of deposition. Whether any cleaning has already been undertaken. Weight of shielding material that can be used and any need to be able to view objects clearly.
Social factors influencing effectiveness	Acceptability of storing/shielding items that are not decontaminated. There may be aesthetic issues related to storage or covering of objects, and potentially implications regarding an items value that need to be considered.
Feasibility	
Equipment	Specialist cleaning equipment for gentle cleaning. Specialist lifting equipment, if object is to be moved into storage.
Utilities and infrastructure	Power and water supplies. Storage facilities.
Consumables	Shielding materials.
Skills	Specialist cleaning skills. Specialist handling skills.
Safety precautions	Gloves and overalls.
Waste	
Amount and type	Waste water will be generated from cleaning. Quantities are unlikely to be large. Waste water may be treated - see Datasheet 26.
Doses	
Averted doses	Not estimated. Cleaning objects will only reduce doses to people while they are indoors and will be very dependent on the specific situation and the objects and other surfaces cleaned.
Factors influencing averted dose	Weather at time of deposition; less material is deposited indoors during wet deposition. Appropriate clean-up of other indoor surfaces and objects.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • enhanced resuspension of activity deposited in the indoor environment leading to inhalation of dust generated Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	Work rate (m^2/team.h): Cleaning of precious objects is likely to take significantly longer than normal cleaning (see Datasheet 29). Team size (people): N/A
Factors influencing costs	Time for gentle cleaning. Provision of adequate storage/shielding.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, the quantities of waste should be small and any impact can be minimised through the control of any disposal route and relevant authorisations.
Social impact	Possible damage of objects with particular heritage significance. Lack of access to objects and buildings by the public.
Practical experience	Some items of special value, such as jewellery or personal items of sentimental value, were cleaned following the incident in Goiania. Some items of furniture with value or historical significance were covered and removed to

Back to list of options

19 Storage, covering, gentle cleaning of precious objects

	storage to allow for radioactive decay following the polonium poisoning event in London.
Key references	Crick MJ and Dimbylow PJ (1985). GRINDS - A computer program for evaluating the shielding provided by buildings from gamma radiation emitted from radionuclides deposited on ground and urban surface. NRPB, Chilton, NRPB-M119. Delacroix D, Guerre JP, Leblanc P and Hickman C (2002). Radionuclide and radiation protection data handbook 2002. Radiation Protection Dosimetry, 98, (1), 1-168. The radiological Accident in Goiânia. International Atomic Energy Agency, STI/PUB/815, ISBN 92-0-129088-8, Vienna
Version	3
Document history	See Table 7.2

Back to list of options

20 Surface removal (buildings)

Objective	To reduce external gamma and beta doses and inhalation doses from contamination on external walls of buildings within inhabited areas, including those within semi-enclosed areas.
Other benefits	Will remove contamination from external building surfaces
Management option description	A number of technologies are available for physical removal of hard surfaces such as concrete, offering a potential alternative to demolition (see Datasheet 8). These can broadly be divided into two categories: blasting options and mechanical options. Although the techniques vary across the technologies, many of the considerations are the same across all these options. **Blasting options** These options remove a thin surface layer, together with the contamination, using a range of blasting media. Abrasive materials and other materials shall be collected in a manner that ensures that they will not disperse contamination to the surroundings. However, to eliminate the risk of contamination translocation on a wall, the treatment must begin at the top and work downwards. If walls are sufficiently contaminated to require treatment, the ground surfaces surrounding the building will almost certainly also be strongly contaminated and the consideration of recovery options for these surfaces is also recommended. If the implementation of any other options to the surrounding ground surfaces is planned, sandblasting of walls should be implemented first. **Sandblasting:** Wet sandblasting is recommended (although dry sandblasting is generally almost as efficient, the resuspension of contaminants is difficult to control). Sand is injected into a high pressure water system and sprayed on to the surface, reached by scaffolding or fire-tender if necessary. A pump is mounted on the ground and hoses are fed to the platform or scaffolding. **Grit blasting:** Abrasive particles are pneumatically accelerated and blasted at a surface. The high speed particles remove surface contamination. A number of different abrasive materials are available commercially. Traditionally iron or aluminium oxide was used, but many crushed or irregular abrasives are now used. Grit blasting can condition the surface for subsequent finishing. As well as being used on open surfaces like walls and floors, can also be used on awkward shaped surfaces like machine parts. **Centrifugal shot blasting:** Hardened steel shot is rapidly propelled at contaminated surfaces. This breaks up the surface, removing paint or light coatings, or abrading the concrete surface directly. The speed of the system, the size of the shot and the amount of shot released into the system can be varied based on the degree of removal required. The system is ideal for removing surfaces of 2-3 mm, but can be used to remove surfaces up to 1-2 cm deep. A dust collection system removes contaminated debris, which reduces airborne contamination. Used shot is separated from debris and recycled in the system. Contamination and smaller pieces of shot that are worn from repeated use are gathered in a collection drum. The operator is warned when more shot must be added to the system. **Dry ice blasting:** This is a slow process, using Carbon dioxide (dry ice) pellets, typically below -70 ^{o}C, 1 to 3 mm in size but possibly up to 4.5 mm as a blasting medium. The dry ice pellets are accelerated using compressed air with typical pressures of 100 to 150 psi, although lower or higher pressures up to 300 psi may be used in some circumstances. As well as the high velocity of the pellets on impact, the rapid expansion of the carbon dioxide into vapour form as the pellets hit the surface helps lift contamination. Additionally, the cold pellets cause the contaminant and the surface to contract. They may contract at different rates, weakening the bond between contaminant and surface, enhancing the removal of contamination. As the carbon dioxide turns to vapour it returns to atmosphere, leaving only the contaminant and any particles removed from the surface as waste. **Soft media blasting:** Soft media (sponges) are propelled through a hose, typically about 2,5 cm diameter, by compressed air against the surface to loosen, remove and absorb contaminants in a recyclable media that disintegrates over time. Different types of soft media are available impregnated with a range of abrasives for different types of surfaces. **Mechanical options** Several types of technology are available to mechanically decontaminate surfaces. All options should include preventing spread of contamination to the surroundings. **Concrete grinder:** A diamond grinding wheel in a lightweight had held device removes surfaces 1.5 to 3 mm deep to create a smooth surface on flat or slightly curved surfaces with little vibration. A dust collection system including HEPA filtration removes dust generated by the grinding process.

Back to list of options

20 Surface removal (buildings)

	Concrete shaver: This 150 kg device is an electrically driven system, using a drum embedded with diamonds as a cutting head for removing contamination from concrete floors. Variable shaving depths from 0.01 to 1.3 cm can be achieved. Commercially available concrete shavers are good for large, wide open concrete floors and slabs. **Concrete spaller:** Holes are drilled in the concrete surface to be decontaminated. A spaller bit is then inserted into a drilled hole and expanded hydraulically, breaking off chunks of the surface up to 5 mm thick and 18 to 41 cm in diameter. A spaller can be used on flat or slightly curved surfaces. It can be used on large areas, or is a good tool for hot spots and decontamination of cracks in concrete. A metal shroud with a HEPA filtration system can collect concrete and control dust. **Scabblers:** Scabbling tools break down a concrete surface, typically by mechanically hitting it. A piston scabbler uses a piston, or series of pistons, to pulverise concrete flooring, A needle scabbler can produce finer decontamination in smaller areas. A remote control robotic wall scabbler uses grit blasting and is specially designed to work on flat surfaced walls using high pressure vacuum suction, but can also work on floors and ceilings. All of these scabblers will produce waste material, which should be collected by vacuum and stored for disposal, thus minimising airborne contamination. An alternative is electro-hydraulic scabbling, where electrodes are placed close to the concrete surface under a thin layer of water. A series of short (microsecond), high current and high voltage (tens of thousands of amps and volts) discharges between the electrodes, at a rate of a few pulse per second, create plasma bubbles and shockwaves which crack and peel away layers of concrete. The depth of scabbling can be controlled by varying the energy and profile of the pulse and the number of pulses. Airborne contamination is eliminated by the water layer.
Target	Highly contaminated external walls of buildings, including those within semi-enclosed areas. If contamination is confirmed to be fixed to the surface, it may not be necessary to fully decontaminate all external walls of a building, as areas above a certain height would not generally be accessible to personnel/the public. Also note that some internal floors and walls with large area hard surfaces (eg within public buildings such as railway stations) may be robust enough to withstand sandblasting.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size building.
Time of application	Maximum benefit if carried out soon after deposition. However, sandblasting of external walls of buildings can be effective up to 10 years after deposition. It is recommended that any treatment of walls is implemented before decontamination of surrounding ground areas.
Constraints	
Legal constraints	Liabilities for possible damage to property (eg flooding). Ownership and access to property. Waste disposal legislation. Use on listed and other historically important buildings.
Environmental/technical constraints	If using wet sandblasting, water may need to be heated in severe cold weather, and walls must be waterproof. Some technologies, eg shot blasting or concrete grinder, may not be suitable for use outside in rainy conditions. If using grit blasting, there are restrictions on the use of any substance that contains more than 2% crystalline silicon dioxide, 0.1% antimony, arsenic, beryllium, cadmium, chromium, cobalt, or lead, 0.5% nickel or 1% tin (dry weights). Glass grit is non-toxic and inert, reducing the likelihood of environmental and respiratory problems and produces less corrosion on prepared surfaces.
Effectiveness	
Reduction in contamination on the surface	Sandblasting and iron shot blasting of concrete and mortar surface of large buildings in Fukushima were found to be at least moderately effective. Sandblasting can produce a decontamination factor (DF) of between 4 and 10 if implemented soon after deposition. Shot blasting of concrete in Fukushima has been seen to produce a DF of 3.

Back to list of options

20 Surface removal (buildings)

	Concrete grinding in Fukushima gave a DF of between 2.5 and 5. Effectiveness may decrease with time after deposition as the contamination penetrates deeper into the material and becomes harder to remove. Repeated application is unlikely to provide any significant increase in DF. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Reduction in surface dose rates	External gamma and beta dose rates from decontaminated external walls of buildings will be reduced by a similar factor as the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by the same value as the DF.
Technical factors influencing effectiveness	Technology used. Variations in exact technique used - choice of media (eg type of sand, choice of grit abrasive or type of soft media), water pressure/ force of delivery, number of times of application. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Type, evenness and condition of surface. Depth of surface removed. Care in application: consistent application (ie operator skill) and care needed to remove contamination from walls and not just move the contamination around the surface. Lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building. Number of buildings in the area ie environment type/land use.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes
Feasibility	
Equipment	The equipment required depends on the technology used. **Sandblasting:** 150 bar (2000 psi) pressure washer; dry abrasive feeder. Depending on whether waste water is collected or filtered the following equipment may also be required: sheeting; tanks; troughs; filters; spate pump; gully sucker. **Grit/shot/dry ice/soft media blasting:** blasting system; air compressor; Depending on the media, a filtration system may be required. **Concrete grinder:** grinding unit, dust collection system, HEPA filtration system **Concrete shaver:** shaver unit **Concrete spaller:** drill, spaller, metal shroud and hose, HEPA filtration system (if required) **Electro-hydraulic scabbling:** scabbling unit **En-vac robotic wall scabbler:** en-vac robot, recycling unit, filter, vaccum unit **Piston scabbler:** scabbling unit, vacuum unt, storage drum Bags or containers for waste will be required. In addition, scaffolding/ roof ladders or mobile lifts for additional roof access may be required.
Utilities and infrastructure	Power supply/generator Roads and vehicles (transport of equipment, materials and waste) Water supply may be required Waste disposal route Public sewer system may be required
Consumables	Depending on technology used, sand, water, abrasive pellets, steel shot, dry ice pellets, soft media, grinding wheel, cutting blades, drill and spaller bits, grit, pistons, filters and hoses may be required. Fuel and parts for generators and transport vehicles.
Skills	Skilled personnel essential to operate equipment.
Safety precautions	For tall buildings: lifeline and safety helmets are required Suitable PPE (gloves, overalls, masks and eye protection) required, particularly in highly contaminated areas. If required, workers should be protected from water spray.

Back to list of options

20 Surface removal (buildings)

	Respiratory protection, to reduce the resuspension hazard to workers, may be required, depending on the technology used, and the effectiveness of any dust collection systems. If connections are made to mains water supplies, precautions are needed to ensure that the water supply is not inadvertently contaminated, eg by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system. Careful control of external exposure due to gamma irradiation from waste is required.
Waste	
Amount and type	The waste generated will depend on the technology used. Typically, contaminated dust/debris will be collected by the system (or manual collection may be required) and must be appropriately disposed of, subject to conditions depending on the activity levels and other properties of the waste. Sandblasting will typically generate around 3 kg m^{-2} solid waste (dust and sand) and 50 l m^{-2} waste water. It is unlikely that it will be practicable to collect the water used for sandblasting, so that some of the waste water will soak into the ground or pass into the drains. If water can be collected see Datasheet 26 for information on treatment of waste water. Shot blasting and concrete grinding were found to generate around 20 bags of concrete debris per hectare when used in Fukushima.
Doses	
Averted doses	Reductions in external doses received by a member of public living in the area will depend on the level of decontamination achieved, the number of buildings in the area and the time spent by individuals close to these buildings. Additionally, doses arising from contamination on buildings are only a contribution to the total dose received by individuals, so depending on the doses received from other sources such as ground contamination, decontamination of the buildings will only have limited impact on the overall external dose. The biggest reductions likely are around 5-10% reduction in external dose for a person living in a typical inhabited area, after dry deposition of ^{137}Cs. This is for illustrative purposes only, and does not include any potential future doses that may arise if contaminated water enters the drainage system and subsequently the wider environment.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Care in application. Care needed to wash contamination from walls and not just move the contamination around the surface. Lower part of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building. Whether the ground surrounding the building and other surfaces on to which run-off may have occurred have been decontaminated after treating the building (if waste was not collected). Population behaviour in the area. Amount of buildings in the area ie environment type/land use. Time after implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • inhalation of dust and water spray generated • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Although many technologies include systems to reduce airborne contamination, the breakdown of concrete surfaces may increase the dust loading and lead to an increased inhalation dose during the period of operation. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.

Back to list of options

20 Surface removal (buildings)

Intervention costs			
Operator time	This depends on the technology used.		
	Technology	Work rate	Team size (people)
	Sandblasting	15 - 20 m^2/team.h (excludes setting up scaffolding)	3 - 6 (depends on equipment used for access to buildings and whether waste water is collected)
	Concrete grinding	40 m^2 / day	unspecified
	Shot blasting of concrete	300 m^2 / day	unspecified
	Depending on the PPE used individuals may need to work restricted shifts.		
Factors influencing costs	Technology and type of equipment used. Weather. Building size. Access. Proximity of water supplies. Use of personal protective equipment (PPE).		

Side effects	
Environmental impact	The disposal or storage of waste arising from this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. If waste water is not collected, some of it will run on to other surfaces (roads, soil, grass etc), resulting in a transfer of contamination which may require subsequent clean-up, generating more waste. If water can be collected see Datasheet 26 for information on treatment of waste water. Sandblasting will create contaminated waste water so appropriate monitoring will be required in the sewage treatment plant.
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system. Decontamination by surface removal treatment may make an area look clean; implementation may give public reassurance. Repair work on some walls may be required.
Practical experience	Sandblasting was tested on realistic scale on selected walls in the Former Soviet Union and Europe after the Chernobyl accident. Sanding/planning and shot blasting were tested in Japan following the Fukushima accident.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315 Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996*). Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Masayuki I (2012) Report of the Results of the Decontamination Model projects. Analysis and Evaluation of the Results of the Decontamination Model Projects - Decontamination Technologies. Presentation to meeting held on March 26, 2012 at Fukushima City Public Hall Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Miyahara K., Tokizawa T., Nakayama S (2012) Decontamination pilot projects: building a knowledge base for Fukushima environmental remediation. Mater Res Soc Symp Proc 2012; 1518:245-256.

Back to list of options

20 Surface removal (buildings)

	Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, **33** (2), 107-116. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheets Sandblasting (datasheet 11) and Surface Removal (datasheet 17) from version 3 of the UK Recovery Handbook for Radiation incidents.

Back to list of options

21 Surface removal (indoor)

Objective	To reduce inhalation and external doses arising from contamination on indoor surfaces of buildings (primarily floors, walls and ceilings) within inhabited areas.
Other benefits	Will remove contamination from indoor surfaces in buildings.
Management option description	If water based cleaning (see Datasheet 29) is not suitable, and if demolition and disposal (see Datasheet 8) is to be avoided, some form of surface removal may be required on indoor surfaces. Although some internal floors and walls with large area hard surfaces (eg within public buildings such as railway stations) may be robust enough to withstand more aggressive techniques such as pressure hosing (see Datasheet 15) or sandblasting (see Datasheet 20), in general internal surfaces will require gentler treatments such as described below. Measures to prevent the generation of dusts or liquid wastes should be used as there may be difficulty in arranging ventilation/liquid run-off collection in indoor environments. **Wooden or metal surfaces:** can be treated using sandpaper, power sanders, or steam cleaners **Paint:** can be removed using paint strippers or hot air guns. Alternatively, commercial sanders can be used though this is likely to produce a lot of dust. Dust control may be possible using an improvised vacuum shroud placed around the sander which is connected to a vacuum cleaner. **Plaster:** can be removed using long-reach pneumatic chisels. **Wallpaper:** can be removed by manual scraping or using steam strippers. **Linoleum and carpet:** if not stuck to floors can be manually removed relatively easily. Linoleum tiles stuck to concrete floors may require machinery to remove. For tiles stuck to hardboard, removal involves removing both the hardboard and tiles together by removing the pins and pulling the hardboard away from the floor. **Wooden floors:** are removed by prising the floor boards from the cross joints which are then themselves removed using saws. **Concrete:** A number of techniques can be used on concrete, as described on Datasheet 20
Target	Indoor surfaces of buildings.
Targeted radionuclides	All radionuclides. Not short-lived radionuclides alone.
Scale of application	Small areas of indoor surfaces in all types of building.
Time of application	Maximum benefit if carried out within a few weeks of deposition when maximum contamination on surfaces.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in listed or other historic buildings and on precious objects.
Environmental constraints	None.
Effectiveness	
Reduction in contamination on the surface	If carried out carefully, these removal processes can remove virtually all the contamination on the surface. However, the process of removing paper, paint or plaster may result in the spread of contamination on to other surfaces via dust. Reductions in external doses received by a member of public living in the area will depend on the amount of time spent by individuals inside the buildings (see below). Repeated application is unlikely to provide any significant increase in DF if implemented thoroughly the first time.
Reduction in surface dose rates	No estimates made.
Reduction in resuspension	No estimates made.
Technical factors influencing effectiveness	Type and condition of surface. Time of operation (the longer the time between deposition and implementation of the option the less effective it will be as contaminated dust migrates over time). Consistent application over the contaminated area; need to ensure all the surface material is removed. Amount of dust on surfaces at the time of deposition.

Back to list of options

21 Surface removal (indoor)

	Collection of all removed surface material. Whether any cleaning has already been undertaken. Weather at time of deposition; less material is deposited indoors during wet deposition. Amount of furniture and furnishings and ventilation rates. Appropriate clean-up of other indoor surfaces and objects.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Scrapers. Sandpaper, power sanders with suitable extract and filter. Steam strippers. Pneumatic chisels. Removing lino tiles from concrete: machine (long reach scaler) to remove tiles stuck to concrete floors. Saws for removing wooden floors. Brooms and dustpans for collecting debris. Bags or containers for waste. Transport vehicles for equipment and waste.
Utilities and infrastructure	Mains electricity supply. Water supply. Roads for transport of equipment and waste.
Consumables	Fuel and parts for transport vehicles. Water and detergent.
Skills	Only a little instruction is likely to be required.
Safety precautions	Gloves and overalls. Waterproof clothing may be required. Personal protective equipment (PPE) may be required under dusty conditions to reduce the hazard from resuspension. Appropriate safety measures and respiratory protection will be required if asbestos is present.
Waste	
Amount and type	See table below.

Surface removed	Amount (kg m^{-2} solid waste)	Type
Wallpaper	1.0	Wallpaper
Paint	1.0	Paint and plaster dust
Plaster	1 10^{1}	Plaster
Carpet	4 10^{-1}	Carpet
Linoleum/linoleum tiles (laid on concrete)	4	Tiles and hardboard
Wood floor	7	Wood

Any water resulting from steam stripping will not be able to be collected and so floor surfaces will need to be covered and covering disposed of.

Disposal will be subject to conditions depending on the activity levels and other properties of the waste.

Doses	
Averted doses	Dose reductions have not been estimated for this option. Some indication of possible dose reductions can be found in Datasheet 29 (water based cleaning). However, it should be noted that removal of surfaces will only reduce doses to people while they are indoors and will be very dependent on the specific situation and the surfaces cleaned.
Factors influencing averted dose	Consistency in effective implementation of option over entire area. Weather at time of deposition; less material is deposited indoors during wet deposition.

Back to list of options

21 Surface removal (indoor)

	Application of appropriate clean-up to other indoor surfaces and objects. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering and cleaning. Care of application. Need to remove contamination from surfaces and not just move it around the surface or on to another surface. Amount of time spent inside buildings.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the indoor environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • *Inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	

Operator time

Surface removed	Work rate (m^2/team.h)
Wallpaper	60 (scraping) 230 (scraping and peeling) 400 (peeling)
Paint	5 (walls) 4 (ceilings)
Plaster	25 (walls and ceilings)
Carpet	100
Linoleum	80
Linoleum tiles (laid on concrete)	20
Linoleum tiles (laid on wood)	200
Wood floor	3

Team size (people): 2 for carpet removal; 1 for all other techniques

Depending on the PPE used individuals may need to work restricted shifts.

Factors influencing costs	Building size. Type of equipment used. Access. Use of personal protective equipment (PPE). Tidiness of houses and amount of 'contents'. Thickness of surface covering/layers of wallpaper and/or paint.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Possible damage to building surfaces. Positive benefit of cleaning houses.
Practical experience	Paint stripping carried out as part of decontamination following the incident in Goiania
Key references	Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited

Back to list of options

21 Surface removal (indoor)

	areas. Environment Agency R&D Technical Report P3-072/TR. The radiological Accident in Goiânia. International Atomic Energy Agency, STI/PUB/815, ISBN 92-0-129088-8, Vienna Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition.
Version	3
Document history	See Table 7.2 Based on indoor surfaces Surface Removal (datasheet 17) in version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

22 Surface removal and replacement (roads)

Objective	To reduce inhalation and external doses from contamination on roads, paved and other outdoor areas with hard surfaces within inhabited areas, including those within semi-enclosed areas.
Other benefits	Removal of contamination from roads and paved areas.
Management option description	The most common forms of hard outdoor surfaces will be tarmac or concrete slabs. Standard machinery to remove asphalt surfaces is available in different sizes. They have a rotating drum with cutting teeth which conveys planed material (about 40 mm thick) to the middle of drum where it is pushed on to a conveyor belt and from there to flat bed truck. If machines do not have brushes for debris collection, this must be added or manual sweeping carried out. Water is sprayed continuously on to the drum to suppress dust. Typical highway maintenance machinery can remove a width of about 2 m per pass. A small excavator/bob-cat can be used to remove concrete slabs. Concrete slabs are replaced by hand. Attention must be paid to removing radioactive materials in the gaps between the blocks. Other mechanical methods are available for surface removal (see Datasheet 20) but these are likely to be more suitable for use on building surfaces and less likely to be used on roads and paved areas, though shot blasting of asphalt can be used for decontamination. Replacing/resurfacing asphalt and concrete roads can be undertaken using standard equipment. For replacement in small areas, manual methods are likely to be used, ie tarmac is deposited in several places and spread by shovel and rake, then tamped. For small surface areas it may also be possible to use a jackhammer to loosen existing tarmac and rubble can be shovelled into wheelbarrows. However, this has not been trialled. The need to resurface asphalt and concrete surfaces will depend on the depth removed and other factors, such as acceptability. The area can be repaved with hot rolled asphalt or concrete paving machine to relay concrete. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material (see Datasheet 23) is recommended prior to implementation to limit the resuspension hazard.
Target	Hard outdoor surfaces (roads, pavements, paths, playgrounds etc) including those within semi-enclosed areas
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone.
Scale of application	Any size road or paved area. If only treating a small area may need to consider technique as use of large equipment may not be appropriate.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is on the surfaces. However surface removal can be effective up to 10 years after deposition.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in conservation areas or at listed sites.
Environmental constraints	If the surface of the road is cambered the removal depth will not be uniform.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of up to 50 can be achieved. Decontamination work in Japan stripping the surface or shot blasting asphalt pavements and roads gave DFs between 2 and 20. Repeated application is unlikely to provide any significant increase in DF. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Reduction in surface dose rates	External gamma and beta dose rates and resuspension above a 'paved' surface will be reduced by the value of the DF. Experience in Japan found that following shot blasting of roads and streets, the ambient dose rate at 1 m above the ground was reduced by between 15 and 66% compared to the value prior to remediation.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by the value of the DF.
Technical factors influencing effectiveness	Evenness and condition of roads. Operator skill.

