UK Health Security Agency

Walkthrough: A Decision-aiding Framework for Recovery Following a Radiation Incident

A supplementary report to the UK Recovery Handbook for Radiation Incidents 2024
Version 5

Contents

Quality assurance

This work was undertaken under the Radiation Assessments Department's Quality Management System, which has been approved by Lloyd's Register Quality Assurance to the Quality Management Standard ISO 9001:2015, Approval Number ISO 9001 – 00002655.

1 Introduction

Following a radiation incident where radioactive contamination is distributed within the environment, the implementation of a remediation strategy is likely to be required. As there are both positive and negative impacts to many of the remediation options available in a recovery situation, complex trade-offs need to be accounted for when selecting the most appropriate strategy. It is not possible to recommend a generic strategy since each radiation emergency is likely to be different in terms of the radionuclides involved, its impact, and duration. Therefore, a 7-step ‘recovery framework’ to develop an inclusive, optimised, and sustainable recovery strategy is proposed in the UK Recovery Handbook for Radiation Incidents 2024, version 5 (UKRHRIv5) (1). A ‘decision-aiding framework for remediation’, described in Section 6 of the UKRHRIv5, is designed to help decision makers identify the most suitable subset of remediation options as part of this process.

There are three worked examples included in Section 7 of the UKRHRIv5 which apply the decision-aiding framework retrospectively to historical radiation emergencies that impacted the UK to illustrate how the framework can be applied. However, those worked examples are limited by the parameters of each of the actual incidents.

This supplementary document, which was written alongside the UKRHRIv5, uses a single hypothetical incident scenario to demonstrate how the decision-aiding framework can be applied to all three land uses (food production, drinking water and inhabited areas) in response to a single release scenario and brings a broader range of protective actions into consideration.

The seven-step iterative process laid out in the recovery framework is as follows:

1. Define the situation
2. Assess impacts
3. Agree goals
4. Identify and evaluate options
5. Make decisions on the recovery strategy
6. Implement the strategy
7. Monitor and evaluate progress

Each of the first five steps of this process are closely followed in the examples provided in this walkthrough. Where used, the look-up tables presented in the UKRHRIv5 are cross-referenced and copies of these tables are provided in Annex A of this document for ease of reference.

The release scenario outlined in this document is entirely hypothetical and was developed specifically for the purpose of demonstrating the decision-aiding framework. The place names used are fictional and the source of the release is a nuclear power plant (NPP) invented for the purposes of the scenario. The details of the hypothetical accident (including quantity of activity released and the resulting radiological impact), have been selected to simulate a plausible but very unlikely event; they do not correspond to any known NPP fault sequence. As a result, any discussion of the consequences of that accident presented in this case study should be viewed as being illustrative only.

The endpoints of the examples in this document (and the product of using the decision-aiding framework up to step 5) are a subset of the most appropriate protective actions, according to the specific characteristics of the radiation emergency. The ultimate choice of which protective actions to implement, and how to combine them into a remediation strategy, belongs to the decision-makers. Importantly, and as reiterated in each example summary, in a real situation, stakeholders and representatives from the local community would be very much involved in any decisions on the remediation strategy.