Back to list of options

22 Surface removal and replacement (roads)

Ineffective removal of contamination around drains and in gutters.

Removal of loose debris from surface.

Depth of surface removed - most of the radiocaesium in dense asphalt pavements was presented within the 2-3 mm from the surface.

Consistency in effective implementation of option over a large area.

Amount of hard outdoor surfaces in the area.

Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.

Order of decontamination - working from topographically higher locations to lower ones, with clean-up of roads the final step helps avoid generating secondary contamination.

Whether decontamination is carried out on adjacent surfaces.

Social factors influencing effectiveness

Public acceptability of waste treatment and storage routes.

Requirements

Equipment

The equipment used for surface removal and replacement will depend on the size of the area being treated.

Small areas	Large areas
Small scale planer	Planer with conveyor
Shovel	Paving machine
Tamper	Road sweeper
Wheelbarrow	Roller
Lorry	JCB
	Lorry

Transport vehicles for equipment and waste.

Utilities and infrastructure

Roads (transport of equipment, materials and waste).

Consumables

Tarmac or concrete or concrete paving slabs.

Tungsten carbide teeth.

Fuel and parts for equipment, generators and vehicles.

Skills

Skilled personnel essential to operate equipment.

Safety precautions

Gloves.

Safety goggles.

Safety helmets.

Respiratory protective equipment (RPE).

Careful control of external exposure due to gamma irradiation from waste is required

Waste

Amount

Asphalt: about 15 kg m^{-2} per cm removed.

Paving slabs (concrete): about 30 kg m^{-2} per cm removed.

Waste depends on thickness removed and density of material. Disposal will be subject to conditions depending on the activity levels and other properties of the waste.

Type

Paving slabs, concrete and asphalt.

A large part of the contaminated material collected from remediation at urban demonstration sites is only slightly contaminated so pathways could be found for disposal outside of the category of radioactive waste. Segregation of wastes at the point of collection from clean-up is recommended. If contaminated waste material is stored in near surface burial, covering with a layer of clean soil or sandbags can provide shielding to reduce dose rates.

Doses

Averted doses

^{137}Cs (% reduction in external dose)				^{239}Pu (% reduction in resuspension dose)			
Over 1st year		Over 50 years		Over 1st year		Over 50 years	
Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
<5	15-20	<5	10	0	5-10	<5	10-15

Back to list of options

22 Surface removal and replacement (roads)

	The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.	
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in area. Amount of hard outdoor surfaces in the area ie environment type/land use. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Whether decontamination is carried out on adjacent paved surfaces.	
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.	
Intervention costs		
Operator time	Work rate (m^2/team.h)	Asphalt: 4 10^2 - 1 10^3; paving slabs (concrete): 4 - 30 Depending on the PPE used individuals may need to work restricted shifts.
	Team size (people)	Asphalt: 2 - 4; paving slabs (concrete): 2 Team of 14 needed if road surface replaced and a team of 4 for paving slab replacement
Factors influencing costs	Weather. Evenness and condition of surface (affects grinding depth). Size of area to be treated. Type of equipment used / planer size / sweeping equipment. Access. Use of personal protective equipment (PPE).	
Side effects		
Environmental impact	Road and pavement condition may be improved providing tarmac or concrete has been laid properly. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.	
Social impact	Method of disposing such a large quantity of contaminated waste may not be acceptable to local residents. Disruption of access if people remain in the area. May improve road conditions.	
Practical experience	Tested on a small scale in the Former Soviet Union, pre-Chernobyl tests in the USA. Following the Fukushima accident, parking lots, roads and paved surfaces were treated with high pressure water in combination with surface removal.	
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Barbier MM and Chester CV (1990). *Decontamination of large horizontal concrete surfaces outdoors.* Proc. Concrete Decontamination Workshop, 28-29 May 1980, CONF-800542, PNL-SA-8855. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315.	

Back to list of options

22 Surface removal and replacement (roads)

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Yasutaka T, Naito W, Nakanishi J (2013) Cost and effectiveness of decontamination strategies in radiation contaminated areas in Fukushima in regard to external radiation dose. PLoS One 2013; 8(9):e75308

More information may become available after the publication of this handbook from the work following the Fukushima accident.

Version	3
Document history	See Table 7.2 Called 'Road planing' in STRATEGY 2003.

Back to list of options

23 Tie-down

Objective	To reduce inhalation doses from material resuspended from external building surfaces, roads, paved areas and other hard outdoor surfaces, and soil/grass areas within inhabited areas in the short or long term. Also used to prevent enhanced resuspension during implementation of options that create dust, particularly in dusty environments.
Other benefits	May also reduce external beta doses.
Management option description	A number of treatments can be used, with the choice of treatment depending on the surface, the aim (long or short term protection, noting that some of the treatments listed below are temporary while others are permanent) and the size of area to be treated. Depending on the objective (long or short term tie-down) and the tie-down material used, repeated application may be necessary to maintain the integrity of the covering. **Acrylic paint (eg Vinacryl)** can be used to treat external building surfaces, or soil/grass areas. When treating external building surfaces, it is sprayed on to the surface by spray injection, and is likely to be only used prior to implementation of other recovery options in order to protect workers from the resuspension hazard. When treating small areas of soil/grass areas, it is sprayed using a fine-mist spray gun with an airless pump to give with droplets 100 µm in diameter to ensure that radioactive particles adhere to the paint rather than being knocked off the surface. For large areas of soil/grass, the paint is applied by tractor-towed spray boom. **Water** can be used as a temporary tie-down measure on hard outdoor surfaces such as roads/paved areas, though this is unlikely to be effective during wet weather. Spraying water on to the surface, from a sprinkler boom mounted on a vehicle, forms a meniscus between the radioactive particles and the paved surface, preventing resuspension. Water can also be used on soil/grass areas, though that this management option should not be used if the aim is to tie contamination to grass prior to grass cutting, as the water will wash the contamination into the soil and root mat. If treating small areas of grass/soil, the area is sprayed with water using a hose connected to a hydrant. For large areas, large hose reels rotated by a water turbine are used. As the reel winds in, a spraying boom is pulled towards the reel, propelling itself over the area. When one area is complete, it is towed by tractor to the next area. **Sand** can be used as a temporary tie-down measure on hard outdoor surfaces such as roads/paved areas. For small areas, sand is shovelled by hand from a lorry on to the paved surface. For large areas, about 1mm of sand is sprinkled on to the paved surface using a lorry fitted with a rotary motorised sprinkler. **Bitumen** can be used to give permanent tie-down on hard outdoor surfaces such as roads/paved areas. For small areas, bitumen is sprayed on to the surface. A tank with a capacity of about 2000 - 3000 litres is required which can be moved by a four-wheel drive vehicle. The coating is permanent. For large areas, bitumen is sprayed on to the surface via a bulk surface-dressing machine. In both cases, if the surface is damp, a bitumen emulsion should be applied. When spraying bitumen, account should be taken of ironworks (eg drain covers) etc within the surface being covered. **Lignin** can be sprayed on to soil surfaces and mixes with the soil particles in a thin top layer of the soil (extent depends on water dilution and environmental moisture). **Peelable coatings** will also give protection against the resuspension hazard while they are in place (see Datasheet 9). **Clean soil** can be used to tie down contaminated soil in order to prevent against resuspension hazard (see Datasheet 7)
Target	External walls and roofs of buildings, hard outdoor surfaces (roads, pavements, paths, playgrounds etc), semi-enclosed surfaces (such as within train stations) and soil/grass surfaces in gardens, parks, playing fields and other open spaces. Tie-down coatings may be particularly useful to prevent mobilisation of contamination in publically inaccessible areas, eg roof area, building external surfaces above a predetermined height, etc to reduce the amount of effort required to clean up surfaces.
Targeted radionuclides	Alpha emitting radionuclides. May be used for other radionuclides if conditions mean that inhalation doses from resuspended material are likely to be of concern.
Scale of application	Any size, although may be difficulties with treating large areas.
Time of application	Can be effective at any time after deposition, however maximum benefit is achieved if carried out soon after deposition when maximum contamination is on the surfaces/before penetration and fixing of the contamination in the soil has occurred. Tie-down is effective for

Back to list of options

23 Tie-down

	the period over which the integrity of the covering is maintained. Effectiveness is reduced after rain has occurred.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed and other historic buildings and in conservation areas. Waste disposal legislation.
Environmental constraints	Severe cold weather, especially for tie-down with water.
Effectiveness	
Reduction in contamination on the surface	This option is not applied to decontaminate a surface. It is assumed that the decontamination factor (DF) is 1. In practice, some contamination may be removed along with the tie-down material (if it is removed), or some activity may be washed on to other surfaces if water is used. If treatment gives long-term tie-down on hard outdoor surfaces, account should be taken of the need for surface repair and access to underlying services (eg gas/water pipes, cables).
Reduction in surface dose rates	While the tie-down material is in place, external beta dose rates adjacent to the surface will be reduced by a factor depending on the tie-down material, its thickness and the energy of the beta emissions. This option will be more effective at reducing dose rates associated with low energy beta emissions. It is not effective at reducing external gamma dose rates adjacent to the surface. When considering tie-down of contamination on a hard surface such as a road, sand (2 mm) would be the most effective at reducing beta dose rates; bitumen (1 mm) and water (1 mm) will give less protection. For example, for ^{90}Sr and its daughter ^{90}Y, which is a strong beta emitter, a reduction of 90% for sand, 70% for bitumen and 45% for water could be expected.
Reduction in resuspension	While the tie-down material is in place, resuspended activity in air adjacent to the surface will be reduced by close to 100%. If treating soil/grass areas, applying water will aid the bonding of activity to soil particles and can wash contamination below the surface, both of which will reduce resuspension in the longer term. However, if plants, shrubs and trees are not removed, these will still contribute to inhalation doses from resuspended material.
Technical factors influencing effectiveness	Weather conditions. Correct and consistent application of tie-down material over the contaminated area. Type, evenness and condition of surface. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Length of time tie-down material is in place. For roads/paved areas: Amount of paved surface. Water and foam application is not suitable for surfaces on slopes. For soil/grass areas: Soil and grass surfaces must not be covered in snow. Length of grass (for lignin and paint): shorter grass is preferable to facilitate bonding.
Social factors influencing effectiveness	None
Feasibility	
Equipment	The equipment required depends on the surface, tie-down material, and size of area being treated. In all cases, transport vehicles for equipment are required. For external building surfaces, using acrylic paint: Airless spray pump and compressor. Access by scaffolding or fire-tender with hydraulic platform. For roads/paved areas: **Water:** a motorised street washer is required. **Sand:** a lorry, sprinkler attachment and JCB loader are required. **Bitumen:** a hot bitumen sprayer or cold emulsion sprayer are required.

Back to list of options

23 Tie-down

	For soil/grass areas: **Water:** on small surface areas, a hydrant and hose are used. For large areas, a winding hose reel, pump and tractor with boom are used. **Paint:** on small surface areas, an airless spray pump and air compressor are used. For large areas, a tractor and boom are used.
Utilities and infrastructure	Roads for transport of equipment, materials and waste. Water supply may be required.
Consumables	Acrylic paint (eg Vinacryl), water, sand, hot bitumen or bitumen emulsion, or lignin may be required. Fuel and parts for transport vehicles and equipment.
Skills	Skilled personnel essential to operate equipment. Personnel applying coatings will need to understand how the coatings will react with the application surface and also how the coatings will stand up to wear and tear and weathering.
Safety precautions	Gloves and overalls. Additional protective clothing may be required when applying paint, including respiratory protective equipment (RPE) to protect against paint spray. Water-resistant clothing recommended when using water. Gloves and overalls for applying bitumen. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, eg by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.
Waste	
Amount and type	The amount of waste depends on the treatment used. Removed material used for temporary tie-down may be contaminated. Disposal will be subject to conditions depending on the activity levels and other properties of the waste. Monitoring would be required to determine if normal disposal routes can be used. For external building surfaces, using acrylic paint: If paint is subsequently removed: amount - 4 10^{-1} kg m^{-2}; type - paint. For roads/paved areas: **Water:** 3 10^{-1} l m^{-2} water and dust **Sand:** 1 - 2 kg m^{-2} sand and dust **Bitumen:** no waste because this is a permanent tie-down option (If bitumen layer is removed in the future, typical quantities of waste from the applied layer would be 1 - 2 kg m^{-2}) For soil/grass areas: No waste
Doses	
Averted doses	Not estimated. Tie-down will be almost 100% effective in reducing resuspension doses from a surface, but only for the period that the tie-down material is in place and with its integrity intact. For water, this is likely to be only for a very short period. The effectiveness in reducing doses to a person living in an inhabited area will be very dependent on the specific situation and the length of time the tie-down material is in place.
Factors influencing averted dose	Consistency in effective implementation of option over a large area. Population behaviour in the area. Environment type/land use - number of buildings, amount of paved surface, amount of grass/soil in the area. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Length of time tie-down material is in place.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)

Back to list of options

23 Tie-down

- *inadvertent ingestion of dust from workers' hands*

Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE.

Exposure routes from transport and disposal of waste are not included.

No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.

Intervention costs

Operator time

Surface/tie-down material	Work rate (m^2/team.h)	Team size (people)
External building surfaces/acrylic paint	1.5 10^2 - 2 10^2 (excludes setting up of scaffolding)	3 - 6 (depends on size of area, equipment used and access to surfaces)
Roads/water	3 10^4	1
Roads/sand	Small areas 5 10^2 Large areas 1 10^4	2
Roads/bitumen	5 10^2 - 1 10^3	2
Soil or grass/ paint or water	2 10^2 - 3 10^3 (depending on tie-down material and equipment used)	2

Depending on the PPE used individuals may need to work restricted shifts.

Factors influencing costs

Weather.

Topography

Height of building.

Size of area.

Type of equipment used.

Access.

Proximity of water supplies.

Side effects

Environmental impact

Some treatment options may give rise to contaminated waste - eg if paint is used on external building surfaces and later removed, or future maintenance of road surfaces treated with bitumen.

The use of water may wash some of the contamination on to other surfaces.

Chemical contamination from acrylic paint (Vinamul) migrating into soil may be an issue.

There may be an environmental impact associated with the disposal and storage of such wastes. However, this should be minimised through the control of any disposal route and relevant authorisations.

Bitumen spraying roads may provide positive impact if road surfaces are poor.

Social impact

Acceptability of contamination remaining in-situ. The use of sand for tie-down is a visible indication that a problem exists.

Acceptability of potential future doses to those maintaining external building or road surfaces (if long-term tie-down is achieved.)

Acceptability of contamination remaining in-situ.

Perception of contamination of the environment with chemicals.

Practical experience

Use of lignin on soil has been tested on a small scale (only a few m^2) in Denmark in conjunction with removal. Full scale tests on the use of lignin for dust suppression have been carried out in the USA and Sweden, where it is routinely used.

Key references

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Back to list of options

23 Tie-down

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Version	1
Document history	See Table 7.2 Based on the three tie-down datasheets (datasheets 12, 24 and 36) in version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

24 Top soil and turf removal

Objective	To reduce inhalation and external beta and gamma doses from contamination on outdoor grassed and soil areas within inhabited areas.
Other benefits	Removal of contamination from grassed and soil areas. Removal of activity from grass areas in gardens may reduce subsequent contamination of soil used for growing food. This in turn may reduce up-take to food crops grown.
Management option description	Decontamination can be achieved by removal of turf with the top 50 mm of topsoil, or by harvesting turf alone. Turf and topsoil can be removed together either manually using a spade, or by bobcat mini-bulldozers, back-hoes or similar equipment. The scale of equipment used will depend on the size of the area, with small areas needing equipment which is easy to manoeuvre. A surface cutter or hammer knife mower is an effective method for covering vast areas. Any plants and shrubs may need to be removed first. Optionally, the soil can be replaced and can be reseeded or re-turfed depending on the size of the area. See Datasheet 7 for information on covering with grass or clean topsoil. Turf removal alone, is carried out using a turf harvester which skims off a thin layer of soil/root mat (about 1 cm) with the turf in rolls or slabs. These machines are available in various sizes. Turf harvesting is optionally followed by reseeding or returfing. This option is likely to give rise to dust. Therefore, if removal is implemented in the first few months following deposition, action is recommended prior to implementation to limit the resuspension hazard. This may be done by application of water to dampen the surface or the use of a tie-down material (see Datasheet 23). If water is used it is important to ensure that run off doesn't occur and that radionuclides do not leach further into the soil. Optionally, a soil hardener, such as Gorilla Snot, may be used before removal of soil in order to prevent dust. In the longer term, most of the contamination is attached to soil particles and is not in the respirable range.
Target	Grass surfaces in gardens, parks, playing fields and other small open spaces. Topsoil removal is not recommended on land that has been tilled since the incident occurred. (Tilled areas can be treated but the waste volume will be much larger, as a greater depth of soil will have to be removed.) For turf to be removed, grassed areas must be mature, ie they must have an established root mat.
Targeted radionuclides	All long-lived radionuclides. Not short-lived radionuclides alone. In general it is found that around 80% of radiocaesium is found in the top 5 cm of soil, at least in the short term. However, depending on the soil type and whether any soil mixing has occurred, radiocaesium may penetrate deeper into the soil.
Scale of application	Generally any size, though manual topsoil may only be suitable for small areas (eg small gardens).
Time of application	Top soil removal remains effectiveness will be achieved for several years after deposition has occurred since most contaminants migrate very slowly down the soil profile. Maximum benefit from turf removal is achieved if carried out soon after deposition before weathering of activity from the grass to the underlying soil occurs. However will continue to be effective for several years after deposition has occurred as some activity will remain in the root mat of the turf. May be beneficial to wait until after first rain so that most of dust has washed off other outdoor surfaces and buildings on to grass areas.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Waste disposal of collected waste, especially as there is a risk of generating very large volumes of waste materials. Use on listed or historically important sites and conservation areas.
Environmental constraints	Severe cold weather. Soil texture: soil removal can be impractical on land that is uneven or that contains roots. In extreme cases, the slope of the area may be a constraint. Evenness of the ground. Turf harvesting equipment is very sensitive to stones and rocks.

Back to list of options

24 Top soil and turf removal

Effectiveness	
Reduction in contamination on the surface	Manual removal of topsoil, or turf harvesting, can achieve a decontamination factor (DF) of 10, while mechanical topsoil removal may achieve a higher DF of between 10 and 30. Experience in Japan following the Fukushima accident gave DFs of 2 to 20, with indications that the DF could potentially be much higher if soil is replaced. These factors may be achieved if implemented soon after deposition and with the removal depth optimised - if a standard removal depth is used, the effectiveness will reduce in time after this as contamination migrates to deeper soil depths. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Reduction in surface dose rates	External gamma and beta dose rates above the soil or grass surface will be reduced by up to the value of the DF. Dose rates were reduced by about 40% (DF = 1.7) following removal of topsoil from residential land in Japanese tests.
Reduction in resuspension	Resuspended activity in air above the surface will be reduced by the value of the DF
Technical factors influencing effectiveness	Weather conditions, particularly those at the time of deposition, and the amount of rain after deposition. Correct implementation of option - all turf/soil must be collected to achieve the DF value quoted. Once contamination has migrated below the removal depth (turf and/or 50 mm topsoil) the technique will start to become less effective unless the depth of removal is increased. Soil texture: dry, crumbly soils will be more difficult to remove completely. Stones will affect the ability to implement the option effectively. If mechanical removal is to be used, soil must be compact enough to bear the equipment. Evenness of ground. Consistency in effective implementation of option. Size of the area with grass/soil coverage. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Also contamination migrates deeper into the soil over time. Whether recovery options have been applied to adjacent ground surfaces.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.

Feasibility	
Equipment	Depends on the technique used and the size of the area being treated. Manual topsoil removal: Spade Mechanical topsoil removal: Motorised scraper; Grader or bulldozer Turf harvesting: Sod cutter/turf harvester (commercial and domestic sizes) Additional equipment: Seeding machine (if required). Bags or containers for waste Transport vehicles for equipment and waste.
Utilities and infrastructure	Roads for transport of equipment, materials and waste.
Consumables	Fuel and parts for vehicles and equipment. Top soil (if required). Plants and turf or grass seed (if required).
Skills	Only a little instruction is likely to be required. Care must be taken to remove soil to the optimal depth and not plough the contamination into the cleaned surface. If removing topsoil manually, this option could, to some extent, be implemented by inhabitants of the affected area as a self-help measure, after instruction from authorities and provision of safety and other required equipment. Otherwise, skilled personnel will be required if large-scale equipment is used.

Back to list of options

24 Top soil and turf removal

	It should be noted that this option requires hard physical work, especially for manual removal of topsoil, which not all persons would be capable of.
Safety precautions	Under very dusty conditions respiratory protection and protective clothes/gloves may be recommended to reduce the hazard from resuspended activity.
Waste	
Amount and type	Top soil removal (50 mm depth removed): 5.5 10^1 - 7 10^1 kg m^{-2} soil and turf Turf harvesting (20 - 25 mm depth removed): 2 10^1 - 3 10^1 kg m^{-2} soil and turf This option has the potential to generate large volumes of waste. Disposal will be subject to conditions depending on the activity levels and other properties of the waste. Segregation of contaminated waste is likely to be difficult. Monitoring of waste to determine if it meets current waste disposal criteria will be important to ensure that the quantity of waste requiring special management is minimised, especially as there is a risk of generating very large volumes of waste materials. It may be possible to use removed topsoil in construction (eg of banks or roads) by digging a trench to bury the contaminated topsoil and covering with clean soil, if the activity levels are suitably low that it will not pose undue risks to members of the public.
Doses	

Averted doses

^{137}Cs (% reduction in external dose)				^{239}Pu (% reduction in resuspension dose)			
Over 1st year		Over 50 years		Over 1st year		Over 50 years	
Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
35-40	40-45	45-50	60-65	5-10	15-20	15-20	30-35
~30	~65						
40-45	45-50	60-65	5-10	15-20	15-20	30-35	35-40

The dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area.

Factors influencing averted dose

Effective implementation of option over a large area.

Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by soil/grass and the time spent by individuals on or close to soil/grassed areas.

Time of implementation. The impact of removing the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering.

Whether adjacent soil surfaces are also decontaminated.

Additional doses

Relevant exposure pathways for workers are:

- external exposure from radionuclides in the environment and contaminated equipment
- inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels)
- *inadvertent ingestion of dust from workers' hands*

Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE.

Exposure routes from transport and disposal of waste are not included.

The potential for additional doses to workers should be considered when planning working procedures. For example, while use of containers to contain wastes may be recommended, if workers are expected to be highly exposed to contaminated dust and radiation when they engage in packaging wastes, then use of containers may not be required, providing efforts are made to stop scattering and leakage of contaminated materials.

No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.

Intervention costs

Operator time	Manual topsoil removal:	1 10^1 m^2 h^{-1} $team^{-1}$ (If soil hardener is used there will be a delay to let topsoil harden prior to removal.)	Team size: 1 to remove topsoil and turf.

Back to list of options

24 Top soil and turf removal

	Mechanical topsoil removal:	1 10^2 - 4 10^2 m^2/team.h (If soil hardener is used there will be a delay to let topsoil harden prior to removal.)	Team size: 2 people for soil and turf removal.
	Turf harvesting:	1.5 10^2 - 1 10^3 m^2/team.h for turf removal (depends on equipment used. Tractors with attached modern turf harvesters can strip about 1200 m^2/h)	Team size: 2 people for turf removal.
	Soil/turf replacement:	80 - 100 m^2 / team.h but likely to be much slower in small areas	In large areas, soil replacement could require an additional 2 people, returfing an additional 4-6 people and reseeding an additional 4 people.
	Depending on the PPE used individuals may need to work restricted shifts.		
Factors influencing costs	Soil type, condition and depth removed. Amount of vegetation to be removed. Weather. Topography. Size of area. Evenness of ground surface. Type of equipment used. Access.		
Side effects			
Environmental impact	Soil erosion risk. Possible adverse impact on bio-diversity. Possible loss of soil fertility, nutrient and water retention. Loss of plants, shrubs etc. Disposal or storage of waste. However, this issue may be minimised through the control of any disposal route and relevant authorisations.		
Social impact	Adverse aesthetic effect of removal, even if replaced. Access to public areas may need to be restricted temporarily before turf and topsoil removal is implemented and afterwards while grass grows/turf settles. Waste disposal may not be acceptable. Loss of public amenities.		
Practical experience	Topsoil removal has been tested on semi-large scale (~ 400 m^2 manual removal, ~ 2000 m^2 mechanical removal) on several occasions in the Former Soviet Union. Manual topsoil removal has also been carried out on a large scale by the Russian authorities after the Chernobyl accident, but not optimised with respect to contaminant distribution, and not carried out consistently over a large area. Topsoil removal carried out following the incident in Goiania. Turf harvesting has been tested on relatively large meadows in the Former Soviet Union. Replacement of garden lawn and topsoil was carried out at a private residence in Cumbria, to remove activity deposited by feral pigeons that were contaminated with radioactive material at the Sellafield site. Topsoil removal was tested on playground and residential areas following the Fukushima accident.		
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223.		

Back to list of options

24 Top soil and turf removal

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More information may become available after the publication of this handbook from the work following the Fukushima accident.

Version	1
Document history	See Table 7.2 Based on datasheets Top Soil and Turf Removal (Manual) (datasheet 37), Top Soil and Turf Removal (Mechanical) (datasheet 38), and Turf Harvesting (datasheet 40) in version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

25 Treatment of walls with ammonium nitrate

Objective	To reduce external dose from caesium contamination on external walls of buildings in inhabited areas.
Other benefits	Will reduce caesium contamination on external walls of buildings.
Management option description	An ammonium nitrate solution in water (0.1 M) is sprayed on the target wall at low pressure using a pump and hose. The ammonium ion exchanges with caesium ions, reducing the wall contamination. A continuous water flow should be applied on the wall to transport contamination to the ground. The washing must start at the top of the wall which must subsequently be washed with clean water to minimise corrosion. The ground surface below the wall should ideally be treated afterwards. Workers may need to be protected against water/chemical spray. The use of chemicals may cause an environmental hazard. Particular care must be taken due to hazards associated with the chemicals involved: • extremely powerful oxidising agent and may cause combustible materials to ignite or explode • mixing with water is highly endothermic • powders and dusts are irritant and in high quantities are toxic • solutions are acidic and corrosive It is unlikely to be practicable to collect the waste water and associated contamination, although this may be done using PVC sheets draped between scaffolding and the wall. The bottom of the sheet hangs in a metal trough sealed to the wall with pitch. Water flows into the trough and a pump delivers the water to collection tanks where it is then filtered and pumped to delay tanks.
Target	Highly contaminated external walls of buildings.
Targeted radionuclides	Caesium.
Scale of application	Suitable for small and large areas.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surfaces and before rain can wash contamination on to adjacent surfaces.
Constraints	
Legal constraints	Liability for possible damage to property. Ownership and access to property. Restrictions on chemical use. Use on listed or other historic buildings.
Environmental constraints	Extreme cold weather (solution needs to be heated). Walls must be water resistant.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of between 1.5 and 2 can be achieved if the option is implemented soon after deposition. Repeated application is unlikely to provide any significant increase in DF. Up to a few years after deposition, DF values of up to 1.5 could still be expected.
Reduction in surface dose rates	External gamma and beta dose rates from walls of buildings will be reduced by approximately the value of the DF.
Reduction in resuspension	N/A
Technical factors influencing effectiveness	Spraying time. Contaminant aerosol type (chemical form of caesium). Permeability of surface (walls must be water resistant). Care taken to wash contamination to the ground and not just transfer it on to the wall. The bottom part of the wall should be cleaned particularly well, as this is closest to any persons outside and close to the building. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.

Back to list of options

25 Treatment of walls with ammonium nitrate

Feasibility	
Equipment	Water hose and pump. Transport vehicles for equipment. Scaffolding or mobile lifts for tall buildings.
Utilities and infrastructure	Water supply Power supply. Fuel and parts for transport vehicles.
Consumables	Ammonium nitrate. Water.
Skills	Only a little instruction required. The method is not recommended for self-help as ammonium nitrate is a highly reactive chemical.
Safety precautions	For tall buildings: lifeline, safety helmets. Normal safety procedures for handling chemicals. Water-proof safety clothing recommended, particularly in highly contaminated areas. Respiratory protection may be considered to protect workers from contaminated water spray if conditions are windy.
Waste	
Amount and type	Approx. 6 l m^{-2} of liquid waste. Disposal will be subject to conditions depending on the activity levels and other properties of the waste.
Doses	
Averted doses	**Dry conditions:** reductions of approx. 4% in external dose rate received by a member of the public living in an inhabited area could be expected shortly after treatment of the building surfaces. **Wet conditions:** reductions in dose rates will be negligible.
Factors influencing averted dose	Consistency in carrying out the procedure over a large area. Whether the surfaces surrounding the building are decontaminated after treating the building. Number of buildings in the area, ie environment type / land use. Population behaviour in the area and time spent by individuals close to or inside buildings.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) Exposure routes from transport and disposal of waste are not included.
Intervention costs	
Operator time	12 m^2 per team hour (team size 1 person). Work rate excludes variable time for setting up scaffolding/transport. Depending on the PPE used individuals may need to work restricted shifts.
Factors influencing costs	Weather. Building size. Access. Proximity of water supplies. Use of personal protective equipment (PPE). Note: costs will increase if scaffolding is required, and if repainting of walls is required.
Side effects	
Environmental impact	Contaminated waste water from ammonium treatment will run on to other surfaces (roads, soil, grass etc), resulting in a transfer of contamination which may require subsequent clean-up, generating more waste. Ammonium nitrate may reach the ground water. Ammonium nitrate can corrode steel surfaces.

Back to list of options

25 Treatment of walls with ammonium nitrate

Social impact	Aesthetic consequences of changes of colour of building surfaces eg colour change on painted metal surfaces.
Practical experience	Tested on realistic scale on selected walls in the Former Soviet Union and Europe, after the Chernobyl accident.
Key references	Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). *Strategies of decontamination.* Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3. Roed J and Andersson KG (1996). Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout. *Journal of Environmental Radioactivity*, **33** (2), 107-116. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Sandalls FJ (1987). Removal of radiocaesium from urban surfaces. *Radiation Protection Dosimetry*, **21**, (1/3), 137-140.
Version	3
Document history	See Table 7.2

Back to list of options

26 Treatment of waste water

Objective	To remove contamination from waste water produced by other management options.
Other benefits	Treatment of water can mean that water can be discharged for normal reuse, rather than being disposed of as contaminated waste water.
Management option description	Contaminated wash water from other management options can be collected and treated using any of a number of treatment options to remove radioactive substances. Treatment may be possible as part of the collection process eg use of caesium absorbers within bunding, to act as a filter to treat the water, or water may need to be collected for treatment. Although small volumes of waste water could be transported in containers, subject to approval, there may be difficulties in transporting large volumes of collected water to remote treatment centres, so local treatment may be required. Treated water will need testing before discharge to ensure that it is sufficiently clean. **Ion exchange:** separates and replaces radionuclides in a waste stream with relatively harmless ions from resin or zeolite. Zeolite adsorption is particularly effective for caesium or strontium, which solidify into the zeolite matrix. However, the design of the system (eg retention times and pore volumes) must be precise. Resins can be periodically be regenerated by exposure to a concentrated solution of the original exchange ion, while zeolite must be disposed of as radioactive waste once it is spent, though the volume of this is much smaller than that of the waste water. If more than one contaminant is present, more than one exchange column may be required. Ferric hexacyanoferrate (AFCF or Prussian Blue, in the form of a fine power rather than a resin) may be an effective alternative to standard ion exchange media for caesium. This can be used as a stand-alone treatment or as part of a sequence of treatments that includes a settling tank for removal of particulates where ferric hexacyanoferrate is added. **Precipitation and filtration:** Chemical precipitation, commonly using carbonates, sulphates, sulphides, phosphates, polymers, lime or hydroxides, converts soluble radionuclides to an insoluble form which can then be removed through filtration or settling. If radioactivity is largely associated with particulate matter in the water, then physical processes such as filtration or settling will be effective on its own. **Flocculation:** A water treatment process in which chemicals are added to the water to remove very fine suspended particulate material. The chemicals combine with the particulate material in the water to form a floc which can be removed by being either allowed to sink by gravity, or made to float and then removed. More information on flocculation is available from the Drinking Water Supplies Handbook. **Membranes:** membranes can concentrate dissolved target contaminants into a smaller volume, leaving a contaminant-free filtrate that can be reused for further decontamination activities or disposed of as non-radioactive waste. Alternative techniques that do not produce treated water include evaporation (which has been used successfully but requires a dedicated plant and equipment), water absoption gels or cementing of small volumes of waste water to produce solid wastes for disposal. Production of solid wastes may be preferred for small volumes of waste water (less than ~1 m^3) as it would not be good practice to contaminate large amounts of clean equipment to process this small amount of waste water.
Target	Waste water produced by other management options (see Datasheet 2 (transport restrictions), Datasheet 12 (ventilation systems) Datasheet 15 (hosing options), Datasheet 17 (roof cleaning), Datasheet 20 (surface removal) and Datasheet 29 (water based cleaning)).
Targeted radionuclides	Most
Scale of application	Any
Time of application	Whenever other decontamination options are implemented. This is likely to be relatively soon after deposition, but this may not always be the case.
Constraints	
Legal constraints	Discharge of treated water into water bodies or public sewers may be subject to authorisations. Water quality standards will apply to any water to be used as drinking water. May be constraints on disposal of contaminated wastes.
Environmental constraints	Discharge of treated water for normal reuse.

Back to list of options

26 Treatment of waste water

Effectiveness

Reduction in contamination on the surface

Removal efficiencies for natural zeolites and ion-exchange are as follows:

Element	Natural zeolites (clay minerals)	Ion-exchange (mixed media)	Flocculation
Molybdenum/technetium	0-10%	Mostly in range 40-70%, though higher than 70% for some radionuclides	Mostly in range 40-70%, though lower (10-40%) for caesium and strontium, and higher than 70% for some radionuclides
Cobalt, ruthenium, iodine, ytterbium, iridium, barium, lanthanum, radium	10-40%		
Selenium, strontium, tellurium, caesium, zirconium, niobium, cerium, uranium, plutonium, americium	40-70%		

Use of reverse-osmosis membranes can remove up to 99% of caesium from waste water.

Use of ferric hexacyanoferrate in a settling tank can remove 85% or more of caesium from waste water.

Reduction in surface dose rates

Not available

Reduction in resuspension

Not available

Technical factors influencing effectiveness

The effectiveness of this option will depend on which strategy is employed.

Ion exchange: pH, temperature, contaminant concentration, waste water flow rate, resin's selectivity and exchange capacity.

Precipitation and filtration: precipitant and dosage, pH, contaminant concentration

Social factors influencing effectiveness

Public acceptability of waste treatment and storage routes.

Feasibility

Equipment

Water collection equipment (eg tanks, booms, dams)

Specific equipment (eg zeolite blocks, ion exchange resins, settlement tanks) will be required depending on the method used.

More information may become available after the publication of this handbook from the work following the Fukushima accident.

Utilities and infrastructure

Exact requirements will depend on the treatment method used. In general, either a transport network/vehicles will be required to transport water to treatment facilities, or local treatment may be required, especially as there may be difficulties in transporting large volumes of collected water to remote treatment centres.

Consumables

Zeolite blocks, resins, chemicals for precipitation, depending on the treatment method used.

Skills

Training of operatives maybe required.

Safety precautions

Monitoring in the treatment works and of operatives may be required to ensure that any limits on operative exposures are not exceeded and to confirm that the new treatment is having the desired effect.

Waste

Amount and type

Zeolite blocks or ion exchange resins, when spent, must be treated as solid waste and disposal will be subject to conditions depending on the activity levels and other properties of the waste. Because the ion exchange process is very effective at concentrating the radioactive content of liquid into a small volume of solid, there can be an issue with the possible production of ILW.

Physical separation will produce an amount of sludge to treat as waste.

Doses

Averted doses

Not estimated

Additional doses

May give rise to incremental doses, but due to the specific nature of variation in tasks it is not possible to give estimates and it is therefore necessary to assess on a case by case basis.

Intervention costs

Operator time

Filtration of water decontaminates at a rate of 2.2 m^3 per day

Coagulative precipitation of water decontaminates at a rate of 18 m^3 per day

Back to list of options

26 Treatment of waste water

Factors influencing costs	Technique used. Ion exchange can be expensive.
Side effects	
Environmental impact	Disposal of wastes and discharge of treated water to water bodies may have an environmental impact, but these will be subject to authorisations to minimise any adverse effects.
Social impact	Potential loss of confidence in water quality. Potential increase in confidence that the situation is being managed.
Practical experience	Artificial zeolite blocks used by the Japanese following the Fukushima accident to decontaminate water in gutters. Filtering and coagulative precipitation used by the Japanese following the Fukushima accident. Companies involved in activities such as fracking or oil production have experience of treating produced water.
Key references	Desrosiers, M., T. Cousins, K. Volchek, D. Velicogna, A. Obenauf, L. Boudreau, M. Hornof, A. Dumouchel, A. Somers, T. Jones, A. Mastilovich, and M. Vijay, ‘Radiological Decontamination - Laboratory Research Study’, Manuscript Report EE-180, Science and Technology Branch, Environment Canada, ON, 2006. IAEA (2002) Application of Ion Exchange Processes for the Treatment of Radioactive Waste and Management of Spent Ion Exchangers. Technical Reports Series No 408, International Atomic Energy Agency, Vienna. Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Miyahara K., Tokizawa T., Nakayama S (2012) Decontamination pilot projects: building a knowledge base for Fukushima environmental remediation. Mater Res Soc Symp Proc 2012; 1518:245-256. Nakayama S (2012) Report of the Results of the Decontamination Model Projects. Analysis and Evaluation fo the Results of the Decontamination Model Projects - Decontamination Wastes (Removed Objects) and Their Temporary Storage. Presentation at Fukushima City Public Hall March 26, 2012. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2

Back to list of options

27 Tree and shrub pruning and removal

Objective	To reduce inhalation and external doses outdoor areas that contain trees, shrubs or plants within inhabited areas. Mainly for use when deposition has occurred under dry conditions and when trees, shrubs and plants are in leaf. After wet deposition, consideration should be given to decontaminating the ground under trees as most of the contamination washes straight off the trees.
Other benefits	Removal of contamination from vegetated areas. Removal of activity in gardens may reduce subsequent contamination of soil used for growing food. This in turn may reduce up-take to food crops grown.
Management option description	Removal or heavy pruning of trees and shrubs with the option of replacement. Pruning should take place in the dormant period where possible, and the extent of pruning should be limited so as to minimise impact on growth. Most importantly, leaves must be removed. Removal or cleaning of tree bark may also be used. primarily concentrating on the tops and sides of main trunks and main branches. If tree felling is conducted on a small scale, incineration of the waste is an option. Smaller prunings and leaves can be shredded for composting. When dealing with smaller plants, a portable brush cutter or forage harvester (depending on the size of the area being treated) is used to remove plant growth. Waste vegetation is removed by loading into trailers. Replanting is likely to be required. For maximum benefit, this should be considered with other options to decontaminate grass areas. This option may give rise to large amounts of dust. However, the use of water to dampen the tree surface or the use of a tie-down material is unlikely to be practicable without moving contamination from the plant on to the underlying soil. Shrubs may be covered in polythene sheeting to prevent resuspension of contamination during removal. If prunings are shredded or chipped to reduce the volume of waste produced, then large amounts of dust will be generated. The use of PPE by workers is therefore recommended to limit the resuspension hazard. It may be possible to ask inhabitants of the affected area to prune trees and shrubs as a 'self-help' option. If contamination is present in forest areas adjacent to inhabited areas, a significant reduction in dose rates in the inhabited area can be seen by decontamination of the first 10 m wide strip of forest nearest to the inhabited area. Pruning may not be required if significant leaf fall occurs thus allowing contaminated leaves to be collected. (see Datasheet 6).
Target	Trees, plant and shrubs in gardens, parks, playing fields and other open spaces. Highly contaminated trees and shrubs in inhabited areas that are in leaf at the time of deposition. Coniferous trees may contribute more to external doses in the long term as they don't lose their leaves annually. However, the overall contributions of deciduous and coniferous trees to external doses depend on the fate of fallen leaves.
Targeted radionuclides	All long-lived radionuclides, not short-lived radionuclides alone.
Scale of application	Any size. Incineration of waste is only an option on a small scale.
Time of application	Maximum benefit if carried out soon after deposition when maximum contamination is on the plants and shrubs and before weathering of activity to the underlying soil has occurred. Pruning/removal of plants and shrubs should be carried out within 1 week of deposition; tree felling should take place within the first month after deposition. Effectiveness is significantly reduced after rain has occurred. In addition, it is important that it is completed before leaf fall for deciduous trees/shrubs. Unlikely to be needed in autumn/winter when much foliage has died.
Constraints	
Legal constraints	Liabilities for possible damage to gardens or property. Ownership and access to property. Use at listed or other historical sites and in conservation areas. Waste disposal of collected vegetation. Organic material may not meet criteria set by the LLWR, therefore authorisation for waste disposal may be required.

Back to list of options

27 Tree and shrub pruning and removal

Environmental constraints	Severe cold weather. Soil type and texture. Extent of root, if it is necessary to remove the root ball.
Effectiveness	
Reduction in contamination on the surface	The reduction in contamination is proportional to the fraction of the tree/shrub removed. Pruning plants and shrubs can achieve a decontamination factor (DF) of 1.4 if this option is implemented within one week of deposition and before significant rain. If a whole tree is felled and all the leaves are collected, a very high DF, of up to about 50, could be achieved. Pruning and removal of low branches, may only give only a small decontamination effect on its own, but this can be worthwhile as preparation for removal of topsoil, which in combination with the branch trimming can give a DF of about 2.5 (reduction in contamination levels by about 60%)
Reduction in surface dose rates	External gamma and beta dose rates from vegetation will be reduced by approximately the value of the DF. Trimming lower branches of forest trees has been found to reduce dose rates by 10 to 20%, while felling these trees reduced dose rates by about 50%.
Reduction in resuspension	Resuspended activity in air adjacent to the trees, shrubs and plants will be reduced by a value similar to the DF. If contamination remains on the surrounding soil however, the reduction in resuspension will be less than the DF.
Technical factors influencing effectiveness	Degree of pruning or removal and effectiveness of leaf collection. Time of implementation: contamination levels will reduce over time due to weathering/ migration of contamination into the soil, so quick implementation will improve effectiveness. Tree type: coniferous trees have a continuous turnover of leaves and it may take several years to lose all the needles initially contaminated. Weather particularly those at the time of deposition, and the amount of rain post deposition. Correct implementation of option - all material must be collected to achieve the DF value quoted. Consistency in effective implementation of option over a large area. Amount of trees, plants and shrubs in the area. Whether recovery options have been applied to adjacent ground surfaces, eg grass areas.
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Equipment depends on the type of vegetation to be pruned or removed and may include: Brush cutter. Chainsaw. Axes / cutters. Ropes and ladders (tall trees). Shredder/chipper A forage harvester may be required for larger areas. Tractor and trailer. Transport vehicles for equipment and waste. An incinerator may be used for waste from small areas.
Utilities and infrastructure	Roads for transport of equipment and waste. Power supply.
Consumables	Fuel and parts for equipment and vehicles. Tree saplings, if replacement option is implemented.
Skills	Skilled personnel may be required to operate equipment, and experience in felling trees may be required.
Safety precautions	Respiratory protection and protective clothing may be required, particularly if conditions are dry/dusty. Facial protection including safety goggles will be required when using brush cutters.

Back to list of options

27 Tree and shrub pruning and removal

	Safety helmets may be required. For tall trees, a lifeline should be used.
Waste	
Amount and type	Tree felling: 1 10^1 kg m^{-2} wood and vegetation Plant/shrub pruning and removal: 2 kg m^{-2} vegetation and shrubby material Trimming lower branches of forest trees: 1 - 3 m^3 of waste per tree. May also get contaminated fruit from orchards. Reduction of volume using a chipper is important for woody materials, such as small trees and pruned branches, though this process will generate large amounts of dust so particular care must be taken to use PPE to reduce the resuspension hazard.
Doses	
Averted doses	**Dry deposition:** reductions of up to 20% in external gamma dose rate received by a member of the public living in an inhabited area could be expected shortly after removal of contaminated trees/shrubs. **Wet deposition:** reductions in dose rate will be negligible.
Factors influencing averted dose	Amount of vegetation in the area ie environment type/land use. Consistency in effective implementation of option over a large area. Population behaviour in area. Time of implementation. The impact of decontamination on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Whether adjacent grass surfaces are also decontaminated.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of plume activity (if radionuclide release is ongoing) • inhalation of radioactive material resuspended from the ground and other surfaces (may be enhanced over normal levels) • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. The potential for additional doses to workers should be considered when planning working procedures. For example, while use of containers to contain wastes may be recommended, if workers are expected to be highly exposed to contaminated dust and radiation when they engage in packaging wastes, then use of containers may not be required, providing efforts are made to stop scattering and leakage of contaminated materials. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.
Intervention costs	
Operator time	Plant/shrub pruning and removal: 1 10^2 - 10^3 m^2/team.h, depending on equipment used Team size: 2 people. Tree felling only: 5 10^1 m^2/team.h Team size: 2 people Tree felling and replacement: 5 10^1 m^2/team.h (replacement work rate is about 4 10^2 m^2/team.h; overall speed is set by the slower felling rate) Team size: 3 people (felling and replacement) Depending on the PPE used individuals may need to work restricted shifts.
Factors influencing costs	Weather. Topography. Size of area. Type and size (height) of vegetation/trees to be removed Degree of removal required. Type of equipment used.