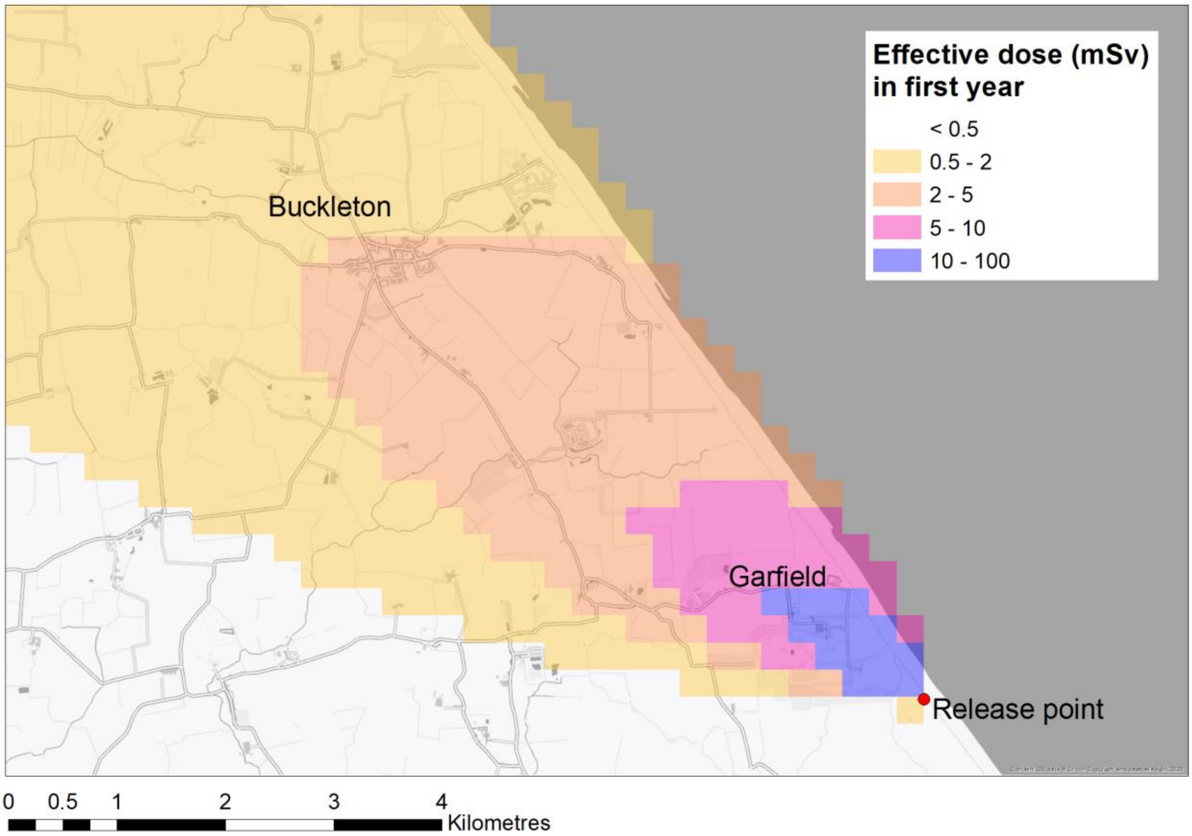
2 Scenario description

The hypothetical accident considered in this case study is at a fictional nuclear power plant on the east coast of England on a fine summer day in June. In this scenario, a fault in the reactor, and subsequent containment failure, led to a significant release of radioactive material to the atmosphere over a period of 24 hours.

In the emergency phase, the dose to the local population was dominated by the inhalation of radioactive iodine, predominantly iodine-131 (^{131}I). However, in the recovery phase, the dose is estimated to be mostly from external irradiation from primarily caesium-134 (^{134}Cs) and caesium-137 (^{137}Cs) deposited on surfaces such as soil, grass and paved surfaces as well as building exteriors.

At the time of the accident there was a light south-easterly wind which takes the radioactive plume over several settlements to the north-northwest of the power plant (see Figure 1). There was no rain during the release of radioactivity (meaning there are no localised hotspots of contamination caused by washout of radioactivity in the plume).

Figure 1. Estimated effective dose to adults in the first year (after the emergency phase) from to the hypothetical accident



In the emergency phase, a local area up to 3 km northwest of the power plant, including the hamlet of Garfield, received instruction to shelter-in-place and take stable iodine tablets. A much larger area, covering about 4,300 km^2 (430,000 hectares), was identified where precautionary restrictions on the selling of various foodstuffs were required due to radiological contamination.

The following sections illustrate how the decision-aiding framework for remediation, as described in the UKRHRIv5 (1), can be used in this hypothetical scenario to help select protective actions. These descriptions are framed from the point of view of analysing and making decisions close to beginning of the recovery phase, after the emergency phase has ended. It should be noted that in the event of a real radiation emergency the decision-aiding process would involve key stakeholders and representatives of the local community. Only Steps 1-5 are included here, as Step 6 ‘Implementation’ and Step 7 ‘Monitoring and Evaluation’, are outside the scope of the UKRHRIv5.

The following examples of inhabited areas, food production, and drinking water supplies have been used to illustrate how protective actions may be selected. More information on the situation in each of these environments is given in the following sections:

- Garfield hamlet (small area, higher contamination) (Section 3)
- Buckleton town (large area, lower contamination) (Section 4)
- Green vegetable production (Section 5)
- Beef production (Section 6)
- Domestic produce (Section 7)
- Drinking water supply (section 8)

3 Inhabited area – Garfield hamlet (small area, higher contamination)

The following steps walk through the decision-aiding process to select remedial protective actions that could be applied to the hamlet of Garfield, which is the most comtaminated nearby settlement.

Step 1 – Define the situation

The release and subsequent dispersion of radioactive material occurred over a period of approximately 24 hours. The hamlet of Garfield is located approximately 1 km downwind from the site (see Figure 1). It comprises 20 dwellings (fewer than 100 total people) each with small gardens either laid to lawn or with patios surrounded by shrubs and mature trees. There was no rain here over the duration of the release and so contamination deposited on the ground was the result of dry deposition. Measurements taken shortly after it was confirmed that the release had ended, indicate significant levels of contamination: averages of 270,000 kBq/m^2 of ^{131}I and 1,500 kBq/m^2 of total radiocaesium (^{134}Cs and ^{137}Cs). Following the passage of the plume, short-term doses to the public from deposited activity did not warrant continuation of urgent protective actions. Consequently, advice to shelter indoors were lifted, although precautionary food restrictions remain in place.

Step 2 – Assess impacts

Through a combination of measurements and modelling, it is estimated that prior to any remedial protective actions, the average committed effective dose to a representative adult resident in Garfield, from exposure to radioactivity released during the accident, will be 12.4 mSv over the first year and 5.7 mSv over the second year (these are in addition to doses received in the emergency phase) (Table 1). These estimated doses include a contribution from external irradiation received over one year from deposited gamma emitting nuclides and the committed effective dose from inhaling resuspended activity during one year. As legally binding restrictions on the selling of commercial foods produced in the area are assumed to be implemented, the dose from ingesting contaminated foods in this period will be negligible. It is estimated that the dose from external irradiation is likely to be at least 100 times greater than that from the inhalation of resuspended activity.

It is estimated that in the first 7 days after cessation of the accidental release of activity, the average outdoor dose rate in Garfield from deposited radioactivity will be 33 µSv/h (Table 1). The contribution to this dose rate at this time is approximately 82% from ^{131}I, 16% from ^{134}Cs and 2% from ^{137}Cs.

The average outdoor dose rate from desposited radioactivity to those living in Garfield during the second year is estimated to be 2.5 µSv/h (averaged over the year). Since ^{131}I has a relatively short half-life (~ 8 days) and so has mostly decayed away, this dose rate would be solely from the decay of the caesium isotopes in a ratio of approximately 80:20 ^{134}Cs:^{137}Cs.

Only outdoor dose rates (µSv/h) are considered here for simplicity. The average dose rates that members of the public would be exposed to would be lower due to time spent indoors and factors such as the shielding effects of buildings. The estimated total doses (mSv) assume an individual under “normal living” conditions, that is, spending a majority of time indoors, with the resulting reduction in dose received.

Table 1. Estimated total effective doses and average dose rates in Garfield at various times after the release has ended

Timescale	Estimated effective dose received in period (mSv)	Average effective dose rate outdoors (µSv/h)	% contribution to dose rate from I-131
1 day – 7 days	1.5	33	82%
7 days – 30 days	2.0	15	58%
30 days – 180 days	4.9	5.6	3.2%
180 days – 1 year	4.0	3.5	0%
1 year – 2 years	5.7	2.5	0%

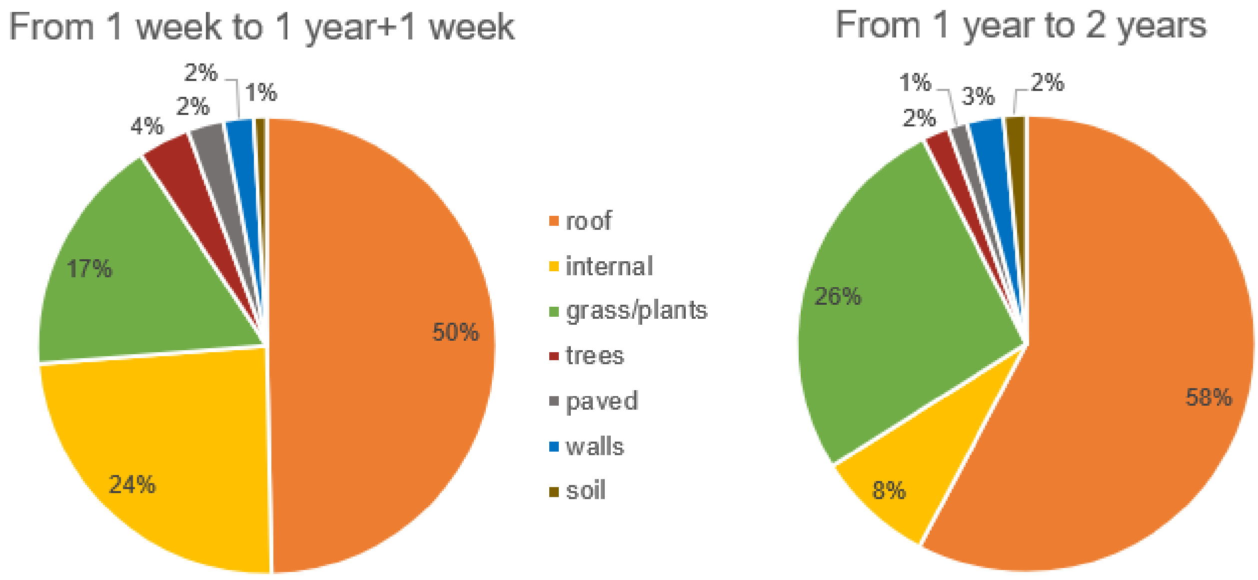
Deposited activity concentrations will vary significantly across surfaces and with time. Figure 2 displays predicted doses (integrated to 1 year) to an adult spending 90% of their time indoors from different surfaces over the first two years following the release.

In the short term, the largest contributions to the total dose is radiation emitted from radionuclides present on roofs and internal surfaces. A higher contribution comes from contamination on roofs because on flat and angled surfaces such as these, contamination is deposited at a higher rate and is retained more readily than on vertical surfaces such as building walls. Although the level of contamination present on internal surfaces will be much lower, these surfaces can still make a significant contribution (depending how airtight the building is) compared to outdoor surfaces since there is far less shielding (materials between the contamination and the individual) for the person spending most of their time indoors.

In the longer term, much of the radioactivity present on building and paved surfaces is affected by weathering with activity being washed off onto grass and soil. As a result, the contribution to the total dose from radioactivity present on grassed and soil surfaces increases with time compared to that from radioactivity present on building and paved surfaces.

While large grassed areas do exist in Garfield, and these may be assumed to be used for recreational purposes by the local population, the limited time spent on them means the dose likely to be recieved during their use will be much less than that received during time spent at home.

Figure 2. Percentage contribution to average total external dose from different surfaces at Garfield in the first two years



Step 3 – Identify options

In Garfield, to identify which options may be viable, it is necessary to consider those that could be applied to houses (external/internal surfaces), gardens and roads/paved areas due to most of the dose being a result of radiation emitted by radionuclides on those surfaces.

Consult the look-up table on surface types (Table 28 of the handbook) to determine whether the 17 protective actions listed are applicable to the surfaces of interest. In this scenario, since there are multiple types of surfaces which contribute to dose, all 17 potential protective actions should be considered further. The list of protective actions below indicates the applicable surfaces.