Back to list of options

27 Tree and shrub pruning and removal

	Access. Distance to transport equipment and waste.
Side effects	
Environmental impact	Possible adverse impact on biodiversity. Possible soil erosion. Possible adverse effect on soil nutrient and water retention. Loss of vegetation. Negative effect on birdlife/wildlife. The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations.
Social impact	Adverse aesthetic effect. Acceptability of tree/plant removal. Restricted access to public areas before implementation. Waste disposal may not be acceptable - especially as large quantities of waste can be generated from relatively small areas. For example treating only the most heavily contaminated forests in Japan following the Fukushima accident produced an estimated 33 milion cubic meters of waste. Decontamination of forest areas can lead to stress, while reassurance may not follow if decontamination is considered unnecessary.
Practical experience	Tree/shrub removal tested on a small scale in Europe after the Chernobyl accident. Tested on a semi-large scale in the Former Soviet Union after the Chernobyl accident. Used in forests and residential gardens in Japan after the Fukushima accident. Used following the incident in Goiania.
Key references	Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas. Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. Journal of Environmental Radioactivity, 46(2), 207-223. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Guillitte O and Willdrocht C (1993). An assessment of experimental and potential countermeasures to reduce radionuclide transfers in forest ecosystems. Science of the Total Environment, 137, 273-288. Hashimoto et al (2012) - Hashimoto S, Linkov I, Shaw G and Kaneko S, Radioactive Contamination of Natural Ecosytems: Seeing the Wood Despite the Trees, Environmental Science and Technology 46(22) 12283-12284 IAEA (1988) The Radiological Accident in Goiania. STI/PUB/815 ISBN 92-0-129088-8, IAEA, Vienna Little J and Bird W (2013) A Tale of Two Forests. Addressing Postnuclear Radiation at Chernobyl and Fukushima, Environmental Health Perspectives, Volume 121, Number 3, March 2013 Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Miyahara K., Tokizawa T., Nakayama S (2012) Decontamination pilot projects: building a knowledge base for Fukushima environmental remediation. Mater Res Soc Symp Proc 2012; 1518:245-256. Roed J, Andersson KG and Prip H (ed.) (1995). Practical means for decontamination 9 years after a nuclear accident. Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p.

Back to list of options

27 Tree and shrub pruning and removal

	Schell WR, Linkov I, Myttenaere C and Morel B (1996). A dynamic model for evaluating radionuclide distribution in forests from nuclear accidents. Health Physics, 70, (3), 318-335. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheets Plant and Shrub Removal (datasheet 32) and Tree and Shrub Pruning/Removal (datasheet 44) from version 3 of the UK Recovery Handbook for Radiation Incidents.

Back to list of options

28 Vacuum cleaning

Objective	To remove contamination from indoor surfaces and objects in buildings and semi-enclosed areas, roads/paved areas and vehicles in inhabited areas.
Other benefits	Will reduce inhalation and external doses arising from contamination on internal surfaces of buildings and indoor objects, semi-enclosed areas, roads and paved areas, and vehicles within inhabited areas. Implementing this option by sweeping roads and pavements will make an area look clean; provide public reassurance and restore public confidence.
Management option description	A variety of vacuum cleaning machines are available - seek specialist advice and guidance. **Indoor:** any domestic or industrial vacuum cleaner can be used to clean surfaces and objects, such as furniture. However, it is preferable to use a vacuum cleaner fitted with high efficiency particulate (HEPA) filters of 99% efficiency to 0.6 µm particles to prevent resuspension. This approach is clean, does not damage materials (so may be suitable where a gentle cleaning method is required), and does not generate waste by-products other than those present in the filters themselves. Machines are electrically operated from mains electricity. Vacuum cleaning may give rise to dust (particularly in dusty environments). Using water to dampen the surface or the use of a fixative coating is unlikely to be practicable and so personal protective equipment (PPE) must be provided for the workers to reduce the re suspension hazard. Decontaminated areas should be wet-wiped after dry vacuuming. A variation, steam vacuum cleaning, may be used. This delivers superheated water to the surface via a steam/vacuum cleaning head. Decontamination is mechanically dislodged by the impulse of the fluid striking the surface, and by the flashing of the superheated water into steam. The hood of the steam/vacuum cleaning head traps and collects the dislodged contaminants, steam and water droplets. The waste passes through a vacuum recovery system consisting of a liquid separator, a demister and a HEPA filter that remove contaminants and discharge clean air to atmosphere. A detergent may be added to the pressurised water stream to improve washing effectiveness. **Outdoor:** municipal vacuum sweepers can be used to clean paved areas. Different types of vacuum sweeper are used for large surface areas, such as roads, and for small surface areas, such as pavements. A disadvantage with these, compared to indoor vacuum cleaners, is that they do not include HEPA filters, so particular care is needed over protection from resuspension. It is recommended that machines with the ability to dampen the surface with water sprays are used to reduce dust (and subsequently reduce the re-suspension hazard). Some road sweepers can operate in wet weather conditions. **Semi-enclosed areas:** depending on the scenario municipal vacuum sweepers may be suitable for use in train stations and subways. However, some surfaces in semi-enclosed areas may need smaller vacuum cleaners, as typically used for indoor environments. **Vehicles:** domestic vacuum cleaners are likely to be most suitable for cleaning the interior of vehicles. Decontaminated areas should be wet-wiped after dry vacuuming.
Target	Internal surfaces (particularly floors, but also other surfaces including the inside of roofs) and objects in buildings and semi-enclosed areas, paved surfaces (roads, pavements, paths, yards, playgrounds etc) and vehicles.
Targeted radionuclides	All radionuclides. Particularly short-lived radionuclides if implemented quickly.
Scale of application	Any. Suitable for indoor surfaces in all types of building or vehicle, or any size road or paved area. Outdoor vacuum sweepers are unlikely to be used immediately around peoples' houses.
Time of application	Maximum benefit if implemented when maximum contamination on surfaces. This is typically within one week of deposition when implemented outside, or within a few weeks of deposition inside. However, over longer periods, contamination may be brought into buildings eg on the soles of shoes, and so repeated application regularly may be beneficial until any surrounding soil or grass areas are cleaned.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use in listed or other historic buildings and on precious objects. Disposal of contaminated water to public sewer system if wet vacuuming.
Environmental constraints	**Indoor vacuuming:** should have a limited environmental impact if waste is disposed of appropriately.

Back to list of options

28 Vacuum cleaning

	Outdoor vacuuming: this will be complicated by weather. Severe cold weather could result in contamination becoming trapped under a layer of ice. Wet conditions will create additional contaminated waste water, which may require filtering prior to disposal. If waste water is not going to be collected, and the hard surfaces are not equipped with drains, this option should not be considered.
Effectiveness	
Reduction in contamination on the surface	**Indoor vacuuming: v**acuum cleaning of carpets will generally have an insignificant effect on activity concentrations of contaminated particles in the region of size 1µm (as observed with the initial caesium contamination after the Chernobyl accident). However, a fraction of the contamination will rapidly become attached to larger house dust particles (>5 µm), for which vacuum cleaning is effective. Soil particles brought into the buildings on shoes or by the wind will be relatively large and therefore easy to remove. A decontamination factor (DF) of 5 can be achieved, although there is likely to be large variation in this value. This assumes that this option is implemented within a few weeks of deposition and no previous cleaning has taken place. Reductions in external doses received by a member of public living in the area will depend on the amount of time spent by individuals inside the buildings (see below). Repeated application is unlikely to give any significant increase in DF if implemented thoroughly the first time. However, over longer periods, contamination may be brought into buildings eg on the soles of shoes, and so repeated application regularly may be beneficial until any surrounding soil or grass areas are cleaned. Dry vacuuming removes only loose particles, and no fixed or subsurface contamination is removed. Thus, dry vacuuming may be used as an initial treatment method, possibly followed by another technology for further treatment to reach desired protection levels. **Outdoor vacuuming: a** decontamination factor (DF) of 2 can be achieved if this option is implemented within one week of deposition and before rain. The factor is likely to be lower if deposition occurred during rainfall. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by outdoor hard surfaces and the time spent by individuals on or close to these surfaces. Since the contamination will be removed rapidly from these surfaces through weathering, the effectiveness of the method will decrease with time and after a few months is unlikely to remove significant contamination. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be same for all radionuclides, with the exception of elemental iodine and tritium, for which thorough cleaning of impermeable surfaces will lead to virtually full removal.
Reduction in surface dose rates	External gamma and beta dose rates immediately above the cleaned surface will be reduced by a value similar to the DF.
Reduction in resuspension	Resuspended activity in air will be reduced by a value similar to the DF.
Technical factors influencing effectiveness	Effectiveness will vary depending on the vacuum cleaning technique used, size and scale of contamination. Specific factors that should be considered include: • type, eveness and condition of surface • time of implementation (effectiveness as a remediation option decreases over time as contaminated dust may disperse from the affected area due to weathering and traffic, or may fix to the surface) • consistent application over the contaminated area; need to ensure edges and corners are cleaned • amount of dust on surfaces at the time of deposition • whether any cleaning has already been undertaken • particle size of dust and efficiency of equipment Factors specifically affecting indoor vacuuming: • weather at time of deposition; less material is deposited indoors during wet deposition. • amount of furniture and furnishings in the buildings and ventilation rates. Factors specifically affecting outdoor vacuuming: • road gutters must be cleaned carefully because contamination tends to accumulate here

Back to list of options

28 Vacuum cleaning

	• the use of water spraying may increase the effectiveness slightly • amount of hard outdoor surfaces in the area • whether decontamination is carried out on adjacent surfaces • run-off of contamination on to other outdoor surfaces
Social factors influencing effectiveness	Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	**Indoor vacuuming:** vacuum cleaner with brush attachment and upholstery cleaning attachment (preferably HEPA filtered industrial vacuum cleaner). Steam vacuum cleaning system if required. Transport vehicles for equipment and waste. **Outdoor vacuuming:** pavement cleaner. Road sweeper. Spate pumps. Storage tanks. Transport vehicles for equipment and waste.
Utilities and infrastructure	Electricity supply. Water supply if using wet or steam vacuuming. Public sewer system for outdoor road/paved area cleaning. Roads for transport of equipment and waste.
Consumables	Fuel and parts for transport vehicles. Filters. Water (if used)
Skills	**Indoor vacuuming:** only a little instruction is likely to be required. Dry vacuuming method could be implemented by the population as a self-help measure, after instruction from authorities and the provision of safety equipment (PPE). **Outdoor vacuuming:** skilled personnel essential to operate vacuum sweeping equipment.
Safety precautions	Personal protective equipment (PPE), including respiratory protection, will be required because dust may be produced. When implementing vacuuming outdoors in highly contaminated areas, the tank containing the dust must be water-filled. It may even be recommended to apply a metal shielding between the operator and the waste vessel. When vacuuming indoors, consideration of radioactive content of waste collection bags should be considered, and frequent changing of bags may be required to avoid high dose rates arising from accumulation of material. This would also help avoid problems with disposal of bags if contents were to exceed the requirements of the LLWR.
Waste	
Amount and type	**Indoor vacuuming:** 5 10^{-3} kg m^{-2} of dust, and 40 g m^{-2} per year contaminated filters which may have high contamination levels. **Outdoor vacuuming:** 1 10^{-1} - 2 10^{-1} kg m^{-2} of dust and sludge. The amount depends on dustiness of surface. If cleaning done under wet conditions and water disposed of directly to drains, then the waste will be higher). Disposal will be subject to conditions depending on the activity levels and other properties of the waste.
Doses	
Averted doses	The magnitude of the averted dose depends on the type of vacuuming and the surface to which it is applied, and also on whether contamination had been deposited by wet or dry deposition. **Indoor vacuuming:** following dry deposition the reduction in external dose from ^{137}Cs would typically be less than 5%, while the reduction in resuspended dose from ^{239}Pu would be around 35%. Following wet deposition, reductions in dose after decontamination of the indoor building surfaces will be negligible. **Outdoor vacuuming:** following dry deposition, the reduction in external dose from ^{137}Cs would typically be less than 5% in the 1st year, and between 5 and 10% over 50 years. The

Back to list of options

28 Vacuum cleaning

	reduction in resuspended dose from ^{239}Pu would be negligible in the first year and less than 5% over 50 years. Following wet deposition, the reduction in external dose from ^{137}Cs and the reduction in resuspended dose from ^{239}Pu would be between 5 and 10% in the 1st year and over 50 years. These dose reductions are for illustrative purposes only and are for a person living in a typical inhabited area. However, it should be noted that these techniques will only reduce exposure to people while they are in particular environment.	
Factors influencing averted dose	Consistent application over the contaminated area; need to ensure edges and corners are cleaned appropriately. Weather at time of deposition; less material is deposited indoors during wet deposition. Initial deposition indoors is also influenced by the amount of furniture and ventilation rates. Population behaviour in area and amount of time spent inside buildings. Types of surfaces in the area ie environment type/land use. Application of appropriate clean-up to other surfaces and objects. Run-off of contamination on to other outdoor surfaces.	
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • *inadvertent ingestion of dust from workers' hands* Contributions from pathways in italics will not be significant and doses from these pathways can be controlled by using PPE. Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.	
Intervention costs		
Operator time	Work rate (m^2/team.h)	Indoor vacuuming: 1.2 10^2 - 1.5 10^2 For cleaning upholstery and soft furnishings: 25 m^2 h^{-1} Outdoor vacuuming: 3 10^3 - 2 10^4. Depends on the equipment used Depending on the PPE used individuals may need to work restricted shifts
	Team size (people)	1
Factors influencing costs	Type of equipment used. Access. Size of area to be treated. Amount of dust/dirt on surfaces. Use of personal protective equipment (PPE). Tidiness of houses and amount of 'contents' (indoor vacuuming). Weather (outdoor vacuuming). Topography (outdoor vacuuming).	
Side effects		
Environmental impact	Disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this should be minimised through the control of any disposal route and relevant authorisations. Outdoor vacuum cleaning in wet conditions will create contaminated waste water, which may be disposed directly to drains or filtered prior to disposal.	
Social impact	Acceptability of active disposal of contaminated waste water into the public sewer system Acceptability of disposal of filtered waste from contaminated water. Possible damage to indoor building surfaces and objects. Positive benefit of cleaning houses. Vacuum cleaning of roads and pavements will make an area look clean; implementation may give public reassurance.	

Back to list of options

28 Vacuum cleaning

Practical experience	Indoor vacuuming - Several small scale tests have been reported before/after the Chernobyl accident in 1986. Used in houses following the incident in Goiania. Outdoor vacuuming - Applied in the Former Soviet Union after the Chernobyl and Fukushima accidents. Small-scale tests conducted in Denmark and USA under varying conditions to examine the influence of eg street dust loading.
Key references	Allott RW, Kelly M and Hewitt CN (1994). A model of environmental behaviour of contaminated dust and its application to determining dust fluxes and residence times. *Atmospheric Environment*, **28**, (4), 679-687. Andersson KG (1996). Evaluation of early phase nuclear accident clean-up procedures for Nordic residential areas. NKS Report NKS/EKO-5 (96) 18, ISBN 87-550-2250-2. Andersson KG and Roed J (1999). A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas. *Journal of Environmental Radioactivity*, **46**, (2), 207-223. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Calvert S, Brattin H and Bhutra S (1984). *Improved street sweepers for controlling urban particulate matter.* A.P.T. Inc., 4901 Morena Blvd., Suite 402, San Diego, CA 97117, EPA-600/7-84-021. IAEA (1988) The Radiological Accident in Goiania. STI/PUB/815 ISBN 92-0-129088-8, IAEA, Vienna Roed J (1985). *Relationships in indoor/outdoor air pollution.* Risø-M-2476, Risø national Laboratory, Roskilde, Denmark. Roed J (1990). *Deposition and removal of radioactive substances in an urban area.* Final report of the NKA Project AKTU-245, Nordic Liaison Committee for Atomic Energy, ISBN 87-7303-514-9. Roed J, Andersson KG and Prip H (ed.) (1995). *Practical means for decontamination 9 years after a nuclear accident.* Risø-R-828(EN), ISBN 87-550-2080-1, ISSN 0106-2840, 82p. Tschiersch J (ed.) (1995). Deposition of radionuclides, their subsequent relocation in the environment and resulting implications. EUR 16604 EN, ISBN 92-827-4903-7. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on Vacuum Cleaning (datasheet 18) and Vacuum Sweeping (datasheet 26) from version 3 of the UK Recovery Handbook for Radiation Incidents

Back to list of options

29 Water-based cleaning

Objective	To reduce inhalation and external doses arising from contamination on external or internal surfaces of buildings, surfaces in semi-enclosed areas, vehicles and indoor objects within inhabited areas.
Other benefits	Will remove contamination from surfaces and objects. Washing and wiping/scrubbing of building surfaces has been found to produce similar levels of decontamination as achieved using high-pressure water jet washing (see Datasheet 15), but with minimal risk of spread of contamination to other surfaces compared with options involving high pressure water jet methods. There may be a positive benefit from cleaning houses and surfaces.
Management option description	A variety of cleaning methods are available (eg scrubbing, shampooing, steam cleaning). The method chosen will be dependent on the target surfaces and the materials. Cleaning shall be performed from high places to low ones so as to avoid dispersing water to the surroundings. Contaminated waste that is produced may be collected. Waste water produced may be treated, see Datasheet 26. **Hard surfaces:** Wash external or semi-enclosed surfaces, vehicles and hard internal surfaces and objects by wiping/scrubbing using warm/hot water and detergent. Surfaces need to be rinsed to remove any residual contamination/detergent. When wiping, all sides of folded paper towels, dustcloths, etc shall be used, using a new side of cloth for each wipe to prevent contamination from re-adhering. However, care is required that none of the surfaces that have already been used for decontamination (wiping) shall be touched with bare hands. An alternative method could be to use proprietary 'tak' rags or wipes. Cleaning may also performed by using scrub brushes, scrubbing brushes, etc. However, scrubbing wood may be inadvisable as contaminated water is forced between cracks, contaminating the surface below. If considering treatment of external roof surfaces, also refer to Datasheet 17. If cleaning internal walls and ceilings, sheeting should be used to prevent contamination of the floor with waste water. **Upholstered surfaces/fabrics:** There is a risk that wet cleaning of internal upholstered surfaces, carpets, tapestries etc will take contamination deeper into the material. Therefore water based cleaning is not recommended for these surfaces. If wet cleaning is attempted, it must be done with great care in a way that only the surface becomes wet, without saturating the fabric. Possible options are spraying with detergent solution and vacuuming off, or using wet or tacky wipes.
Target	External surfaces of buildings, surfaces within semi-enclosed areas, vehicles, indoor hard surfaces, particularly floors, and objects, and those that are robust enough to be cleaned with water.
Targeted radionuclides	Long-lived radionuclides. Unlikely to be worthwhile for short-lived radionuclides alone unless implemented quickly.
Scale of application	Any size building/surface.
Time of application	Maximum benefit if carried out within a few weeks of deposition when maximum contamination remains on surfaces and before natural weathering or 'traffic' can disperse contamination throughout the environment.
Constraints	
Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Use on listed or other historic buildings or on precious objects. May be constraints on disposal of contaminated wastes.
Environmental constraints	The disposal or storage of waste arising from the implementation of this option may have an environmental impact, especially if chemicals are used. However, this should be minimised through the control of any disposal route and relevant authorisations. Steam cleaners, which use very hot water, are not suitable for all surfaces.
Effectiveness	
Reduction in contamination on the surface	**External surfaces:** Manual washing or wiping of walls or roofs with water can achieve a decontamination factor

Back to list of options

29 Water-based cleaning

	(DF) of between 1 and 4 **Hard internal surfaces:** A DF of up to 5 can be achieved. Fabric/upholstered surfaces: A DF of up to 5 can be achieved for carpets, rugs, tapestries, upholstery, bedding and soft furnishings There are likely to be large variations in these values. Decontamination factors are likely to be much lower for cleaning rough surfaces such as concrete, stone and brick surfaces (floors, walls, ceilings) and for carpets, rugs, tapestries, upholstery, bedding and soft furnishings. Experience in Japan following the Fukushima accident found that effectiveness was reduced when washing concrete surfaces of larger buildings such as schools and factories. The quoted DFs assume that this option is implemented within a few weeks of deposition and no previous cleaning has taken place. Reductions in external doses received by a member of public living in the area will depend on the amount of time spent by individuals inside the buildings (see below). Repeated application is unlikely to provide any significant increase in DF if implemented thoroughly the first time.
Reduction in surface dose rates	External gamma and beta dose rates from the decontaminated surface will be reduced by approximately the value of the DF.
Reduction in resuspension	Resuspended activity in air arising from the decontaminated surface will be reduced by approximately the value of the DF.
Technical factors influencing effectiveness	The effectiveness is very dependent on the material/surface involved and its condition and the cleaning method used. In some cases the results of the decontamination will be smaller due to effects from roofing materials like cement tiles, matte clay tiles, and painted steel sheets, as well as from rust. When rust is present, the rust itself must be removed by being wiped away. Time of implementation (the longer the time between deposition and implementation of the option the less effective it will be as contaminated dust migrates over time). Consistency and care of application over the contaminated area (ie operator skill); need to wash contamination off surfaces and not just move it around the surface or on to another surface, and also ensure edges and corners are cleaned. For indoor surfaces and objects the following factors also influence effectiveness: Amount of dust on surfaces at the time of deposition. Whether any cleaning has already been done. Efficiency of equipment. Solubility of contaminating radionuclides. Weather (less material is deposited indoors during wet deposition). Appropriate clean-up of other indoor surfaces and objects. Ability to clean surfaces and objects thoroughly.
Social **factors** influencing effectiveness	Access to properties and possible damage to building surfaces. Public acceptability of waste treatment and storage routes.
Feasibility	
Equipment	Equipment required depends on exact technique used. The following may be required: Detergent sprayer. PVC sheeting. Equipment such as ladders, scaffolding may be required to gain access to upper areas of buildings. Scrubbing machines with solution dispenser. Steam cleaners. Spray machines. Wet vacuum cleaner for indoor surfaces. Rotating brush for indoor surfaces or objects. Monitoring equipment to determine efficacy of management option.

Back to list of options

29 Water-based cleaning

	Transport vehicles for equipment and waste.
Utilities and infrastructure	Water supply. Power supply may be required depending on equipment used. Roads for transport of equipment and waste. Disposal route or storage for waste.
Consumables	Water, detergent, wash cloths. Fuel and parts for transport vehicles.
Skills	Only a little instruction is likely to be required. The method could, at least partially, be implemented by the population as a self-help measure, after instruction by authorities and provision of safety and other required equipment. However, it is important that the specific objectives and potential problems associated with the cleaning techniques are fully explained.
Safety precautions	Gloves and overalls. Waterproof clothing may be required. If detergents are used, normal safety procedure for handling chemicals. Safety equipment may be required if working at height.
Waste	
Amount and type	Wiping hard surfaces produces waste water, dust and wash cloths, generating around $1\ 10^{-3}$ - $2\ 10^{-3}$ kg m^{-2} of dust and water. Cleaning upholstered surfaces produces water, detergent, dust, contaminated filters, generating around 1.3 kg m^{-2}. Where possible, measures shall be taken to prevent the dispersion of the cleaning water. Disposal will be subject to conditions depending on the activity levels and other properties of the waste. Waste water produced may be treated, see Datasheet 26.
Doses	
Averted doses	There should be a significant reduction in potential exposures to members of the public living in the affected area. Averted exposure will be dependent on specific situations and the surfaces cleaned.
Factors influencing averted dose	Consistent application over the contaminated area; need to ensure edges and corners are cleaned. Application of appropriate clean-up to other. indoor surfaces and objects. Time of implementation. The impact of cleaning the surfaces on the overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. Care of application. Need to wash contamination off surfaces and not just move it around the surface or on to another surface. Amount of time spent inside buildings. Weather at time of deposition; less material is deposited indoors during wet deposition.
Additional doses	Relevant exposure pathways for workers are: • external exposure from radionuclides on surfaces and contaminated equipment and in the indoor environment • inhalation of radioactive material resuspended from surfaces (may be enhanced over normal levels) • inhalation of dust generated • inadvertent ingestion of contamination from workers' hands (this will not be a significant contribution and can be controlled by use of PPE) Exposure routes from transport and disposal of waste are not included. No illustrative doses are provided as they will be very specific to the type of contamination, environmental conditions, the tasks undertaken by an individual, controls placed on working and the use of PPE.

Back to list of options

29 Water-based cleaning

Intervention costs	
Operator time	Washing internal surfaces may achieve a decontamination rate of 15 - 30 m^2 per person hour, depending on surface type. Japanese projects following Fukushima estimate that decontamination speeds of 120 m^2 per day brushing or wiping roofs of residential houses may be achieved.
Factors influencing costs	Building size/surface area. Type of equipment used. Access. Use of PPE. For indoor surfaces and objects the following factors also influence costs: Tidiness of houses and amount of 'contents'. Amount of dust/dirt on surfaces.
Side effects	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact. However, this could be minimised through the control of any disposal route and relevant authorisations. It is possible that restrictions on the use of sludge containing radioactive materials and problems with disposal of such material may lead to accumulation of sludge at wastewater treatment plants. Treatment of water that has been used to wash waste cloths may be required - see Datasheet 26.
Social impact	Possible damage to buildings, surfaces and objects. Positive benefits of cleaning buildings. Maintainance of use of environment.
Practical experience	Several small scale tests have been reported before/after the Chernobyl accident in 1986. Experience in Japan after the Fukushima accident in 2011.
Key references	Allott RW, Kelly M and Hewitt CN (1994). A model of environmental behaviour of contaminated dust and its application to determining dust fluxes and residence times. *Atmospheric Environment*, **28**, (4), 679-687. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). *Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas.* Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark. Brown J and Jones AL (2000). Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0. NRPB, Chilton, NRPB-R315. Brown J, Charnock T and Morrey M (2003). DEWAR - Effectiveness of decontamination options, waste arising and other practical aspects of recovery countermeasures in inhabited areas. Environment Agency R&D Technical Report P3-072/TR. Ito M (2012) Report of the Results of the Decontamination Model projects. Analysis and Evaluation of the Results of the Decontamination Model Projects - Decontamination Technologies. Presentation to meeting held on March 26, 2012 at Fukushima City Public Hall Kihara S (2012) Report of the Results of the Decontamination Model projects. Overview of the Results of the Decontamination Model Projects - Overview of the Results of Decontamination Demonstration Tests Conducted in Date City and Minami Soma City. Presentation to meeting held on March 26, 2012 at Fukushima City Public Hall Ministry of the Environment, Japan (2013) Progress on Off-Site Cleanup Efforts in Japan, presentation by Ministry of the Environment on Oct 7th 2013 Ministry of the Environment, Japan (2013) Decontamination Guidelines, 2nd Edition. Miyahara K., Tokizawa T., Nakayama S (2012) Decontamination pilot projects: building a knowledge base for Fukushima environmental remediation. Mater Res Soc Symp Proc 2012; 1518:245-256.Roed J (1985). *Relationships in indoor/outdoor air pollution.* Risø-M-2476, Risø national Laboratory, Roskilde, Denmark. Tschiersch J (ed.) (1995). Deposition of radionuclides, their subsequent relocation in the environment and resulting implications. EUR 16604 EN, ISBN 92-827-4903-7. Tsuhima I, Ogoshi M and Harada I (2013) Leachate tests with sewage sludge contaminated by radioactive cesium, Journal of Environmental Science and Health, Part A (2013) 48,

Back to list of options

29 Water-based cleaning

	1717-1722. More information may become available after the publication of this handbook from the work following the Fukushima accident.
Version	1
Document history	See Table 7.2 Based on datasheets Washing (datasheet 19) and Other Cleaning Methods (datasheet 15) from version 3 of the UK Recovery Handbook for Radiation Incidents and datasheets Physical Decontamination Techniques and other Water based Cleaning Methods from version 1 of the UK Recovery handbook for Chemical Incidents

8 Glossary

Term	Definition
Action level	The level of dose rate, activity concentration or any other measurable quantity above which intervention should be undertaken during chronic or emergency exposure.
Activity	The rate at which nuclear decays occur in a given amount of radioactive material. The SI unit for activity is the becquerel (Bq), defined as one decay per second (1 Bq = 1 s^{-1}).
Activity concentration	The activity per unit mass of a radioactive material. Unit: Bq kg^{-1}.
Alpha particle, α	A particle which consists of two protons and two neutrons (identical to a nucleus of helium). Emitted by the nucleus of a radionuclide during alpha decay.
Beta particle, β	A particle consisting of a fast moving electron or positron. Emitted by the nucleus during beta decay.
Collective dose	The sum of individual doses in a specified population. Often approximated to be the average effective dose in a population exposed to a particular source of ionising radiation multiplied by the number of people exposed. Unit: manSv.
Contamination / radioactive contamination	The deposition of radioactive material on the surfaces in inhabited areas or on to or into drinking water sources and supplies.
Countermeasure	See management option.
Datasheet	A compilation of data and information about a management option designed to support decision-makers in the evaluation of an option and the impact of its implementation.
Decontamination factor (DF)	Effectiveness of a removal option is expressed as a decontamination factor (DF). The DF is the ratio of the amount of contamination initially present on a specific surface (eg buildings, paved surfaces, grass, soil, and shrubs) to that remaining after implementing the option. For example, a DF of 5 indicates that 80% of the activity can be removed.
Deterministic effect	Previously known as a non-stochastic effect. A radiation-induced health effect characterised by a severity which increases with dose above some clinical threshold, and above which threshold such effects are always observed. Examples of deterministic effects are nausea and radiation burns.
Dose	General term used for a quantity of ionising radiation. Unless used in a specific context, it refers to the effective dose.
Dose rate	General term used for a quantity of ionising radiation received per unit time. Unless used in reference to a particular organ in the body, it refers to the effective dose rate.
Effective dose	The effective dose is the sum of the weighted equivalent doses in all the tissues and organs of the body. It takes account of the relative biological effectiveness of different types of radiation and variation in the susceptibility of organs and tissues to radiation damage. Unit sievert, Sv.
Emergency phase (early phase)	The time period during which urgent actions are required to protect people from short-term relatively high radiation exposures in the event of a radiation emergency or incident.
Emergency countermeasures	Actions taken during the emergency phase with the aim of protecting people from short-term relatively high radiation exposures, eg evacuation, sheltering, taking stable iodine tablets.
Equivalent dose	A quantity used in radiological protection dosimetry, which incorporates the ability of different types of radiation to cause harm in living tissue. Unit sievert, Sv (1 Sv = 1 J kg^{-1}).
Gamma ray, γ	High energy photons, without mass or charge, emitted from the nucleus of a radionuclide following radioactive decay, as an electromagnetic wave. They are very penetrating.
Half-life	The time taken for the activity of a radionuclide to lose half its value by decay.
Incremental dose	The additional dose received by an individual as a result of implementing a management option that specifically does not take into account exposure to activity already present in the environment as a result of deposition of radionuclides on the ground.

Term	Definition
Inhabited areas	Places where people spend time (eg at home, at work and during recreation).
Ionising radiation	Radiation that produces ionisation in matter. Examples are alpha particles, gamma rays, X-rays and neutrons. When these radiations pass through the tissues of the body, they have sufficient energy to damage DNA.
Isotope	Nuclides with the same number of protons (ie same atomic number) but different numbers of neutrons. Not a synonym for nuclide.
Location factor	Ratio of the dose rate determined at a particular location to that in a reference location. Typically used in the estimation of doses to people indoors from measurements made in an outdoor reference location. For example, the dose rate inside a typical residential building could be ten times lower than that above a reference outdoor open grass area; in this case the location factor would have a value of 0.1.
Long-lived radionuclides	Defined for the handbook as radionuclides with a radioactive half-life greater than three weeks.
Management option	An action, which is part of an intervention, intended to reduce or avert the contamination or likelihood of contamination of food production systems. Previously known as a ‘countermeasure’.
Molecule	The smallest division of a substance that can exist independently while retaining the properties of that substance.
Normal lifestyle	Situation where people can live and work in an area without the radiological emergency and its consequences being foremost in their minds.
Occupancy factor	Fraction of the time spent in a particular location, eg inside and outside buildings. Typically used in the estimation of’ normal living’ doses, ie taking into account normal day-to-day activities.
Personal protective equipment (PPE)	Equipment worn by a person at work to protect against one or more health or safety risks eg safety helmets, gloves, eye protection, high-visibility clothing, safety footwear and safety harnesses.
Photon	A quantum or packet of electromagnetic radiation (eg gamma rays or visible light) which may be considered a particle.
Radioactive decay	The process by which radionuclides undergo spontaneous nuclear change, thereby emitting ionising radiation
Radioactivity	The spontaneous emission of ionising radiation from a radionuclide as a result of atomic or nuclear changes. Measured in Becquerels, Bq.
Radiation emergency or incident	Any event, accidental or otherwise, which involves a release of radioactivity into the environment.
Radionuclide	A type of atomic nucleus which is unstable and which may undergo spontaneous decay to another atom by emission of ionising radiation, usually alpha, beta or gamma radiation.
Recovery phase	The time period during which activities focus on the restoration of normal lifestyles for all affected populations. There are no exact boundaries between the emergency phase and the recovery phase. However, within the handbook the recovery phase should be seen as starting after the incident has been contained.
Recovery strategy	A strategy which aims for a return to normal living. It covers all aspects of the long-term management of the contaminated area and the implementation of specific management options. The development of the strategy should involve all stakeholders.
Respiratory protection	Equipment designed to prevent or reduce the inhalation of radioactive material by individuals.
Resuspension	A renewed suspension of contaminated particles in the air. The subsequent inhalation of radioactivity is recognised as a potentially significant exposure pathway. Many factors influence resuspension, including climate, wind speed, time since deposition.
Short-lived radionuclides	Defined for the handbook as radionuclides with a radioactive half-life of less than 3 weeks.
Sievert	The SI unit of effective dose. Symbol: Sv (1 Sv = 1 J kg^{-1}). The effective dose is commonly expressed in millisieverts (mSv), ie one thousandth of one sievert, and microsieverts (μSv), ie one thousandth of a millisievert. The average annual radiation dose to the UK population is 2.7 mSv.

Term	Definition
Stakeholder	A person or group of persons with a direct or perceived interest, involvement, or investment in something
Stochastic health effect	A radiation induced health effect characterised by a severity which does not depend on dose and for which no lower threshold exists. The probability of such an effect being observed is proportional to the dose. An example of a stochastic effect is cancer.
Surfaces	Examples of surfaces considered in this handbook include: soil, vegetation and buildings. Management options usually target a specific surface. A surface can have a depth (eg soil) and this can influence the effectiveness of management options in removing contamination from the surface.
Worker	In the handbook, a worker is defined as an individual who is formally involved with the practical implementation of a recovery strategy. Exposures to workers must be controlled.

Appendix A Types of Hazards and Radionuclides

A1 General factors determining the hazard

Table A1 summarises factors that determine the health hazard to people in connection with exposure to ionising radiation. The most important property of radiation, with respect to the exposure of people, is its ability to penetrate matter that lies between the radioactive source and the person and also within the body. Table A2 describes the different types of radiation that may contribute to the exposure hazard for humans, focussing particularly on their penetrative characteristics. The radionuclides considered in the handbook have been grouped according to both their physical half-lives and whether their hazard arises predominantly from emissions of gamma rays, beta particles or alpha particles. The half-lives and the most important pathway of exposure based on the radiation emitted for the radionuclides considered are given in Table A3.

Table A1 General factors determining the hazard of exposure to radionuclides

Factor	Explanation
Half-life of radionuclide(s)	Radiation is emitted as the radionuclide decays. The activity of a source is reduced with time, as more and more of the radionuclide decays. The half-life of a radionuclide is the time taken for its activity to decay to half of its original value. Half-lives of different radionuclides can vary between a fraction of a second and millions of years. This means that the radiation from some radionuclides will rapidly reduce to virtually nothing, whereas radiation from others will persist over a very long time.
Type(s) of radiation emitted from the radionuclide(s)	Different radionuclides may emit different types of radiation. Of particular importance in this context are gamma, beta and alpha radiation (see Table A2). Each radionuclide emits radiation with characteristic energies. For a specific type of radiation, the penetration into human tissue increases with the energy. The radiation will, to a varying extent, be weakened by any material present between the radioactive source and the person (eg a wall, clothing and even air).
Locations of sources, humans and shielding elements	Hazards may be imposed on humans by internal radiation from radionuclides taken into the body (eg after inhalation or ingestion), and/or radiation from sources outside the body. Radionuclides can migrate in the environment (eg they may be removed from building surfaces by wind and rain and in some cases be resuspended in the air). This can add to the hazard from inhalation of radionuclides.

Table A2 Descriptions of the different types of radiation that may contribute to the exposure hazard for humans

Radiation type	Description
Alpha particles	An alpha particle consists of two protons and two neutrons (identical to a nucleus of helium) that is emitted by the nucleus of a radionuclide during alpha decay. Alpha particles have a very short range in human tissue. They are generally completely absorbed by a piece of paper or a few centimetres of air (Kaplan, 1979). The human body is protected by a layer of dead skin cells with a thickness of typically 50-80 µm (ICRP, 1992) and alpha particles are generally unable to penetrate this layer. Alpha particles thus only pose a hazard to humans if they are ingested, inhaled or taken in through a wound.
Beta particles	A beta particle consists of a fast moving electron or positron that is emitted by the nucleus of a radionuclide during beta decay. Beta particles can penetrate to significantly greater depth in human tissue than alpha particles. Many beta particles will have sufficient energy to penetrate through the dead skin layer, and can result in skin burns and skin cancer. However, beta particles emitted outside the body can in general not penetrate into the internal human organs. Beta particles can pose a hazard to internal human organs if they are emitted inside the body, eg after inhalation, ingestion or through a skin wound. High energy beta particles can have a range of up to a few metres in air. This means that beta particles emitted from contamination on surfaces in the indoor or outdoor environment can contribute to the hazard. A thin layer of clothing between the source and the skin surface can reduce skin penetration considerably. Bremsstrahlung is a secondary radiation which is produced as a reaction in shielding material by beta particles. The majority of Bremsstrahlung rays will have low energy (Gopala et al, 1986) and it is not considered further in the handbook.
Gamma rays	A gamma ray is a high energy photon without mass or charge, emitted from the nucleus of a radionuclide following radioactive decay. Gamma rays can penetrate through dense structures, including house walls and human bodies. This means that gamma-emitting radionuclides both outside as well as inside the human body can constitute a health hazard.

Table A3 Predominant hazard and half-life for each radionuclide considered in the handbook

	Internal[#]	External[†]			
Radionuclide*	**Alpha**	**Beta**	**Gamma**	**Half-life**	
^{60}Co	-	×	✓	Long	5.27 y
^{75}Se	-	-	✓	Long	119.8 d
^{90}Sr	-	✓	-	Long	29.12 y
^{95}Zr	-	×	✓	Long	63.98 d
^{95}Nb	-	×	✓	Long	66 h
^{99}Mo	-	s	✓	Short	39.28 d
^{103}Ru	-	×	✓	Long	39.28 d
^{106}Ru	-	s	✓	Long	368.2 d
^{131}I	-	×	✓	Short	8.04 d
^{132}Te	-	×	✓	Short	3.26 d
^{134}Cs	-	×	✓	Long	2.062 y
^{136}Cs	-	×	✓	Short	13.1 d
^{137}Cs	-	×	✓	Long	30 y
^{140}Ba	-	×	✓	Short	12.74 d
^{140}La	-	×	✓	Short	1.68 d
^{144}Ce	-	s	✓	Long	284.3 d
^{169}Yb	-	×	✓	Short	32.01 d
^{192}Ir	-	×	✓	Long	74.02 d
^{226}Ra	✓	×	g	Long	1.6 10^{3} y
^{235}U	✓	×	g	Long	7.04 10^{8} y
^{238}Pu	✓	-	g	Long	87.74 y
^{239}Pu	✓	-	g	Long	2.4 10^{4} y
^{241}Am	✓	-	g	Long	432.2 y

Key:

×: minor contribution to exposure. Can be ignored

s: doses to skin may need to be considered

g: minor contribution to exposure from gamma-ray emissions. Can be ignored compared to internal pathway. However, note that if resuspension is stopped through the use of tie-down a small external dose will be received.

Short: half-life < 3 weeks

Long: half-life > 3 weeks

*: The ingrowth of all significant radioactive daughters is taken into account

#: Internal doses from resuspension

†: Beta and gamma-ray emitters may also give rise to small resuspension doses

A2 Types of contaminant

Different types of radiation or nuclear emergencies lead to different types of contaminants released to the atmosphere. The Chernobyl accident, demonstrated that a wide range of radionuclides with different physical and chemical forms can be released from large nuclear power plant accidents (Andersson et al, 2002). For example, radioisotopes of the highly volatile element iodine would be likely to appear in three main physical/chemical forms: as highly reactive elemental iodine vapour; adsorbed on small ambient particles; or in organic gaseous compounds. Other radiologically important, relatively volatile elements (eg caesium and ruthenium) would be expected to evaporate during an accident involving high temperatures and form small condensation particles with a size in the range of 0.5-1 µm. Such small particles can travel far in the atmosphere before they are deposited on surfaces in an inhabited environment, since gravitational forces have little impact on them. Radionuclides of more refractory elements, such as strontium, zirconium and cerium, are associated with larger fragmentary particles, and thus are generally deposited at shorter distances. Releases at ground level, for example conventional explosions, may result in the generation of predominantly very large particles which would only remain airborne over rather shorter distances. This was demonstrated by the Thule accident in 1968 (Risø Research Establishment, 1970).

Due to gravity, dry deposition of large particles on horizontal surfaces would be more pronounced than that of small particles. This means that the distribution of small and large particles on the various surfaces in an inhabited area would differ. Although dry deposition can lead to high levels of contamination, it should be noted that particulate contaminants are very effectively washed out from the plume by precipitation. Therefore, areas where it rains during the passage of the contaminated plume typically receive much higher levels of contamination than areas where concentrations of radionuclides in air are similar but it does not rain.

It is often assumed that contamination is homogeneously distributed over a surface. However, various processes can lead to the formation of particularly highly radioactive particles, often termed hot particles. The presence of such particles in the environment can lead to very high local doses. If hot particles may have been deposited in the environment, the possibility of exposure from inhalation, ingestion and skin contamination should always be considered and the likelihood of deterministic effects to the respiratory tract, lower large intestine and the skin evaluated.

A3 General guidance on hazards and the use of shielding

This section provides some information on the behaviour of beta and gamma emitting radionuclides and whether shielding is likely to be useful in reducing doses. In particular, it provides generic guidance that can be used for radionuclides that are not considered in the handbook.

A3.1 Beta emitting radionuclides

Beta particles have a well defined range. For energies less than 2.5 MeV, the range, R, of a beta particle of energy E is given empirically by:

$$R = 412\ E^{1.265-0.0954\ln(E)}$$

where E is the maximum beta energy of the radionuclide (MeV) and R is expressed as a mass thickness in mg cm^{-2}. The mass thickness can be converted into a distance in any material (eg air or soil). To convert the range in mg cm^{-2} to a distance in a material (cm), the mass thickness is divided by the density of the material (mg cm^{-3}). For example the range of a beta emitting radionuclide with maximum energy of 1.0 MeV is 412 mg cm^{-2}. The density of air is about 1.3 mg cm^{-3}, which gives a distance range in air of about 3.2 m.

Figure A1 shows the range of beta particles in air as a function of beta energy. This can be used to scope whether beta contamination is likely to be of concern when the location of people relative to the contamination is known.

The effectiveness of materials as a shield against beta emissions depends on the density of the material and its thickness, as described above. A useful tool to estimate the thickness of material needed to give a certain level of shielding as a function of the maximum beta energy of the radionuclide is available in the form of a nomogram (Longworth, 1998). The nomogram is shown in Figure A2. To use the nomogram, for example, to find the absorber thickness required to reduce the dose-rate from a beta emitting radionuclide with a maximum energy 1.0 MeV by 50%, draw a straight line connecting 1.0 MeV through 50% absorption. This intersects the absorber thickness line at about 45 mg cm^{-2}. This would be about a thickness of 20 mm of concrete assuming a density of concrete of 2400 kg m^{-3}. Densities of materials that could be considered as shielding materials in inhabited areas are given in Table A4.

Table A4 Densities of materials that could be used as shielding media

Material	Density, mg cm^{-2}	Relevant option data sheets
Soil	1500	Covering outdoor areas with clean soil
Water	1000	Tie-down (outdoor)
Asphalt	1400	Remove and replace roads etc
Concrete	2400	Remove and replace roads etc
Sand	1600	Tie-down (outdoor)
Polystyrene foam	125	Foam (outdoor)
Rubber	910	Peelable coatings (outdoor)
Bitumen	1000	Tie-down (outdoor)
Perspex	1190	Shielding of precious objects
Paper	1000	Covering indoor surfaces
Paint	1000	Covering indoor surfaces

The ranges of beta particles in some materials that are likely to be used as shielding materials in inhabited areas is also given as a function of beta energy in Figure A3. The value of the range is effectively the thickness of the material needed to stop a beta particle.

As discussed in Section A1 the use of a shielding material on top of the beta contamination increases the intensity of the Bremsstrahlung radiation. The increase is dependent on the shielding material used and is not important for the materials likely to be used. However, if lead or other metals with high atomic numbers and densities are used, Bremsstrahlung doses should be considered, particularly for high energy beta emitters such as ^{90}Sr.

For information, the maximum beta energies for the radionuclides considered in the handbook are given in Table A5. Maximum beta energies were taken from Delacroix et al (2002), unless otherwise indicated.

Table A5 Maximum beta energies for radionuclides considered in handbook

Radionuclide*	Maximum energy#, MeV
^{60}Co	1.5
^{75}Se	-
^{90}Sr+	2.3
^{95}Zr+	0.4
^{95}Nb	0.16
^{99}Mo+	1.2
^{103}Ru+	0.72
^{106}Ru+	3.5
^{132}Te+	2.1
^{131}I	0.61
^{134}Cs	0.66
^{136}Cs$^{\sim}$	0.66
^{137}Cs	1.2
^{140}Ba+	2.2
^{140}La	2.2
^{144}Ce+	3.0
^{169}Yb	-
^{192}Ir	0.67
^{226}Ra+	3.3
^{235}U+#	0.3
^{238}Pu+	-
^{239}Pu+	-
^{241}Am+	-

* Radionuclides for which the ingrowth of daughter radionuclides following deposition of the parent radionuclide was considered are indicated with the '+' sign.

Maximum beta energies based on data taken from ICRP (1983). As ICRP (1983) only gives the average energy for each beta particle emission, the average energies have been multiplied by three to give approximate maximum energies, consistent with those in Delacroix et al (2002).