Options available for inhabited areas (n=17)

No remediation

- Natural attenuation with monitoring *(applicable to all surfaces)*

Restrict access

- Prohibit public access *(applicable to all surfaces)*
- Temporary relocation *(applicable to all surfaces)*

Shielding

- Cover contaminated soil and grass *(applicable to open spaces)*
- Ploughing methods and mechanical digging techniques *(applicable to open spaces)*
- Store and cover personal and precious objects *(applicable to interior of buildings)*
- Tie down *(applicable to all surfaces)*

Physical removal techniques

- High pressure washing including water jetting (*applicable to exterior of buildings, interior of large public buildings, and roads and paved*)
- Remove and replace road and paved surfaces *(applicable to roads and paved)*
- Remove building surfaces *(applicable to exterior of buildings, interior of large public buildings)*
- Remove grass after cutting *(applicable to open spaces)*
- Remove plant material *(applicable to open spaces)*
- Remove topsoil (and turf) *(applicable to open spaces)*
- Strippable coatings *(applicable to exterior and interior of buildings)*
- Vacuum cleaning (indoor and outdoor) *(applicable to interior of buildings, and roads and paved)*

Chemical removal techniques

- Reactive liquids (domestic chemicals) *(applicable to interior and some exterior of buildings as well as outdoor objects such as fences, benches, playground equipment)*
- Water-based cleaning *(applicable to interior and some exterior of buildings as well as outdoor objects such as fences, benches, playground equipment)*

Step 4 – Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclides of concern in this scenario are ^{131}I, ^{134}Cs and ^{137}Cs.

Consult the look-up table on radionuclide applicability (Table 29 of the handbook) to determine applicability of each option for ^{131}I, ^{134}Cs and ^{137}Cs.

Some options would not be justified were they being applied to radioiodine contamination alone, due to its short 8-day half-life (the level of disruption and quantities of waste that would be generated would be disproportionate given the limited short-term dose reduction achieved). However, as the radionuclide mix also includes the longer lived caesium isotopes, these options cannot be excluded. Nevertheless, there are 2 options that are not applicable ('natural attenuation with monitoring' and 'store and cover personal and precious objects') because the longer lived caesium isotopes remain in the environment for several years and make a significant contribution to the overall dose. While the relatively long half-life of ^{137}Cs is listed as a constraint for ploughing methods and mechanical digging techniques, given that ^{131}I and ^{134}Cs contribute much more significantly to dose over the first two years, this option should be retained.

Conclusion:

- **Eliminate:** 'natural attenuation with monitoring', 'store and cover personal and precious objects'

- **Retain:** ‘prohibit public access’, ‘temporary relocation’, ‘cover contaminated soil and grass’, ‘ploughing methods and mechanical digging techniques’, ‘tie down’, ‘high pressure washing including water jetting’, ‘remove and replace road and paved surfaces’, ‘remove building surfaces’, ‘remove grass after cutting’, ‘remove plant material’, ‘remove topsoil (and turf)’, ‘strippable coatings’, ‘vacuum cleaning (indoor and outdoor)’, ‘reactive liquids (domestic chemicals)’, ‘water-based cleaning’.

Consider key constraints that will influence applicability of each protective action

There are constraints such as waste generation, effectiveness in reducing dose, doses to implementers, technical limitations, time constraints, weather, time of year and cost, that may reduce the applicability of a protective action according to the circumstances under consideration.

Consult look-up table on constraints (Table 30 in the handbook) to identify if the major or moderate constraints of any of the protective actions are relevant for the current scenario.

The discussion below is subdivided into 5 sections: (i) management of the population; (ii) management of open spaces; (iii) management of roads and paved areas; (iv) management of exterior building surfaces, including objects; and (v) management of building interiors. Some protective actions are applicable to more than one type of surface.

Management of the population

There are two protective actions to consider:

- Prohibit public access
- Temporary relocation

The estimated committed effective dose in the first year is 12.4 mSv, due mainly to external irradiation from ^{134}Cs and, to a lesser extent, ^{137}Cs. Although this dose fits within the range of reference levels that may be put in place in Garfield, between 1 and 20 mSv, its magnitude shows that it is unlikely to represent an optimised situation. Consequently, actions that may reduce doses further should be reviewed for applicability. Therefore, consideration should be given to the prompt (within 2 days of the emergency) temporary relocation of all the inhabitants of Garfield for 1 to 2 weeks to allow the area to be remediated. Given the relatively few numbers of people affected (fewer than 100), alternative accommodation and transport to aid relocation would be readily available and the costs would not be disproportionate. During the period of temporary relocation, public access to Garfield would be prohibited. Without the population in place, it would be possible to carry out more thorough remediation of the area more easily.

Conclusion:

- **Retain:** ‘prohibit public access’, ‘temporary relocation’

Management of open spaces (that is, soils, grass and other plant material)

Figure 2 shows that contamination on grass/plants near residences is one of the biggest contributors to overall effective dose in Garfield (17% in the first year and 26% in the second year). Protective actions to reduce the dose from contamination on these surfaces should be considered. There are 3 shielding options and 3 physical decontamination options to consider.

Shielding

- Cover contaminated soil and grass
- Ploughing methods and mechanical digging techniques
- Tie down

All three options are highly effective at reducing external gamma dose rates, although depending on the land use, it may not be acceptable for the contamination to remain in place. There are significant technical constraints in terms of access and operation of large machinery in small domestic gardens which would make ploughing and digging options difficult. The covering of soils and grass with either clean soil or impermeable materials is likely to destroy the landscape and aesthetics of the gardens, potentially making this option unpopular with residents. In addition, there may be anxiety that the longer-lived isotopes of radiocaesium could be brought back to the surface, depending on how the gardens are subsequently managed. In terms of cost, covering contaminated grass and soil is expensive as large quantities of materials are required.