Figure A1 Range of beta particles in air as a function of beta energy

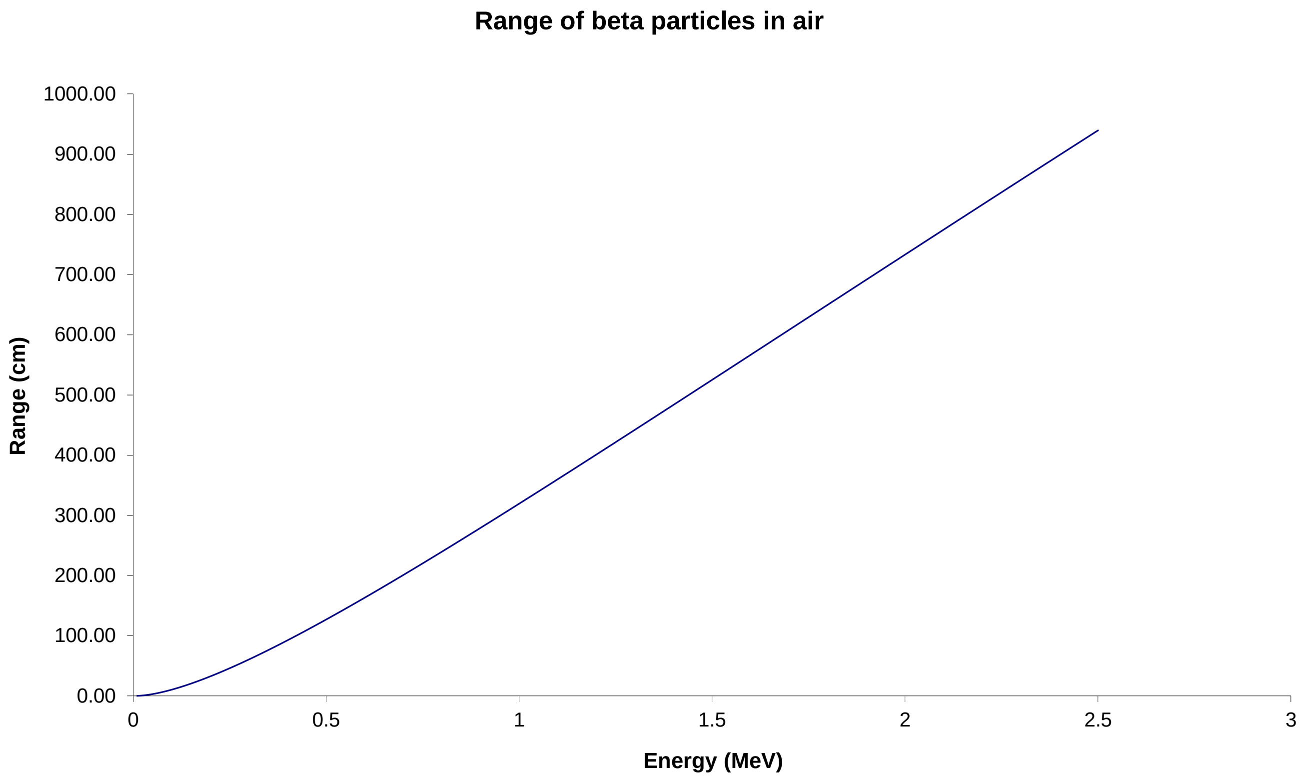


Figure A2 Range nomogram for ascertaining thickness of material needed to reduce beta dose rates as a function of beta energy (taken from Longworth, 1998)

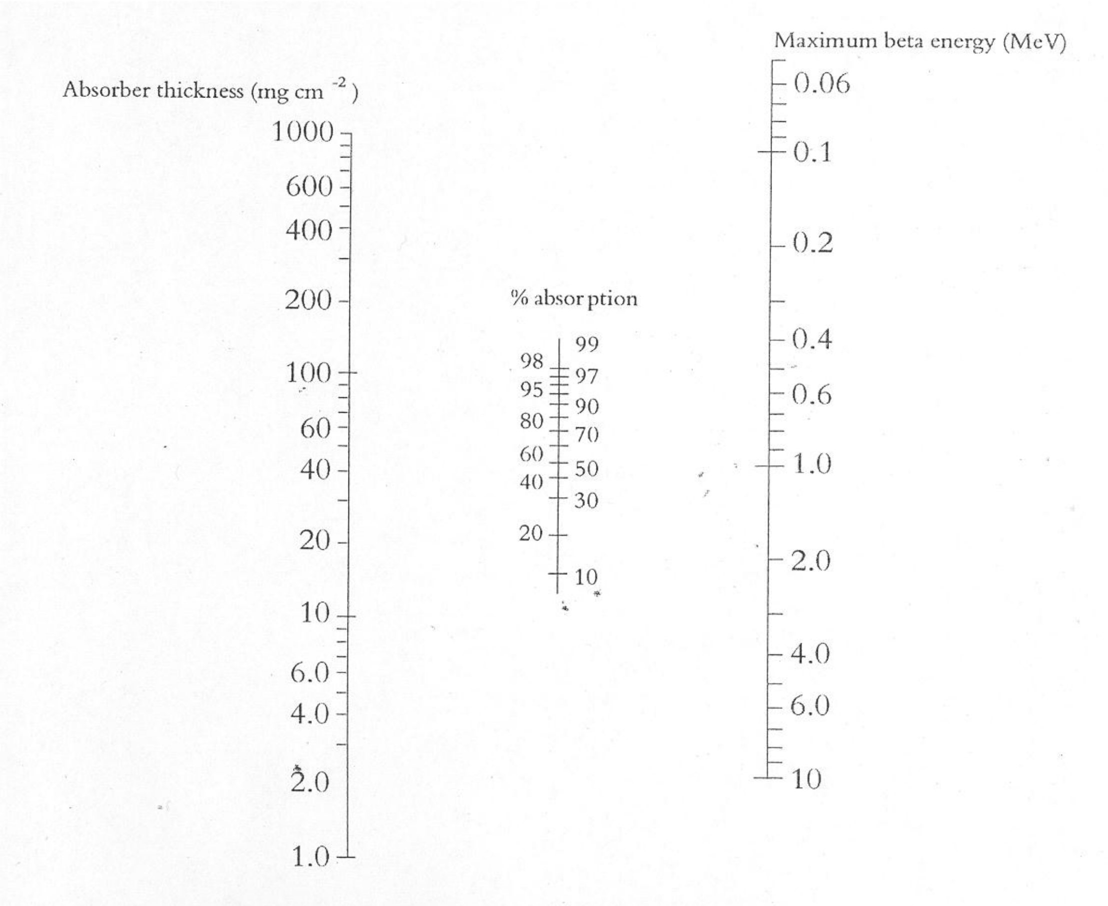
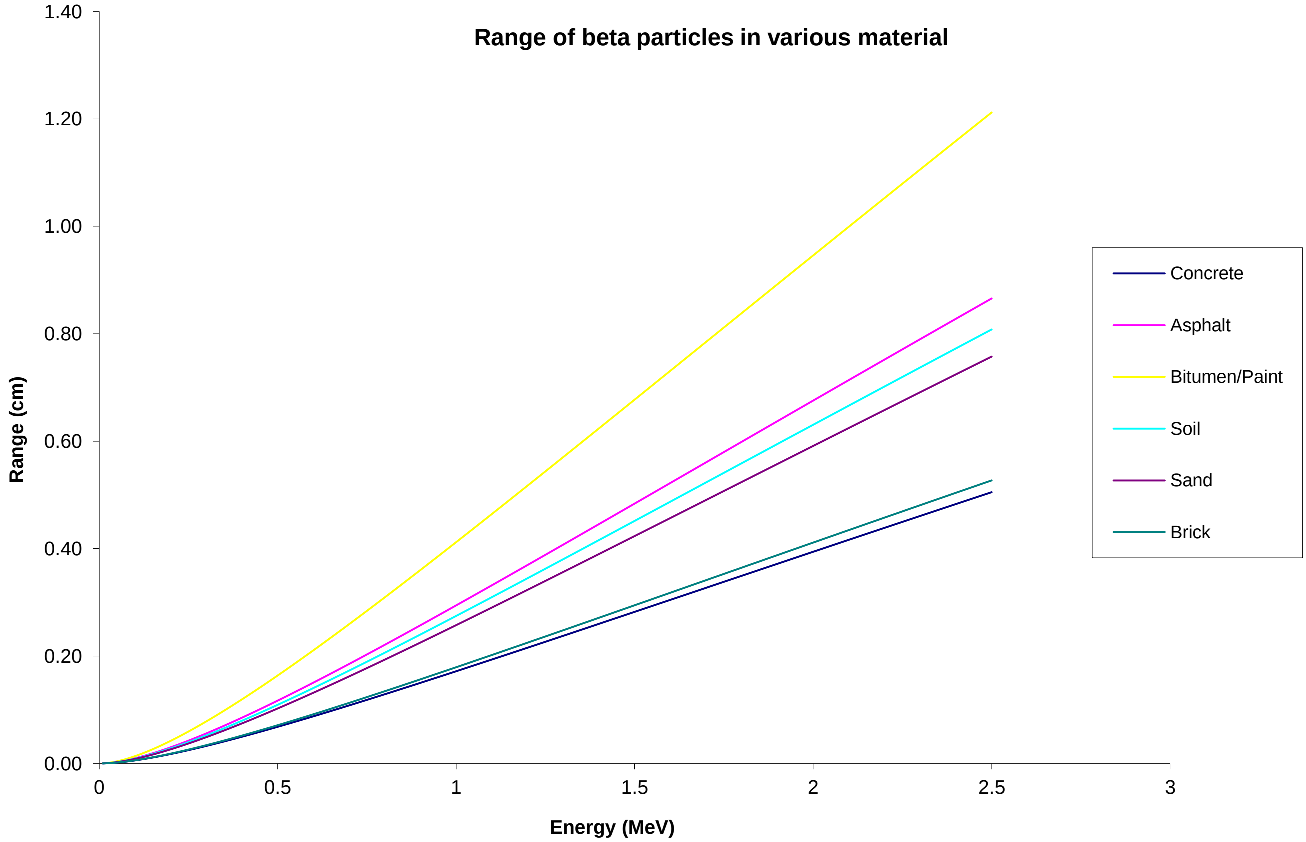


Figure A3 Range of beta particles in materials likely to be used for shielding in inhabited areas as a function of maximum beta energy



A4 Gamma emitting radionuclides

Gamma rays are attenuated by the material they pass through but they do not have a defined range.

The attenuation of a narrow beam of gamma or X-rays is given by:

$$I = I_0 \, e^{-\mu t}$$

where I is the fluence rate after passing through a thickness t (cm), I_0 is the initial fluence rate and μ is the linear attenuation coefficient of the attenuating medium (cm^{-1}). In the case of broad or uncollimated beams, build-up can occur due to scattered photons still reaching the target which causes the attenuation to be less rapid than indicated in the above equation.

Materials with high atomic number and high density, such as lead, provide the best shields for gamma and X-rays, although these are unlikely to be practicable for shielding within contaminated inhabited areas.

The greater the density of a material the smaller the thickness needed to decrease the gamma ray intensity to a specified extent. This means that the mass of materials needed to decrease the intensity of the radiation by a certain amount is very nearly the same irrespective of the material. Two quantities are normally used to specify the thickness: the half value thickness and the tenth value thickness which are the thicknesses of a material required to reduce the gamma ray intensity by a factor of two or by a factor of ten, expressed by:

$$\text{Half value thickness (cm)} = \frac{0.693}{\mu}$$

$$\text{Tenth value thickness (cm)} = \frac{2.3}{\mu}$$

where μ is the linear attenuation coefficient in the shielding material for the gamma energy of concern (cm^{-1}).

Table A6 gives linear attenuation coefficients in air as a function of gamma energy. Linear attenuation coefficients for other materials can be estimated using the assumption that the linear attenuation coefficient is approximately proportional to the density of the material. This assumption holds for gamma energies in the range of about 0.05 - 5.0 MeV for most of the materials that are considered as shielding materials in Section A3. For materials, such as lead, that have a high atomic number, this approach would not be appropriate. However, linear attenuation coefficients are readily available for lead and are given in Table A7 for a range of gamma energies (Kaplan, 1979).

For other shielding materials of relevance for use in recovery options in inhabited areas, the linear attenuation coefficient for the material of interest can be estimated in the following way:

$$\mu_{material} = \mu_{air} \frac{\rho_{material}}{\rho_{air}}$$

where μ is the linear attenuation coefficient in material (cm^{-1}), μ_{air} is the linear attenuation coefficient in air (cm^{-1}) $\rho_{material}$ is the density of material ($kg\ m^{-3}$) and ρ_{air} is the density of air ($1.293\ kg\ m^{-3}$).

For example, if the radionuclide in the contamination has a gamma energy of 1MeV and the material to be used is soil (1500 $kg\ m^{-3}$) the linear attenuation coefficient for soil can be calculated to be

$$\mu_{soil} = 8.23 \cdot 10^{-5}\ cm^{-1}\ \frac{1500\ kg\ m^{-3}}{1.293\ kg\ m^{-3}} = 0.095\ cm^{-1}$$

Assuming a thickness of soil of 10 cm is used, the intensity of gamma irradiation with soil shielding is 0.39 I_0 where I_0 is the intensity of gamma irradiation with no shielding. This means that 10 cm of soil reduce the intensity of the gamma irradiation from the radionuclide to about 40% of that with no shielding in place.

The half value thickness for the radionuclide can be estimated to be about 7 cm of soil, ie a thickness of 7 cm reduces the intensity by a half. The tenth value thickness for the radionuclide can be estimated to be about 24 cm, ie a thickness of 24 cm reduces the intensity to a tenth.

Table A6 Linear attenuation coefficients for gamma rays in air

Gamma energy (MeV)	Linear attenuation coefficient (cm^{-1}) *
0.1	$1.99\ 10^{-4}$
0.2	$1.60\ 10^{-4}$
0.3	$1.38\ 10^{-4}$
0.5	$1.13\ 10^{-4}$
0.6	$1.04\ 10^{-4}$
0.8	$9.15\ 10^{-5}$
1.0	$8.23\ 10^{-5}$
2.0	$5.75\ 10^{-5}$
3.0	$4.63\ 10^{-5}$
5.0	$3.56\ 10^{-5}$
10.0	$2.64\ 10^{-5}$

* The attenuation coefficients are calculated assuming that air consists of 78% nitrogen, 21% oxygen and 1% argon and has a density of 1.293 kg m^{-3}.

Table A7 Linear attenuation coefficients for lead

Gamma energy (MeV)	Linear attenuation coefficient (cm^{-1}) *
0.1	60
0.2	10
0.3	3.8
0.5	1.6
0.6	1.3
0.8	0.95
1.0	0.77
2.0	0.51
3.0	0.46
5.0	0.49
10.0	0.57

* Calculated assuming a density of lead of $1.134\ 10^{4}$ kg m^{-3}

A5 References

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Appendix B Estimating Doses in the Affected Area

Doses to people in inhabited areas can come from a variety of different exposure pathways. For a given amount of radioactive material deposited, the resultant dose to an individual can vary widely, depending on the radionuclides involved, the spread of contamination between different surfaces and the time spent by individuals in different locations relative to the contamination.

An individual living in a contaminated environment is exposed to a combination of dose rates arising from the differing levels of contamination on different surfaces and objects in a variety of locations (eg houses, work places, recreational areas). The dose rate at a single location also varies with time as radionuclides decay or are removed by rain and other weathering processes. The cumulative dose experienced by an individual is therefore determined by the time spent at each location and the dose rate at that location.

This section provides some guidance on robust methods to calculate of doses in an inhabited area from contamination levels on surfaces or from resuspension. It should be stressed that these methods are in general basic and only intended to give the user a general idea of the levels of dose that would be received. When selecting recovery management options, it is recommended that more detailed and complex models are used, such as the model implemented in the CONDO decision support systems or those identified in Charnock et al (2003). Such a model can take account of the characteristics of each of the areas being considered (eg the types of building in the area, the level of urbanisation, the amount of the area used as gardens, parks) and the partitioning of contamination within this environment as a function of time. The following information is given in this appendix to aid the calculation of doses to members of the public in inhabited areas:

- indicative outdoor effective dose rates and doses from external irradiation from gamma emitting material deposited on the ground (see Section B1, Table B1 and Table B2)
- location and occupancy factors to estimate doses to people under normal living conditions (see Section B2 and Table B3)
- indicative effective dose rates and doses deposited on the ground for ^{90}Sr (see Section B3)
- outdoor inhalation doses from resuspended material per unit activity deposited on the ground as a function of time (see Section B4 and Table B4)

B1 External gamma doses from contamination on outdoor surfaces in the environment

Table B1 and Table B2 provide dose rates and doses that would be expected over different periods in an inhabited area once levels of deposition on grass and underlying soil, away from buildings, are available. Generic soil with the density of 1.5 g cm^{-3} was assumed in the calculations, with a composition by mass of O 60%, Si 25%, C 7%, H 4%, Al 3% and Fe 1%. Table B1 provides dose rates in Sv h^{-1} per 1 Bq m^{-2} deposited on the ground from external gamma from radioactive material deposited outdoors to an individual outdoors for different times after the event. The dose rates are calculated 1 m above an infinite soil surface (or grass with underlying soil), taking into account the migration of radioactive contamination down through the soil with time. Table B2 provides doses per unit activity deposition on the ground from external gamma from radioactive material deposited outdoors to an individual outdoors for different times after the event. The values in the tables give conservative estimates of dose rates and doses for the following reasons:

- it is assumed that all the contamination is initially located on the surface of the soil. In reality, not all of the deposited material will remain on the surface; processes such as bioturbation and water washing contamination directly into the soil during rainfall provide some shielding from the contamination. Migration of contamination down through the soil in the longer term is taken into account
- doses from contamination on the ground come from limited areas since an inhabited area usually has many shielding elements (eg buildings). Andersson (1996) calculated that about one-third of the dose rate would, in a large open area, come from contamination that is more than 16 m away with about one-eighth of the dose rate coming from contamination more than 64 m away

No account has been taken of the shielding provided by buildings for a person outside and this may lead to dose rates outdoors being overestimated. Reductions in dose rate relative to dose rates in a large open area have been estimated for a number of different types of inhabited area (eg with lots of trees and vegetation compared to a heavily urbanised area (Meckbach et al, 1998b; Brown and Jones 1993). For most situations it is appropriate to assume that shielding from buildings does not reduce dose rates outdoors significantly and it can be ignored for scoping calculations of external doses. More complex models used to assess doses within specific areas can take into account any shielding provided by buildings.

Table B1 Effective external gamma dose rates after an instantaneous deposit of 1 Bq m^{-2} on the ground (Health Protection Agency, 2005)

	Dose rate (Sv h^{-1})[a]											
Radionuclide	**0**	**6 hours**	**12 hours**	**1 day**	**2 days**	**7 days**	**30 days**	**1 year**	**2 years**	**5 years**	**10 years**	**50 years**
^{60}Co	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.6\ 10^{-12}$	$5.5\ 10^{-12}$	$4.4\ 10^{-12}$	$3.5\ 10^{-12}$	$1.8\ 10^{-12}$	$6.9\ 10^{-13}$	$9.9\ 10^{-16}$
^{75}Se	$8.9\ 10^{-13}$	$8.9\ 10^{-13}$	$8.9\ 10^{-13}$	$8.8\ 10^{-13}$	$8.8\ 10^{-13}$	$8.5\ 10^{-13}$	$7.4\ 10^{-13}$	$9.5\ 10^{-14}$	$1.0\ 10^{-14}$	$1.3\ 10^{-17}$	$7.4\ 10^{-22}$	$2.3\ 10^{-26}$
^{95}Zr[b]	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.8\ 10^{-12}$	$1.8\ 10^{-12}$	$1.9\ 10^{-12}$	$9.4\ 10^{-14}$	$1.6\ 10^{-15}$	$4.6\ 10^{-20}$	$1.6\ 10^{-23}$	0
^{95}Nb	$1.8\ 10^{-12}$	$1.8\ 10^{-12}$	$1.8\ 10^{-12}$	$1.7\ 10^{-12}$	$1.7\ 10^{-12}$	$1.6\ 10^{-12}$	$9.7\ 10^{-13}$	$1.2\ 10^{-15}$	$8.7\ 10^{-19}$	$7.5\ 10^{-23}$	$1.3\ 10^{-26}$	0
^{99}Mo[b]	$3.5\ 10^{-13}$	$3.3\ 10^{-13}$	$3.1\ 10^{-13}$	$2.7\ 10^{-13}$	$2.1\ 10^{-13}$	$5.9\ 10^{-14}$	$1.8\ 10^{-16}$	0	0	0	0	0
^{103}Ru[b]	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$1.1\ 10^{-12}$	$9.8\ 10^{-13}$	$6.5\ 10^{-13}$	$1.6\ 10^{-15}$	$2.3\ 10^{-18}$	$2.9\ 10^{-22}$	$6.6\ 10^{-26}$	0
^{106}Ru[b]	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.8\ 10^{-13}$	$4.7\ 10^{-13}$	$4.5\ 10^{-13}$	$2.2\ 10^{-13}$	$9.7\ 10^{-14}$	$9.4\ 10^{-15}$	$2.2\ 10^{-16}$	$2.8\ 10^{-24}$
^{132}Te[b]	$5.0\ 10^{-13}$	$4.7\ 10^{-12}$	$5.2\ 10^{-12}$	$4.8\ 10^{-12}$	$3.9\ 10^{-12}$	$1.3\ 10^{-12}$	$9.9\ 10^{-15}$	0	0	0	0	0
^{131}I[b]	$8.9\ 10^{-13}$	$8.8\ 10^{-13}$	$8.6\ 10^{-13}$	$8.2\ 10^{-13}$	$7.5\ 10^{-13}$	$4.9\ 10^{-13}$	$6.7\ 10^{-14}$	$1.5\ 10^{-22}$	$1.1\ 10^{-25}$	0	0	0
^{134}Cs	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.6\ 10^{-12}$	$3.5\ 10^{-12}$	$2.3\ 10^{-12}$	$1.5\ 10^{-12}$	$4.1\ 10^{-13}$	$5.5\ 10^{-14}$	$2.3\ 10^{-20}$
^{136}Cs	$5.0\ 10^{-12}$	$4.9\ 10^{-12}$	$4.8\ 10^{-12}$	$4.7\ 10^{-12}$	$4.5\ 10^{-12}$	$3.4\ 10^{-12}$	$1.0\ 10^{-12}$	$1.1\ 10^{-19}$	$8.0\ 10^{-23}$	0	0	0
^{137}Cs[b]	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.4\ 10^{-12}$	$1.2\ 10^{-12}$	$1.1\ 10^{-12}$	$7.5\ 10^{-13}$	$4.8\ 10^{-13}$	$4.4\ 10^{-14}$
^{140}Ba[b]	$4.2\ 10^{-13}$	$9.2\ 10^{-13}$	$1.4\ 10^{-12}$	$2.1\ 10^{-12}$	$3.1\ 10^{-12}$	$4.0\ 10^{-12}$	$1.2\ 10^{-12}$	$7.1\ 10^{-20}$	$5.3\ 10^{-23}$	0	0	0
^{144}Ce[b]	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.1\ 10^{-13}$	$1.00\ 10^{-13}$	$3.9\ 10^{-14}$	$1.4\ 10^{-14}$	$6.9\ 10^{-16}$	$5.3\ 10^{-18}$	$1.9\ 10^{-25}$
^{169}Yb	$6.0\ 10^{-13}$	$6.0\ 10^{-13}$	$6.0\ 10^{-13}$	$5.9\ 10^{-13}$	$5.8\ 10^{-13}$	$5.2\ 10^{-13}$	$3.1\ 10^{-13}$	$1.9\ 10^{-16}$	$7.8\ 10^{-20}$	$1.1\ 10^{-22}$	$1.5\ 10^{-26}$	0
^{192}Ir	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.9\ 10^{-12}$	$1.8\ 10^{-12}$	$1.4\ 10^{-12}$	$5.6\ 10^{-14}$	$1.7\ 10^{-15}$	$6.3\ 10^{-20}$	$2.2\ 10^{-23}$	0
^{226}Ra[b]	$1.5\ 10^{-14}$	$1.7\ 10^{-13}$	$3.3\ 10^{-13}$	$6.4\ 10^{-13}$	$1.2\ 10^{-12}$	$2.8\ 10^{-12}$	$3.9\ 10^{-12}$	$3.5\ 10^{-12}$	$3.2\ 10^{-12}$	$2.4\ 10^{-12}$	$1.8\ 10^{-12}$	$4.6\ 10^{-13}$
^{235}U[b]	$3.4\ 10^{-13}$	$3.5\ 10^{-13}$	$3.5\ 10^{-13}$	$3.5\ 10^{-13}$	$3.6\ 10^{-13}$	$3.6\ 10^{-13}$	$3.6\ 10^{-13}$	$3.2\ 10^{-13}$	$2.8\ 10^{-13}$	$2.1\ 10^{-13}$	$1.4\ 10^{-13}$	$2.4\ 10^{-14}$
^{238}Pu	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$2.1\ 10^{-16}$	$1.7\ 10^{-16}$	$1.3\ 10^{-16}$	$6.7\ 10^{-17}$	$2.4\ 10^{-17}$	$7.2\ 10^{-19}$
^{239}Pu	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.8\ 10^{-16}$	$1.7\ 10^{-16}$	$1.5\ 10^{-16}$	$1.2\ 10^{-16}$	$8.0\ 10^{-17}$	$4.6\ 10^{-17}$	$7.2\ 10^{-18}$
^{241}Am	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.7\ 10^{-14}$	$3.6\ 10^{-14}$	$3.6\ 10^{-14}$	$3.1\ 10^{-14}$	$3.0\ 10^{-14}$	$1.7\ 10^{-14}$	$9.3\ 10^{-15}$	$8.9\ 10^{-16}$

a) Generic soil of 1.5 g cm^{-3} assumed in calculation, with composition by weight O 0.6, Si 0.25, C 0.07, H 0.04, Al 0.03 Fe 0.01.

b) The doses from the ingrowth of daughter radionuclides are included with the parent, ie ^{95}Zr includes ^{95m}Nb, ^{95}Nb; ^{99}Mo includes ^{99m}Tc, ^{99}Tc; ^{103}Ru includes ^{103m}Rh; ^{106}Ru includes ^{106}Rh; ^{132}Te includes ^{132}I; ^{131}I includes ^{131m}Xe; ^{135}I includes ^{135m}Xe, ^{135}Xe; ^{137}Cs includes ^{137m}Ba; ^{140}Ba includes ^{140}La; ^{144}Ce includes ^{144}Pr; ^{226}Ra includes ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po; ^{235}U includes ^{231}Th.