Physical decontamination

- Remove grass after cutting
- Remove plant material
- Remove topsoil (and turf)

To be effective, removal of grass cuttings and other plant material needs to be carried out as soon as possible after deposition, and before any rain. Removal of plant material is effective in the right circumstances and in this case would involve the pruning of trees to remove leaves and branches and the removal of shrubs. Even if carried out quickly, removal of grass after cutting still has only moderate effectiveness (that is, by reducing levels of contamination by a factor of 2 or less) and so this option can be eliminated is this case, where a more effective option is required. In contrast, the removal of topsoil and turf (top 5cm) is highly effective, and can be carried out using small powered tools or manually.

Sometimes, turf removal alone can provide the required level of protection. Topsoil and turf removal and removal of leaves and branches and shrubs both produce large quantities of putrescible waste, so options for volume reduction should be considered.

Conclusion:

- **Eliminate:** ‘cover contaminated soil and grass’, ‘ploughing methods and mechanical digging techniques’, ‘remove grass after cutting’
- **Retain:** ‘tie down’, ‘remove plant material’, ’remove topsoil (and turf)’

Management of roads and paved areas

Figure 2 shows that contamination on roads and paved areas does not make a significant contribution to total effective dose in Garfield, so taking no action is a possibility. However, it is still worth considering whether any protective actions could be applicable to improve the radiological situation, or to provide reassurance to the population. There are 3 physical decontamination options and 1 shielding option to consider.

Shielding

- Tie down

Tie down is mainly used where the inhalation dose from resuspended material is likely to be of concern (that is, not in this scenario). However, it may be required for a short duration to prevent secondary contamination if physical decontamination options are selected that generate dust.

Physical decontamination

- High pressure washing including water jetting
- Remove and replace road and paved surfaces
- Vacuum cleaning (indoor and outdoor)

Removal and replacement of roads and paved surfaces is a disruptive and expensive option that generates large volumes of waste. Due to the associated costs of implementing this option, it is unlikely to be justified given the limited potential for reduction in overall dose. High pressure washing and water jetting of roads and paved surfaces is likely to be a moderately effective alternative (especially if carried out rapidly to remove loose contamination before weathering and vehicular movements redistributes it). For outdoor vacuuming, specialist road sweepers that use a water filtration system and have high pressure jet nozzles to blast contamination from cracks are well suited. Smaller paved areas can also be vacuumed with machines fitted with HEPA filters but material can easily be redistributed. The effectiveness of both types of vacuuming is highly variable, and therefore, on balance, high pressure washing including water jetting, being simpler to apply, would be the preferred option. Furthermore, this would not require tie down.

Conclusion:

- **Eliminate:** ‘tie down’, ‘remove and replace road and paved surfaces’, ‘vacuum cleaning (indoor and outdoor)’
- **Retain:** ‘high pressure washing including water jetting’

Management of exterior building surfaces, including objects

Figure 2 shows that radionuclides present on roofs make the biggest single contribution to the total dose. Protective actions should therefore be directed at reducing exposure to radionuclides present on roofs. The potential for contamination of children’s play equipment and garden furniture in the properties in Garfield – surfaces that people are likely to have close contact with – means consideration should be given to decontamination of these surfaces, although this is likely to be more for reassurance purposes than any significant dose reduction. There are 3 physical decontamination options and 1 shielding option to consider for roofs, and 1 chemical removal option for the play equipment and garden furniture.

Shielding

- Tie down

Use of temporary tie down in the form of PVC sheeting or tarpaulin would be useful to reduce resuspension and the spread of contamination by weathering in the short-term as cleaning of roofs is likely to take time to organise.

Physical decontamination

- High pressure washing including water jetting
- Remove building surfaces
- Strippable coatings

Given that contamination on roofs makes a significant contribution to dose, some form of decontamination of roofs should be considered, ensuring that contamination isn't redistributed onto walls and ground surfaces. High pressure washing and water jetting under low pressure can be used on roofs in the first week to remove loose contamination. Modified guttering and drainpipes should be used to feed wastewater into collection tanks to prevent runoff to soils/vegetation, roads and paved areas, and the public sewer network.

Removal of building surfaces requires specialist equipment and trained individuals. It is also a disruptive and potentially damaging technique that may produce large quantities of waste. It is unlikely to be part of an optimised strategy in this scenario, accounting for the other options available. Other methods, such as strippable coatings, are not generally applicable to roofs, especially on the scale required in this scenario.

Chemical decontamination

- Reactive liquids (domestic chemicals)
- Water-based cleaning

Simple domestic or light industrial chemicals can be applied to external, non-porous surfaces (metal, glass, paint or varnished) to remove contamination. Chemically impregnated wipes are particularly useful for high touchpoint areas that might be found on children's play equipment. Water-based cleaning can be applied to some outdoor metal and wooden surfaces such as garden furniture and children's play equipment. The exact method will be dependent on the type of surface but in all cases care should be taken to ensure material is not redistributed to other surfaces.