Table B2 Integrated effective external gamma dose after an instantaneous deposit of 1 Bq m^{-2} on the ground (Health Protection Agency, 2005)

	Dose (Sv)[a]											
Radionuclide	**0**	**6 hours**	**12 hours**	**1 day**	**2 days**	**7 days**	**30 days**	**1 year**	**2 years**	**5 years**	**10 years**	**50 years**
^{60}Co	0	3.4 10^{-11}	6.8 10^{-11}	1.4 10^{-10}	2.7 10^{-10}	9.5 10^{-10}	4.0 10^{-9}	4.4 10^{-8}	7.8 10^{-8}	1.5 10^{-7}	2.0 10^{-7}	2.3 10^{-7}
^{75}Se	0	5.3 10^{-12}	1.1 10^{-11}	2.1 10^{-11}	4.2 10^{-11}	1.5 10^{-10}	5.8 10^{-10}	3.1 10^{-9}	4.4 10^{-9}	3.5 10^{-9}	3.5 10^{-9}	3.5 10^{-9}
^{95}Zr[b]	0	1.0 10^{-11}	2.1 10^{-11}	4.1 10^{-11}	8.3 10^{-11}	3.0 10^{-10}	1.3 10^{-9}	7.3 10^{-9}	7.5 10^{-9}	7.5 10^{-9}	7.5 10^{-9}	7.5 10^{-9}
^{95}Nb	0	1.1 10^{-11}	2.1 10^{-11}	4.2 10^{-11}	8.4 10^{-11}	2.8 10^{-10}	9.6 10^{-10}	2.1 10^{-9}	2.1 10^{-9}	2.1 10^{-9}	2.1 10^{-9}	2.1 10^{-9}
^{99}Mo[b]	0	2.0 10^{-12}	3.9 10^{-12}	7.3 10^{-12}	1.3 10^{-11}	2.7 10^{-11}	3.3 10^{-11}	3.3 10^{-11}	3.3 10^{-11}	3.3 10^{-11}	3.3 10^{-11}	3.3 10^{-11}
^{103}Ru[b]	0	6.7 10^{-12}	1.3 10^{-11}	2.7 10^{-11}	5.3 10^{-11}	1.8 10^{-10}	6.2 10^{-10}	1.5 10^{-9}	1.5 10^{-9}	1.5 10^{-9}	1.5 10^{-9}	1.5 10^{-9}
^{106}Ru[b]	0	2.9 10^{-12}	5.8 10^{-12}	1.2 10^{-11}	2.3 10^{-11}	8.0 10^{-11}	3.4 10^{-10}	2.9 10^{-9}	4.2 10^{-9}	5.2 10^{-9}	5.3 10^{-9}	5.3 10^{-9}
^{132}Te[b]	0	1.9 10^{-11}	5.0 10^{-11}	1.1 10^{-10}	2.1 10^{-10}	5.0 10^{-10}	6.5 10^{-10}	6. 10^{-10}	6.5 10^{-10}	6.5 10^{-10}	6.5 10^{-10}	6.5 10^{-10}
^{131}I[b]	0	5.3 10^{-12}	1.1 10^{-11}	2.1 10^{-11}	3.9 10^{-11}	1.1 10^{-10}	2.3 10^{-10}	2.5 10^{-10}	2.5 10^{-10}	2.5 10^{-10}	2.5 10^{-10}	2.5 10^{-10}
^{134}Cs	0	2.2 10^{-11}	4.3 10^{-11}	8.7 10^{-11}	1.7 10^{-10}	6.1 10^{-10}	2.6 10^{-9}	2.6 10^{-8}	4.2 10^{-8}	6.4 10^{-8}	7.1 10^{-8}	7.2 10^{-8}
^{136}Cs	0	2.9 10^{-11}	5.9 10^{-11}	1.2 10^{-10}	2.3 10^{-10}	7.0 10^{-10}	1.8 10^{-9}	2.2 10^{-9}	2.2 10^{-9}	2.2 10^{-9}	2.2 10^{-9}	2.2 10^{-9}
^{137}Cs[b]	0	8.4 10^{-12}	1.7 10^{-11}	3.3 10^{-11}	6.7 10^{-11}	2.3 10^{-10}	9.9 10^{-10}	1.1 10^{-8}	2.1 10^{-8}	4.5 10^{-8}	7.1 10^{-8}	1.3 10^{-7}
^{140}Ba[b]	0	4.1 10^{-12}	1.1 10^{-11}	3.2 10^{-11}	9.5 10^{-11}	5.6 10^{-10}	1.9 10^{-9}	2.5 10^{-9}	2.5 10^{-9}	2.5 10^{-9}	2.5 10^{-9}	2.5 10^{-9}
^{144}Ce[b]	0	6.5 10^{-13}	1.3 10^{-12}	2.6 10^{-12}	5.2 10^{-12}	1.8 10^{-11}	7.5 10^{-11}	6.0 10^{-10}	8.1 10^{-10}	9.2 10^{-10}	9.3 10^{-10}	9.3 10^{-10}
^{169}Yb	0	3.6 10^{-12}	7.2 10^{-12}	1.4 10^{-11}	2.8 10^{-11}	9.4 10^{-11}	3.2 10^{-10}	6.6 10^{-10}	6.6 10^{-10}	6.6 10^{-10}	6.6 10^{-10}	6.6 10^{-10}
^{192}Ir	0	1.2 10^{-11}	2.3 10^{-11}	4.6 10^{-11}	9.2 10^{-11}	3.1 10^{-10}	1.2 10^{-9}	4.6 10^{-9}	4.8 10^{-9}	4.8 10^{-9}	4.8 10^{-9}	4.8 10^{-9}
^{226}Ra[b]	0	5.1 10^{-13}	2.0 10^{-12}	7.8 10^{-12}	3.0 10^{-11}	2.8 10^{-10}	2.3 10^{-9}	3.2 10^{-8}	6.1 10^{-8}	1.3 10^{-7}	2.2 10^{-7}	5.4 10^{-7}
^{235}U[b]	0	2.1 10^{-12}	4.1 10^{-12}	8.3 10^{-12}	1.7 10^{-11}	6.0 10^{-11}	2.6 10^{-10}	3.0 10^{-9}	5.6 10^{-9}	1.2 10^{-8}	1.9 10^{-8}	4.1 10^{-8}
^{238}Pu	0	1.3 10^{-15}	2.6 10^{-15}	5.1 10^{-15}	1.0 10^{-14}	3.6 10^{-14}	1.5 10^{-13}	1.7 10^{-12}	3.0 10^{-12}	5.5 10^{-12}	7.3 10^{-12}	8.8 10^{-12}
^{239}Pu	0	1.1 10^{-15}	2.1 10^{-15}	4.2 10^{-15}	8.4 10^{-15}	2.9 10^{-14}	1.3 10^{-13}	1.4 10^{-12}	2.6 10^{-12}	5.2 10^{-12}	7.8 10^{-12}	1.4 10^{-11}
^{241}Am	0	2.2 10^{-13}	4.4 10^{-13}	8.8 10^{-13}	1.8 10^{-12}	6.1 10^{-12}	2.6 10^{-11}	2.9 10^{-10}	5.4 10^{-10}	1.1 10^{-9}	1.6 10^{-9}	2.7 10^{-9}

a) Generic soil of 1.5 g cm^{-3} assumed in calculation, with composition by weight O 0.6, Si 0.25, C 0.07, H 0.04, Al 0.03 Fe 0.01.

b) The doses from the ingrowth of daughter radionuclides are included with the parent, ie ^{95}Zr includes ^{95m}Nb, ^{95}Nb; ^{99}Mo includes ^{99m}Tc, ^{99}Tc; ^{103}Ru includes ^{103m}Rh; ^{106}Ru includes ^{106}Rh; ^{132}Te includes ^{132}I; ^{131}I includes ^{131m}Xe; ^{135}I includes ^{135m}Xe, ^{135}Xe; ^{137}Cs includes ^{137m}Ba; ^{140}Ba includes ^{140}La; ^{144}Ce includes ^{144}Pr; ^{226}Ra includes ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po; ^{235}U includes ^{231}Th.

B2 Location and occupancy factors to estimate doses to people indoors from deposition outdoors

People typically tend to stay indoors for about 80% to 95% of the time (Andersson, 1996; Jenkins et al, 1992; Kousa et al, 2002; Long et al, 2001). During this time, they are shielded against radiation from outdoor contamination. The extent of this shielding depends on the characteristics of the specific buildings. The values in Table B1 and Table B2 therefore need to be modified using a location factor, which takes into account the shielding provided by the building in question.

Table B3 shows typical location factors for areas with buildings with different characteristics, ranging from thin wooden walls to thick brick and concrete walls (Andersson and Roed, 2005). The location factors are given for ^{137}Cs (representative of medium-high energy gamma emitters) shortly after deposition. These location factors can be used as default values for all the radionuclides considered in the handbook. It should be noted, however, that the shielding offered by medium and high shielding buildings could be about twice as large for gamma-emitting radionuclides with energies around 300 keV compared to those with energies around 3 MeV (Meckbach et al, 1988a). The location factor changes with time, since the natural removal and migration processes of contamination on different surfaces are different. However, for areas with relatively large unpaved ground areas, such as a garden, changes to the location factors over a period of 10 years are expected to be limited (within about 50%) and can be ignored for the purposes of estimating doses. For urban centres with little or no unpaved ground, long-term doses estimated using time-invariable location factors in Table B3 are likely to be conservative. The presence of airborne contaminants inside buildings leads to deposition on interior surfaces of the building. These deposits will give rise to a dose contribution to persons staying in the buildings. The location factors given in Table B3 take into account that some of the dose received come from contamination that was deposited indoors and that this dose is not affected substantially by the shielding offered by building walls.

Table B3 Location factors for ^{137}Cs (662 keV) for buildings with different shielding properties

Area type	Location factor estimate
Low shielding building	0.62
Medium shielding building	0.14
High shielding building	0.03

Using the values given in Table B2 and Table B3, a simple estimate of external gamma dose from material deposited outdoors can be made using the :

$$D_{ext.,gamma} = Dep \times Ext_{outdoors}\left(F_{outdoors} + LF \times F_{indoors}\right)$$

where $D_{ext,\,gamma}$ is the external gamma dose (Sv), Dep is the deposition on ground (Bq m^{-2}) $Ext_{outdoors}$ is the external gamma dose outdoors per unit deposition (Sv m^2 Bq^{-1}), $F_{outdoors}$ and $F_{indoors}$ are the fractions of time spent outdoors and indoors respectively and LF is the location factor.

B3 External beta doses from contamination on outdoor or indoor surfaces

Beta particles have a short range in any material, including air. Therefore beta radiation from contaminated surfaces in the environment is only likely to be significant if the distance between the exposed person and the source is of a few metres at most, the energy of the emitted beta particles is high and there is virtually no shielding material between the person and the source: even thin cotton clothing protects well against most types of beta radiation (ICRU, 1997). A highly conservative estimate of the dose rate to skin from the high energy beta particles emitted from a uniform ^{90}Sr contamination on a ground surface would be of the order of 4 10^{-11} Sv h^{-1} per Bq^{-1} m^2 (Eckerman and Ryman, 1993). The effective dose would typically be about 2 orders of magnitude lower (4 10^{-13} Sv h^{-1} per Bq^{-1} m^2). Doses from external exposures to beta radiation are likely to be of low significance, particularly if radionuclides emitting gamma rays are also present. The estimates given above are based on contamination lying on the surface of the ground. The shielding effect of soil is so great that the dose rate to the skin would be about 3 orders of magnitude lower if the contamination was 1 cm under the surface, as it would be expected to be shortly after an airborne contamination, particularly if it occurred in rain. Contamination on impermeable surfaces, such as asphalted playgrounds may, however, give rise to doses from external exposure to beta radiation over longer periods of time as contamination does not penetrate into the surface and natural weathering is relatively slower. However, most of the contamination on these types of asphalt surfaces is typically gone within a year (Andersson and Roed, 2005).

Migration of contaminants into indoor surfaces is likely to be less significant than on outdoor surfaces. People may be in close contact with the radioactivity when they are sitting or lying on contaminated surfaces. In such cases, doses from beta radiation can be compared with those from the same activity deposited on skin/clothing on the body. As even thin fabric offers some protection against beta radiation, the most critical situations would be those where unshielded skin comes into direct contact with a contaminated surface; for example if a pillowcase is contaminated, the face may be in direct contact with the surface for a number of hours. If ordinary machine washing of pillowcases is efficient in removing the contaminants, these doses are likely to be limited to a short period of time after the contamination took place (Andersson et al, 2002). However, based on current knowledge, it cannot be ruled out that bedding and frequent use of chairs or sofas, if contaminated, may result in significant doses from external exposure to beta radiation or internal exposure from inhalation of resuspended material.

B4 Doses from inhalation of resuspended contaminants

Resuspension of contaminated particles may lead to further inhalation doses after deposition has occurred. Nevertheless, doses from inhalation of resuspended matter would in many cases be very low compared with doses from external exposure to beta particles and gamma rays and also lower than those received during the passage of the initial contaminating plume (Andersson et al, 2004). However, for radionuclides that are only alpha emitters, or predominantly alpha emitters, this could be the only significant exposure route during the recovery phase. Doses from inhalation of resuspended contaminants greatly depend on the processes leading to the resuspension and are influenced by factors such as dust concentrations on surfaces, dust particle sizes, mechanical disturbances (eg heavy traffic) and weather conditions. Resuspension factors (the ratios of aerosol concentration in air at a reference height above a surface to the aerosol particle loading per unit area of the surface) have been reported to vary by many orders of magnitude for particles deposited in inhabited areas (Sehmel, 1980). Due to the complexity of the calculations involved, inhalation doses from resuspension should be evaluated by experts, taking into account the relevant factors on a site specific basis. Indicative estimates of outdoor inhalation doses from resuspension have been reported (Walsh, 2002) and are given in Table B4. Doses are given per unit activity deposition on the ground; they were calculated assuming lung absorption type S (ICRP, 1995) and an inhalation rate of 2.3 10^{-4} m^3 s^{-1}. It is recommended that the values be used with caution and only where more exact models are not available.

Andersson et al (2004) demonstrated that even the most vigorous physical activity leads to only low levels of resuspended contaminants indoors. The resulting redistribution of contaminants on the various indoor surfaces does not contribute significantly to the dose from external exposure. Some cleaning techniques such as vacuum cleaning with machines with poor dust filters and shaking of cushions and other fabrics may give rise to higher levels of resuspended contaminants indoors and some redistribution of contamination within buildings.

Table B4 Adult committed effective dose from inhalation of resuspended contaminated material from the ground (Sv m^2 Bq^{-1})

	Inhalation period after deposition							
Radionuclide	**1 day**	**3 days**	**1 week**	**1 month**	**6 months**	**1 year**	**4 years**	**10 years**
^{106}Ru	1.6 10^{-12}	3.3 10^{-12}	4.6 10^{-12}	6.9 10^{-12}	9.3 10^{-12}	9.9 10^{-12}	1.1 10^{-11}	1.1 10^{-11}
^{103}Ru	7.2 10^{-14}	1.5 10^{-13}	2.0 10^{-13}	2.8 10^{-13}	3.2 10^{-13}	3.2 10^{-13}	3.2 10^{-13}	3.2 10^{-13}
^{137}Cs	9.3 10^{-13}	2.0 10^{-12}	2.7 10^{-12}	4.1 10^{-12}	5.8 10^{-12}	6.4 10^{-12}	7.6 10^{-12}	8.4 10^{-12}
^{226}Ra	2.3 10^{-10}	4.8 10^{-10}	6.7 10^{-10}	1.0 10^{-9}	1.4 10^{-9}	1.6 10^{-9}	1.9 10^{-9}	2.1 10^{-9}
^{235}U	2.0 10^{-10}	4.3 10^{-10}	6.0 10^{-10}	9.0 10^{-10}	1.3 10^{-9}	1.4 10^{-9}	1.7 10^{-9}	1.9 10^{-9}
^{238}Pu	3.8 10^{-10}	8.0 10^{-10}	1.1 10^{-9}	1.7 10^{-9}	2.4 10^{-9}	2.6 10^{-9}	3.2 10^{-9}	3.5 10^{-9}
^{239}Pu	3.8 10^{-10}	8.0 10^{-10}	1.1 10^{-9}	1.7 10^{-9}	2.4 10^{-9}	2.6 10^{-9}	3.2 10^{-9}	3.5 10^{-9}
^{241}Am	3.8 10^{-10}	8.0 10^{-10}	1.1 10^{-9}	1.7 10^{-9}	2.4 10^{-9}	2.6 10^{-9}	3.2 10^{-9}	3.5 10^{-9}

B5 Other potential exposure pathways

B5.1 Bremsstrahlung doses

All beta contamination on a surface gives rise to small quantities of bremsstrahlung radiation. Bremsstrahlung emissions are photons produced by beta particles interacting with surrounding matter which are more penetrating than beta particles in the body. These also contribute to effective dose. The dose from bremsstrahlung radiation from material on a surface is generally small compared to the effective dose from beta emissions. However, for very high levels of beta contamination, doses from bremsstrahlung radiation may need to be included in the estimated doses while planning a recovery strategy.

If the beta radiation is stopped by a shielding material, bremsstrahlung radiation is still created. The shielding material used on top of the beta contamination increases the intensity of the bremsstrahlung radiation and the increase is dependent on the shielding material used. The increase in dose from bremsstrahlung radiation for materials likely to be used for shielding in inhabited areas such as tarmac and soil, is small compared to the dose from beta radiation. If lead is used as a shielding material for small areas of contamination in special situations, more bremsstrahlung radiation is created and therefore an assessment of the bremsstrahlung doses that could be expected should be made, particularly for high energy beta emitters such as ^{90}Sr and its daughter ^{90}Y.

If both beta and gamma emitters are present, any increase in dose from bremsstrahlung radiation is likely to be small compared to the dose from external exposure to gamma emitters. In this case, bremsstrahlung radiation is only an issue if beta radiation is stopped by shielding. However, this is not expected to be of concern as shielding is very unlikely to be used against gamma emitters.

B5.2 Doses from 'hot particles'

'Hot particles' are small highly radioactive particles which may be deposited in the environment if an explosion occurs, eg after a Radiological Dispersion Device (RDD), also called a 'dirty bomb'. These particles are likely to be too big to cause any significant exposure via inhalation, although it is possible that they may deposit in the nose. The most important exposure pathways for hot particles are, in general, ingestion and skin contamination. Contamination of skin can give rise to very high local skin doses from both beta and gamma emitters. Small, hot particles produce spatially non-uniform acute doses to small areas of the skin and can produce erythema, ulceration and in the most severe cases moist desquamation (NRPB, 1996; Wilkins et al, 1998. Delacroix et al (2002) indicates that dose rates of up to 4 mSv h^{-1} per kBq cm^{-2} on the skin for high energy emitters could be expected for uniform contamination of the skin and 2 mSv h^{-1} expected for a droplet of 1 kBq on the skin.

Deterministic effects to the lower large intestine may result from the ingestion of hot particles. The passage of a fuel fragment through the gastrointestinal (GI) tract will be different to normal radionuclides ingested as a dissolved fraction in food. Fragments may become lodged in the parts of the GI tract and as a result the normal residence time in particular organs may be increased. Additional information on deterministic effects is presented by Charles and Harrison (2007).

B6 Relative importance of different surfaces in contributing to external doses

Many outdoor surfaces in an inhabited area would become contaminated following deposition of airborne contaminants. The distribution of the contaminants on the different surfaces depends on whether the deposition occurred in dry weather or while it was raining. The Chernobyl accident showed that the deposition of small condensation particles in the 1 µm range, carrying radiocaesium, generally followed two characteristic patterns, depending on whether the weather was dry or the deposition occurred while it was raining. Table B5 shows the expected contamination levels on different surfaces of such particles, shortly after the accident, relative to that on a surface with grass and underlying soil (a cut lawn) for both wet and dry deposition (Roed, 1990). Different figures could be expected for other particle sizes, such as those originating from other types of radiation emergencies. It should be noted that the ratios given in Table B5 apply to deposition from a plume dispersing from a source well outside the inhabited area under consideration. The figures for trees/shrubs are per unit of area covered by the vegetation. The relative deposition for trees/shrubs in leaf is particularly high for dry deposition, as the leaves filter the contamination very effectively. The use of these values is only recommended to obtain an approximate estimate of contamination levels on different surfaces in situations where actual measurements on the different surfaces are not available. The actual relative deposition to surfaces from a source within the inhabited area depends on a number of factors, such as the type and size of the particles and the distance from the point of release.