Conclusion:

- **Eliminate:** 'remove building surfaces', 'strippable coatings'
- **Retain:** 'tie down' and 'high pressure washing including water jetting' for roofs; 'reactive liquids (domestic chemicals)' and 'water-based cleaning' for play equipment and garden furniture

Management of building interiors

Figure 2 shows that at 1 week, the contribution to the total individual dose from contamination on indoor surfaces is relatively high. However, the level of activity is comparatively low (versus outdoor surfaces) and the relatively high contribution to dose is largely due to the amount of time an individual spends inside their home and the fact that there is little to no reduction in the dose rate due to materials being present that provide shielding. The figure also shows that the relative contribution from indoor surfaces decreases more sharply with time as regular cleaning routines steadily remove contamination. Furthermore, contamination indoors is likely to be highly variable across properties and would be very difficult to predict without direct measurements. It would seem prudent to wait until all of the remediation work is completed outdoors before monitoring the interior of all the properties in Garfield. At this point a decision can be made on whether any additional protective actions would be justified.

Step 5 – Make decisions

By working through Step 3 (Identify options) and Step 4 (Evaluate options), it is possible to propose a shortlist of protective actions suitable for inclusion in a remediation strategy for Garfield as follows:

Management of the population

- Temporary relocation
- Prohibit public access

Soils and grass in residential gardens

- Remove plant material
- Remove topsoil and turf

Roads and paved areas

- High pressure washing including water jetting

Buildings external (roofs and garden furniture, play equipment)

- Tie down (temporary) (roofs)
- High pressure washing including water jetting (roofs)
- Reactive liquids (domestic chemicals) (garden furniture and children’s play equipment)
- Water-based cleaning (garden furniture and children’s play equipment)

Buildings (internal)

- Internal surfaces would be subject to monitoring once remediation of outdoor areas had been completed. Only then would it be possible to make decisions on implementation of further protective actions

In terms of timing, temporary relocation and prohibiting of public access would be implemented first to allow other actions to be carried out more easily. Tie down of contamination on roofs would be implemented as early as possible, until high pressure washing or water jetting of those surfaces can be implemented. Since some of the contamination on roofs can be transferred to lower surroundings during washing, it would be most effective to implement other actions (relating to plants, topsoil and turf, roads and paved areas and garden furniture) after cleaning of roofs has been completed (assuming roof cleaning can be arranged without much delay).

In a real situation, stakeholders and representatives from the local community would be very much involved in any decisions on the remediation strategy.

4 Inhabited area – Buckleton town (large area, lower contamination)

The following steps walk through the decision-aiding process to select remedial protective actions that could be applied to the town of Buckleton, which has lower levels of contamination than Garfield.

Step 1 – Define the situation

The release and subsequent dispersion of radioactive material occurred over a period of approximately 24 hours. The town of Buckleton is located approximately 6.5 km downwind (north-northwest) from the site (see Figure 1). It is home to a population of approximately 1,300 people with a variety of housing stock as well as communal areas for commerce and recreation. There was no rain here over the duration of the release and so contamination deposited on the ground was the result of dry deposition. Measurements taken shortly after it was confirmed that the release had ended, indicate significant levels of contamination: averages of 4,800 kBq/m^2 of ^{131}I and 350 kBq/m^2 of total radiocaesium (^{134}Cs and ^{137}Cs). No urgent protective actions to protect members of the public were implemented in this area while the emergency was ongoing but precautionary food restrictions remain in place.

Step 2 – Assess impacts

Through a combination of measurements and modelling, it is estimated that prior to any remedial protective actions, the average committed effective dose to a representative adult resident in Buckleton, from exposure to radioactivity released during the accident, will be 2.5 mSv over the first year and 1.0 mSv over the second year (these are in addition to doses received in the emergency phase) (Table 2). These estimated doses include a contribution from external irradiation received over one year from deposited gamma emitting nuclides and the committed effective dose from inhaling resuspended activity during one year. As legally binding restrictions on the selling of commercial foods produced in the area are assumed to be implemented, the dose from ingesting contaminated foods in this period will be negligible. It is estimated that the dose from external irradiation is likely to be at least 100 times greater than that from the inhalation of resuspended activity.

It is estimated that in the first 7 days after cessation of the accidental release of activity, the average outdoor dose rate in Buckleton from deposited radioactivity will be 5.9 µSv/h (compared with 33 µSv/h in Garfield) (Table 2). The contribution to the dose rate at this time is approximately 77% from ^{131}I, 20% from ^{134}Cs and 3% from ^{137}Cs.

The average outdoor dose rate from desposited radioactivity to those living in Buckleton during the second year is estimated to be of the order of 0.4 µSv/h (averaged over the year) (compared with 2.5 µSv/h in Garfield). Since ^{131}I has a relatively short half-life (~ 8 days) and so has mostly decayed away, this dose rate would be solely from the decay of the caesium isotopes.

Only outdoor dose rates (µSv/h) are considered here for simplicity. The average dose rates that members of the public would be exposed to would be lower due to time spent indoors and factors such as the shielding effects of buildings. The estimated total doses (mSv) assume an individual under “normal living” conditions, that is, spending a majority of time indoors, with the resulting reduction in dose received.

Table 2. Estimated total effective doses and average dose rates in Buckleton at various times after the release has ended

Timescale	Estimated effective dose received in period (mSv)	Average effective dose rate outdoors (µSv/h)	% contribution to dose rate from I-131
1 day – 7 days	0.3	5.9	77%
7 days – 30 days	0.4	2.7	50%
30 days – 180 days	1.1	1.1	2.6%
180 days – 1 year	0.8	0.7	0%
1 year – 2 years	1.0	0.4	0%

Deposited activity concentrations will vary significantly across surfaces and with time, with a similar pattern as for Garfield (Figure 2).

In the short term, the largest contributions to the total dose is radiation emitted from radionuclides present on roofs and internal surfaces (the reasons for which are described in the equivalent step of Section 3). However, the activity concentrations present on each surface in Buckleton are significantly lower than those in Garfield.

In Buckleton, there is significant public interest in whether the primary school and sports ground can continue to be used as normal or whether they will need to be closed for any period of time. The remediation options considered at these sites may not be justified in terms of reducing dose alone, but may also have a role in reassurance as part of a strategy to be agreed with local representatives.

Step 3 – Identify options

To illustrate how a remediation strategy may be developed for Buckleton, this section focuses on the identification of remedial protective actions for the school and sports ground on the assumption that this is what local stakeholders would be most interested in. Although not considered, it is acknowledged that some of the more easily implemented options may have a role in public reassurance and reducing doses from contamination present in residential areas recognising that, depending on the reference level decided upon, large scale remediation of such areas may not be required.

Consult the look-up table on surface types (Table 28 of the handbook) to determine whether the 17 protective actions listed are applicable to the surfaces of interest. Since there are multiple types of surfaces affected, all 17 potential protective actions should be considered further. The list of protective actions below, indicates the applicable surfaces.

Options available for inhabited areas (n=17)

No remediation

- Natural attenuation with monitoring *(applicable to all surfaces)*

Restrict access

- Prohibit public access (*applicable to all surfaces*)
- Temporary relocation (*applicable to all surfaces*)

Shielding

- Cover contaminated soil and grass *(applicable to open spaces)*
- Ploughing methods and mechanical digging techniques *(applicable to open spaces)*
- Store and cover personal and precious objects *(applicable to interior of buildings)*
- Tie down *(applicable to all surfaces)*

Physical removal techniques

- High pressure washing including water jetting *(applicable to exterior of buildings, interior of large public buildings, and roads and paved)*
- Remove and replace road and paved surfaces *(applicable to roads and paved)*
- Remove building surfaces *(applicable to exterior of buildings, interior of large public buildings)*
- Remove grass after cutting *(applicable to open spaces)*
- Remove plant material *(applicable to open spaces)*
- Remove topsoil (and turf) *(applicable to open spaces)*
- Strippable coatings *(applicable to exterior and interior of buildings)*
- Vacuum cleaning (indoor and outdoor) *(applicable to interior of buildings, and roads and paved)*

Chemical removal techniques

- Reactive liquids (domestic chemicals) *(applicable to interior and some exterior of buildings as well as outdoor objects such as fences, benches, playground equipment)*
- Water-based cleaning *(applicable to interior and some exterior of buildings as well as outdoor objects such as fences benches, playground equipment)*

Step 4 – Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclides of concern in this scenario are ^{131}I, ^{134}Cs and ^{137}Cs.

Consult the look-up table on radionuclide applicability (Table 29 in the handbook) to determine applicability of each option for ^{131}I, ^{134}Cs and ^{137}Cs.

Some options would not be justified were they being applied to radioiodine contamination alone, due to its short 8-day half-life (the level of disruption and quantities of waste that would be generated would be disproportionate given the limited short-term dose reduction achieved). However, as the radionuclide mix also includes the longer lived radiocaesium isotopes, these options cannot be excluded. Nevertheless, there are 2 options that are not applicable (‘natural attenuation with monitoring’ and ‘store and cover personal and precious objects’) because the longer lived caesium radionuclides will remain in the environment for several years and make a significant contribution to the overall dose. While the relatively long half-life of ^{137}Cs is listed as a constraint for ploughing methods and mechanical digging techniques, given that ^{131}I and ^{134}Cs contribute much more significantly to dose over the first two years, this option should be retained.

Conclusion:

- **Eliminate:** ‘natural attenuation with monitoring’ and ‘store and cover personal and precious objects’
- **Retain:** ‘prohibit public access’, ‘temporary relocation’, ‘cover contaminated soil and grass’, ‘ploughing methods and mechanical digging techniques’, ‘tie down’, ‘high pressure washing including water jetting’, ‘remove and replace road and paved surfaces’, ‘remove building surfaces’, ‘remove grass after cutting’, ‘remove plant material’, ‘remove topsoil (and turf)’, ‘strippable coatings’, ‘vacuum cleaning’ (indoor and outdoor), ‘reactive liquids’ (domestic chemicals), ‘water-based cleaning’.

Consider key constraints that will influence applicability of each protective action

There are constraints such as waste generation, effectiveness in reducing dose, doses to implementers, technical limitations, time constraints, weather, time of year and cost, that may reduce the applicability of a protective action according to the circumstances under consideration.

Consult look-up table on constraints (Table 30 in the handbook) to identify if the major or moderate constraints of any of the protective actions are relevant for the current scenario.

The discussion below is subdivided into 5 sections: (i) management of the population; (ii) management of open spaces; (iii) management of road and paved areas; (iv) management of exterior building surfaces, including objects; and (v) management of building interiors. Some protective actions are applicable to more than one type of surface.