Table B5 Typical contamination levels of 1 µm particles measured on different surfaces after the Chernobyl accident

Surfaces	Relative dry deposition	Relative wet deposition
Walls	0.1	0.01
Roofs	1.0	0.4
Cut lawn	1.0	1.0
Roads	0.4	0.5
Trees and shrubs	3.0	0.1

After deposition, the contamination on roads, external house walls and roof will be depleted by wind and weather (Roed, 1990). The Chernobyl accident provided much information on the natural removal of radiocaesium on such surfaces. As caesium can bind particularly strongly to the surface of most common construction materials, use of this information to describe the behaviour of other radionuclides will lead to cautious dose estimates.

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Appendix C Management of Contaminated Waste from Clean-up

C1 Processes to treat or minimise the volume of contaminated waste

The management of contaminated waste may include a number of the treatment processes prior to final storage or disposal of the waste. In addition, if, for example, the dose rate is dominated by contributions from short-lived radionuclides or if the waste requires the use of various treatment processes prior to final disposal it may be beneficial to store contaminated waste in a temporary repository for a period of time.

C1.1 Filtration of solid particles out of waste water

A number of management options involve the use of water to wash off particles consisting of other materials (eg algae and moss, roof materials). These particles normally retain the contamination well (particularly caesium) and can be collected along with the wash-water. Simple filtration through an inexpensive polymer fibre textile with a pore size of 0.14 mm has been found to be highly effective in isolating the solid particles, which contained virtually all caesium contamination, from the water in areas contaminated by the Chernobyl accident (Fogh et al, 1999). The water could then be safely disposed of via sewers or even re-applied on the roof.

C1.2 Treatments for contaminants in liquid waste

Some management options involve the use of detergent solutions. Some of these detergents will be diluted and non-aggressive, whereas others may be highly acidic or alkaline. The acidity of the solution determines to a great extent the degree of contaminant association with particles.

Several methods may be applicable to remove contaminant ions from the waste solution, if required prior to disposal. One of the more simple methods is to concentrate the contamination in a solid residue using evaporation. This technique requires very large amounts of energy (> 1000 kWh m^{-3}) (Turner et al, 1994) and may not be easy to handle with strong, reactive solutions. Furthermore, the presence of volatile contaminants, such as ruthenium, would be problematic.

An alternative method is to precipitate the contaminants by adding a flocculant agent and adjusting the solution pH to neutral. However, the neutralisation process would lead to the generation of large amounts of precipitate (IAEA, 1993). Also, the typical decontaminating effect of gravitational settling by neutralisation has been reported to be limited (maximum DF of about 10) (Turner et al, 1994). In connection with both evaporation and precipitation, very large, specialised handling facilities would be required.

A further, potentially attractive, alternative method is to remove the contaminants from the solution by ion exchange (IX). This has been reported to be a highly efficient technique. In addition, the required size of the handling facility would be much less than that of an evaporation or gravity settling plant (Turner et al, 1994).

For treatment of relatively large amounts of contaminated liquid, membrane filters based on the reverse osmosis principle may be highly attractive. Membrane filters are reported to be highly efficient in reducing the concentrations of radionuclides in liquid waste (DF of several hundreds per cycle) (Zakrzewska-Trznadel et al, 2001).

Liquid radioactive waste could be diluted to give sufficiently low activity concentrations in the waste that it can be disposed of as ordinary waste liquid. Stirring systems for certification of the homogeneity of solutions of radioactive liquid waste have been developed for this purpose (Ogata and Nishizawa, 1999). However, dilution must be sufficiently effective with respect to toxicity, acidity and radionuclide content.

C1.3 Stabilisation of solid waste to avoid migration of contaminants

Some types of collected solid waste arising from the implementation of a management option (eg street dust, ash from combustion of contaminated biomass) can contain particularly high concentrations of radionuclides. In constructing ground repositories for strongly contaminated solid waste it may be appropriate to introduce special measures to prevent migration of contaminants to the groundwater. Thick plastic lining or other membranes around the contaminated material will generally provide good protection together with clay barriers and draining layers of gravel, and would be recommended for any ground repository for solid waste.

To stabilise further waste from highly contaminated surfaces, cementation could be considered, particularly if the contaminants would otherwise have high environmental mobility. For instance, fly-ash from combustion would be a 'natural' ingredient in a cement mixture. However, conventional cementation processes is not possible for all materials because the presence of some materials (eg humic materials) retards or prevents solidification.

C2 Waste management options for solid waste arising from clean-up

Waste disposal schemes for solid contaminated waste must be selected with care. To cope with a radiation emergency, the identification of waste management options, including the construction of repositories and storage facilities, is required fairly quickly. Waste management options should therefore be planned for and the required materials, transport vehicles, skilled workers, infrastructure, etc should be put in place to manage the waste appropriately. If permanent disposal options are required, engineered facilities could not realistically be constructed on the timescales needed. Therefore, temporary or indefinite storage options for the waste are also important. A checklist for setting up facility for temporary storage can be found in Table C1.

Table C1 Checklist for temporary storage

Potential Issue	Consider
Water infiltration	Need to store waste in watertight drums or containers inside a building.
Containment	Do containers need to be chemically and radiologically stable? Provide shielding? Be mechanically robust (impact, thermal)? Be portable?
Leachate and atmospheric emissions	Means to collect any leachate, particularly from organic material. Consider sloped concrete floor leading to isolated drainage system Need for gas extraction and collection system and for heat removal systems.
Monitoring	Routine monitoring of storage facility Monitor leachate Leakage detection system - alarm system in case of release of activity.
Waste conditioning	Does waste need to be conditioned prior to storage? Will storage of waste in natural form compromise future disposal eg grass decomposition? Unconditioned organic waste may generate methane and carbon dioxide and reactions involving metals will generate hydrogen. All these gases could contain traces of radionuclides and lead to exposures to workers and members of the public.
Type of storage site/facility used	Ease of decontaminating storage facility after use or how any residual contamination will be managed.
Incident response	Risks of integrity of storage facility being breached (eg fire/ incident involving radioactive waste material) and plan accordingly.
Location of storage facility	Natural hazards that could affect integrity of stored waste (eg flooding).
Radiation protection	Protection of workers, personal monitoring and other equipment Requirements for controlled access.
Security	Controls needed to manage acts of vandalism, terrorist attacks and other threats.
Transport	Access to site, transport routes, proximity to final disposal facility and other aspects.

C2.1 Management options for organic waste

Organic waste from an inhabited area may include grass or turf which has been removed from a lawn, or trees and shrubs (prunings and whole plants) removed from gardens and park areas. Large quantities of organic waste could potentially be generated and the activity in the waste may be high. Furthermore, leaves may have high activity concentrations immediately after dry deposition. Reduction in waste volumes can therefore be very important. It is also necessary to stabilise the waste due its organic nature.

Depending on the level of contamination, a number of methods may be considered to treat the contaminated biomass. For example, aerobic degradation (composting) produces material that may be useful for fertilisation of soil, whereas anaerobic degradation produces gas that may be used in energy production. If an existing composting facility is used or a new facility developed, the run-off of radioactive liquid from the composted waste and its management need to be considered. Core wood from contaminated trees may be applied in industry (eg to make furniture) particularly in the early period after an accident where the contamination is likely to be largely confined to the outer surface.

C2.2 Other waste management options

Two other waste management options which may be appropriate in special circumstances are the storage of material which retains contamination well and the reapplication on a road of new hot asphalt mixed with granulated asphalt waste from a road surface.

An example of a material which retains contamination well is roof tiles. Roof tiles are particularly effective in retaining deposited caesium ions; it may take many years for weathering to halve the caesium level. Therefore, storage of such materials in a restricted area will present only a minimal risk of the contamination migrating into the surrounding soil.

The dilution of contaminated asphalt from a road surface with new asphalt together with the shielding provided by the new material mean that the radiation from a road paved with this mixture is likely to be lower than that from the road following planing. This is because virtually all the remaining contamination after planing would have remained on top of the surface. Before this technique is applied, it should be carefully assessed whether enough new asphalt is available to dilute the contamination sufficiently. In addition, the general public may not find the reapplication of contaminated material acceptable, despite its dilution.

C3 Waste management options for liquid waste arising from clean-up

Table 5.13 identifies some management options that give rise to liquid waste which could be contaminated. Before implementing these options, a decision should be made between disposing directly to the sewage system and collecting the waste for storage. It should be noted that storage of large quantities of liquid waste is not likely to be practicable. If the contaminated run-off is allowed to enter the sewer system, an authorisation will be required. In this case, as part of the authorisation it would be necessary to estimate doses to sewage treatment plant workers, potential doses to members of the public and the levels of other contaminants in the water, such as detergents.

Factors to consider for waste water collection and disposal of waste water directly to the sewage system are given in Table C2 and Table C3, respectively.

Table C2 Factors to consider for collection of waste water

Task	Factors to consider
Collection of waste water	How waste water and decontamination products can be collected or contained. Is this practicable for buildings? How to control waste water that normally goes directly to soak-aways (eg from roofs). How and where collected waste water can be stored prior to disposal.
Treatment of waste water	How to minimise the volume of waste water as a result of clean-up. Consider separation of contamination via filtering, ion-exchange and other methods. Can this type of treatment be done in local sewage treatment plants? Can treatment be added to normal systems at a local level? Would special facilities be required? Is the option available at nuclear sites? Can treated water be re-used for other clean-up options requiring water (eg sandblasting)?
Disposal	Are there options other than sewage plants? It may be worth exploring if nuclear site effluent routes could be used

Table C3 Factors to consider for the disposal of waste water

Issue	Factors to consider
Environmental impact	Control of discharges to sewage system: bypass of sewage treatment works during storm events should be avoided as control of contaminated waste will be lost. Doses to workers and management of sewage by-products also need to be controlled.
Monitoring	The monitoring of waste water needs to be undertaken to asses radiological consequences and to demonstrate control and compliance with any authorisations.
Doses to workers and public	Risk assessments need to be undertaken for people implementing any clean-up options in sewerage systems. Doses should also be assessed for people working in sewage treatment plants handling contaminated waste water. Disposal into rivers may result in doses to public and it may be necessary to consider restrictions on swimming, fishing, including commercial fish farming, and extracting drinking water downstream for a certain period. Sewage sludge could be retained of for longer than normal before incineration or land spreading in order to minimise public doses.
Acceptability	Two way communications with stakeholders will help to find the most acceptable solution. Even if impact is assessed as being small, perceived lack of control of waste water and deliberate contamination of sewage plants and environment may not be acceptable to the public Dilution of contamination in the environment by disposing of contaminated waste water from clean-up of contaminated areas via the sewage system may be favoured. However, this may be very hard to 'sell' to stakeholders.

C4 Sewers and sewage treatment systems and disposal options for sludge

The radionuclides in contaminated waste water are either in solution or adsorbed to suspended solids and the distribution between these two phases depend on the radionuclides involved. Sewage treatment plants typically use a combination of physical and biological methods to treat waste water. During the treatment, radionuclides are partitioned into sewage effluents and sewage sludge. Disposal options for sewage sludge are described in Table C4. Effluent disposal routes are likely to include discharge to rivers or directly to sea.

Radioactive decay and sorption on walls of the sewers during transit has little effect on the overall activity entering the sewage treatment plant. Radioactive decay during the treatment of sewage sludge will only be significant for short-lived radionuclides. Radionuclides are found in both the solid and effluent phases of the waste. The removal of radionuclides in sewage sludge depends on the general chemistry of the element and the chemical and biological compound that the radionuclides are associated with when disposed. The transfer of radionuclides from sewage to the sewage sludge occurs mainly within the secondary treatment phase. The partitioning of radionuclides in effluent sewage treatment is expressed in terms of a removal coefficient, which is the fraction of the radionuclide remaining in the effluent after a sewage treatment phase. A removal coefficient of 1 implies that all of the activity remains in the effluent and none is transferred to the sludge. Table C5 gives the removal coefficients for selected radionuclides. Further information on partitioning can be found in Titley et al (2000) and Ham et al (2003).

Table C4 Disposal options for effluent and sludge arising from sewage treatment

Disposal Option	Description
Effluent disposal	**Treated liquid effluents are disposed of to rivers or the sea.**
Stabilisation of sludge and disposal to landfill	The practice of sending sludge to landfill directly is diminishing, with only about 5% of all landfills receiving sludge. This represents less than 1% of the waste disposed of via this route. Normally the proportion of sludge co-disposed with municipal waste is less than 20% by weight. It is also usually dewatered, so the solid content of the sludge is about 15 - 25%. The disposal of radionuclides to landfill means that in the near future any radionuclides present will be retained in the waste. Most radionuclides will therefore decay in the landfill site.
Incineration of sludge and disposal of ash to landfill	Incineration is an increasingly common way of disposing of dried sludge. The fraction of sludge incinerated in the UK was 7% in the early 1990s; this is expected to rise substantially as sea dumping is now prohibited. During incineration radionuclides are either released to air, from where they disperse and may deposit to the ground, are captured in offgas scrubbers or are retained in the ash. The ash residue left can be substantial (a typical sludge has an ash content of 25 -30% of dry solids). The ash is normally taken to a landfill site and buried, although some companies are researching more beneficial uses of incinerator ash. Off gas scrubbers may produce slurry which may be returned to earlier parts of the sewage treatment system for treatment.
Land spreading of sludge	The application of sewage sludge to farmland is the most popular single disposal method (around 44% of sludge in the UK and 37% in Europe is disposed of via this route). The sludge is a rich source of phosphates, and anaerobically digested sludge has considerable quantities of ammoniacal nitrogen. Sludge can be applied either by spreading or by direct injection during ploughing. Land spreading leads to the incorporation of radionuclides in the environment and in foodstuffs. These may then result in the exposure of farmers and the public. The transfer of radionuclides into foodstuffs is dependent on the rate and nature of the application of the sludge to the land and the subsequent use of the land (in particular crop type and time of harvesting relative to the application of sludge). Sludge is usually only spread on to land once or twice annually (in intervening times it is stockpiled centrally or on farms). There is therefore usually a period during which radionuclides decay prior to its use. This will significantly reduce contamination of the soil and doses to farmers for short-lived radionuclides.

Table C5 Removal coefficients for typical secondary treatment

Radionuclide	Bq m^{-3} in effluent per Bq m^{-3} entering sewers
^{60}Co	0.2
^{90}Sr	0.9
^{131}I	0.8
^{241}Am	0.8

* The transfer of radionuclides from sewage to the sewage sludge occurs mainly within the secondary treatment phase

C5 Doses from waste management options

C5.1 Doses from management of contaminated refuse

Table C6 provides hourly dose rates to workers managing refuse. The dose rates were calculated for the following tasks:

- handling and collection of waste bags and transfer to refuse lorries
- travelling in refuse vehicle to waste transfer station
- handling of waste at transfer station
- handling of waste at sorting facility
- incinerator maintenance by engineers
- transport of incinerator ash to landfill
- disposal operations at landfill sites by bulldozer or compactor
- composting operations at composting facility

Dose rates were estimated for ^{90}Sr, ^{131}I, ^{137}Cs and ^{239}Pu, based on assumptions from Harvey et al, 1995, but ignoring allowance for any mixing with uncontaminated refuse. The exposure pathways considered were external exposure, inhalation of resuspended dust and external skin dose from ash dust. Doses from skin contact with contaminated material were not estimated for refuse workers as it was assumed that they would wear gloves and suitable clothing. The dose rates given in Table C6 apply only to the period when workers are handling contaminated material and are normalised to the contamination levels in the waste being managed at the point the task is undertaken. It should be remembered that the contaminated refuse may be mixed with uncontaminated refuse at some of these stages, resulting in a lower activity concentration in the managed material.

It is important to note that the majority of these doses are only likely to be received in the short term. This emphasises the importance of having a monitoring scheme in place for measuring contamination levels in the refuse and garden waste, preferably at a number of stages.

Dose rates in Table C6 should be used for scoping calculations only and to help identify that tasks that give rise to the highest doses. Actual dose rates depend on the specific situation and the use of estimated values, such as those given in the table, should not replace a detailed assessment of doses to the workers.

Doses to the public may arise following disposal of contaminated refuse via incineration, landfill and composting. The main processes and potential exposure pathways to members of the public that may occur are listed in Table C7. In the event of a radiation emergency, it will be necessary to undertake a full assessment (including the assessment of potential doses to members of the public) if existing legal authorisations are changed, or if new disposal sites or other disposal or storage options are authorised.

Table C6 Doses to people working with contaminated refuse

	Dose rates per unit activity concentration waste handled (Sv h^{-1} Bq^{-1} kg)			
Task	^{90}Sr (+^{90}Y)	^{131}I*	^{137}Cs$^{\#}$	^{239}Pu†
Refuse collection	8 10^{-13}	1 10^{-11}	2 10^{-11}	5 10^{-11}
Refuse vehicle	1 10^{-12}	2 10^{-11}	3 10^{-11}	5 10^{-11}
Transfer station	1 10^{-12}	2 10^{-11}	3 10^{-11}	5 10^{-11}
Sorting facility	4 10^{-12}	3 10^{-12}	4 10^{-12}	5 10^{-11}
Municipal incinerator	7 10^{-13}	3 10^{-14}	4 10^{-13}	1 10^{-9}
Secondary transport (incineration)	1 10^{-11}	4 10^{-12}	1 10^{-10}	2 10^{-15}
Landfill operations	1 10^{-11}	3 10^{-10}	5 10^{-10}	4 10^{-11}
Composting facility‡	8 10^{-12}	3 10^{-10}	4 10^{-10}	1 10^{-10}

*: Can be used for ^{99}Mo, ^{132}Te, ^{136}Cs, ^{140}La, ^{140}Ba, ^{169}Yb

$^{\#}$: Can be used for ^{60}Co, ^{75}Se, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{134}Cs, ^{144}Ce, ^{192}Ir, ^{235}U, ^{226}Ra

†: Can be used for ^{238}Pu, ^{241}Am

‡: Composting may take from a few weeks up to 2 to 3 months. Operators may be exposed over these timescales, even if new waste entering the plant is no longer contaminated.

Table C7 Potential exposure pathways for members of the public following disposal of contaminated refuse

Disposal process	Potential exposure pathways
Stack discharges from incineration	People living downwind of incinerator: external dose and inhalation of resuspended material following deposition. Note that most radionuclides, notably excluding ^{131}I, are trapped in the incinerator filters and are not released to atmosphere. Ingestion of food grown on contaminated land
Landfill	People using closed landfill sites for recreation (eg walking dogs): external dose and inhalation of dust. Long-term migration of radionuclides through soil: external dose and inhalation of resuspended material from contaminated soil, ingestion of food grown on contaminated soil. Future use of closed landfill for building: external dose and inhalation of resuspended material from contaminated land, ingestion of food grown on contaminated land.
Use of composted material on land (commercial and domestic)	Application of compost: external dose and inhalation of dust; ingestion of food grown on contaminated land; possible skin dose to hands.

For normal UK facilities used for disposal of radioactive solid waste, these doses are explicitly taken into account in the authorisations for disposal issued under RSA 93 (MAFF, 1993). The current criteria for disposal authorisations ensure that the doses to members of the public are sufficiently low that they are very unlikely to be of concern on radiological protection grounds. If, in the event of an incident, existing authorisations are changed, new sites or other disposal or storage options are authorised, it will be necessary to undertake a full assessment of the impact of such a practice including the assessment of potential doses to members of the public.

C5.2 Doses from sewage treatment and disposal

Indicative dose rates for workers at sewage treatment plant have been estimated for a selection of the radionuclides considered in the handbook: ^{90}Sr, ^{131}I, ^{60}Co and ^{241}Am (Harvey et al, 1995; Titley et al, 2000). These radionuclides should be taken as being illustrative of strong* beta emitters (^{90}Sr, and its daughter ^{90}Y), short-lived high energy beta/gamma emitters (^{131}I), long-lived high energy beta/gamma emitters (^{60}Co) and alpha emitters (^{241}Am). The dose rates are presented in Table C8 and are generally applicable to UK sewage treatment plants servicing small towns. For large sewage treatment plants, doses to workers involved in all activities except maintenance of sewer pipes are likely to be significantly lower (they could be assumed to be a factor of 10 lower). Doses to workers at sewage treatment plants may generally vary depending on the time they spend during each task, the size of the plant and the procedures used. However, it is unlikely that doses to these workers vary significantly across different treatment plants. Exposure pathways considered in the calculation of the dose rates presented in Table C8 are external exposure, inhalation of resuspended material; shielding was not taken into account. The types of worker considered were:

- sewer pipe workers who spend most of the time checking and unblocking the main sewers
- general sewer workers undertaking tasks around a plant adopting sludge stabilisation prior to disposal
- general sewer workers undertaking tasks around a plant adopting sludge incineration
- sludge press workers working in the sludge press room near incinerators
- workers at landfill site where sludge is disposed

Doses to members of the public from disposal of radionuclides depend on the final disposal routes of the effluent and the sludge. Effluents can be disposed of to rivers or the sea while sludge can be disposed of to landfill and agricultural land and through incineration. Methodologies which can be used to calculate doses to members of the public are described in Chen et al (2007) (sludge to landfill), Mobbs et al (2005) (sludge to farmland) and Titley et al (2000) (all other disposal routes).

If calculation of dose based on generic methodologies suggest that doses to workers or members of the public may be of concern, it is important to take into account details of the specific procedures used in the sewage treatment plants in the area and the habits of workers and the population. The main factors that need to be taken into account are listed in Table C9. For long-lived radionuclides, long-term contamination and doses to workers at the sewage treatment plant also needs to be considered. Persistence of contamination in the systems and the effectiveness of any normal cleaning practices will need to be taken into account.

* For the purposes of the handbook, a strong beta emitter is defined as having a maximum beta energy higher than 2 MeV.

Table C8 Indicative dose rates to workers involved in sewage treatment and disposal

Radionuclide	Dose rates per unit activity concentration in the water entering sewage treatment plant (Sv h^{-1} Bq^{-1} m^3)			
	^{60}Co*	^{90}Sr	^{131}I$^{\#}$	^{241}Am^{+}
Sewer pipe worker	6 10^{-12}	7 10^{-15}	4.10^{-13}	8 10^{-13}
General worker (sludge stabilisation)	7 10^{-9}	4 10^{-13}	2 10^{-10}	4 10^{-10}
General worker (sludge incineration)	2 10^{-8}	2 10^{-12}	3 10^{-10}	3 10^{-10}
Sludge press worker (sludge incineration)	4 10^{-9}	5 10^{-13}	1 10^{-10}	9 10^{-10}
Landfill worker (incinerated ash)	1 10^{-10}	8 10^{-14}	3 10^{-13}	5 10^{-14}

* Values for ^{60}Co can also be used for ^{75}Se, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{134}Cs, ^{144}Ce, ^{192}Ir, ^{235}U and ^{226}Ra

$^{\#}$ Values for ^{131}I can also be used for ^{99}Mo, ^{132}Te, ^{136}Cs, ^{140}La, ^{140}Ba, ^{169}Yb

$^{+}$ Values for ^{241}Am can also be used for ^{238}Pu and ^{239}Pu.

Table C9 Site specific information needed for detailed dose assessment

Information required	Details
Type of sewer system	Combined, separate or mixed
Capacity of sewer and water treatment plant	Sewer size (diameter), sewer flow rate
Aquatic environment that treated or untreated waste water is discharged into:	Volumetric flow rate, width, depth, usage of river water, salinity
Treatment processes of sewage effluent and sewage sludge	What processes are in operation
Discharge route of waste streams from sewage treatment works	Sewage application rates to farmland, weather conditions at incinerator

C6 References

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