Management of the population

There are 2 protective actions to consider:

- Prohibit public access
- Temporary relocation

The estimated committed effective dose in the first year is 2.5 mSv, due mainly to external irradiation from ^{134}Cs and, to a lesser extent, ^{137}Cs. This level of dose is likely not to exceed the reference level selected for this area (in the range 1 – 10 mSv) by much and so particularly disruptive protactive actions, such as temporary relocation of all the inhabitants of Buckleton (~ 1,300 people), would not be justified. However, there may be pressure to carry out remediation at the school, which will require public access to be prohibited while this is being implemented. As the accident occurred in late June, it is likely that the school would remain closed for the last few weeks of term, to enable the school to be empty while work is carried out. Options for pupils to continue their studies at other locations or online would be explored by the authorities. Similarly, pressure to remediate the sports ground may require public access to be prohibited until the work is complete.

Conclusion

- **Retain:** ‘prohibit public access’, ‘temporary relocation’ (school only)

Management of open spaces (that is, soils, grass and other plant material)

There are 3 shielding options and 3 physical decontamination options to consider.

Shielding

- Cover contaminated soil and grass
- Ploughing methods and mechanical digging techniques
- Tie down

All three options are highly effective at reducing external gamma dose rates. However, as all three leave the contamination in place there may be public anxiety due to the sensitive nature of the school and sports ground. Therefore, covering the contaminated soils and grass, or mixing the contamination by ploughing and digging may not be acceptable options and can be eliminated. Temporary tie down should be considered as a complementary short-term option to reduce resuspension of dust if physical removal techniques are selected.

Physical decontamination

- Remove grass after cutting
- Remove plant material
- Remove topsoil (and turf)

To be effective, removal of grass cuttings and other plant material needs to be carried out as soon as possible after deposition, and before any rain. Removal of grass after cutting has a relatively low effectiveness (that is, by reducing levels of contamination by a factor of 2 or less) but could be carried out initially at both the school and sports ground to remove a portion of the deposited contamination. Removal of plant material (pruning of trees to remove leaves and branches and the removal of shrubs) from the school grounds along with volume reduction (for example, chipping) should also be considered in areas close to where pupils spend their time. If, after these actions, subsequent measurements of contamination levels remain unacceptable to local stakeholders, removal of topsoil and turf might be carried out, bearing in mind that while this option is highly effective, it generates large volumes of putrescible waste that require disposal.

Conclusion:

- **Eliminate**: 'cover contaminated soil and grass', 'ploughing methods and mechanical digging techniques'
- **Retain**: 'tie down', 'remove grass after cutting', 'remove plant material' and 'remove topsoil (and turf)'

Management of roads and paved areas

There are 3 physical decontamination options and 1 shielding option to consider.

Shielding

- Tie down

Tie down is mainly used where the inhalation dose from resuspended material is likely to be of concern (that is, not in this scenario). However, temporary tie down could be considered as a complementary option to reduce resuspension of dust, if any of the physical removal techniques are selected.

Physical decontamination

- High pressure washing including water jetting
- Remove and replace road and paved surfaces
- Vacuum cleaning (indoor and outdoor)

Depending on the levels of contamination present, some form of physical decontamination may be required for paved areas in and around the school. High pressure washing including water jetting, and vacuum cleaning are the least disruptive, and likely to be moderately effective if carried out in the first week to remove loose contamination. Removal and replacement of paved surfaces is a disruptive and expensive option that generates large volumes of waste and is unlikely to be justified for the levels of dose arising from the contamination present.

Conclusion:

- **Eliminate**: 'remove and replace road and paved surfaces'
- **Retain**: school only: 'tie down', 'high pressure washing including water jetting', 'vacuum cleaning (indoor and outdoor)'

Management of exterior building surfaces, including objects

The doses from contamination on external building surfaces, particularly walls, are low. The highest contribution to the overall dose from deposited activity is due to exposure to radionuclides present on the school roofs.

There are 3 physical decontamination options and 1 shielding option to consider for roofs at the school, and 1 chemical removal option for the play equipment and outdoor furniture in the playground.

Shielding

- Tie down

Use of temporary tie down in the form of PVC sheeting or tarpaulin would be useful to reduce resuspension and the spread of contamination by weathering in the short-term as cleaning of roofs is likely to take time to organise.

Physical decontamination

- High pressure washing including water jetting
- Remove building surfaces
- Strippable coatings

High pressure washing and water jetting under low pressure can be used on roofs in the first week to remove loose contamination. Modified guttering and drainpipes should be used to feed wastewater into collection tanks to prevent runoff to soils/vegetation, roads and paved areas, and the public sewer network.

Removal of building surfaces requires specialist equipment and trained individuals. It is also a disruptive and potentially damaging technique that may produce large quantities of waste. It is unlikely to be part of an optimised strategy in this scenario, given the relatively low levels of contamination present and accounting for the other options available. Other methods, such as strippable coatings, are not generally applicable to roofs.

Chemical decontamination

- Reactive liquids (domestic chemicals)
- Water-based cleaning

Simple domestic or light industrial chemicals can be applied to external, non-porous surfaces (metal, glass, paint or varnished) to remove contamination. Chemically impregnated wipes are particularly useful for high touchpoint areas that might be found on children's play equipment. Water-based cleaning can be applied to some outdoor metal and wooden surfaces such as garden furniture and children's play equipment. The exact method will be dependent on the type of surface but in all cases care should be taken to ensure material is not redistributed to other surfaces.

Conclusion:

- **Eliminate**: 'remove building surfaces' and 'strippable coatings'
- **Retain**: 'tie down' and 'high pressure washing including water jetting' for school roofs; reactive liquids (domestic chemicals) and 'water-based cleaning' for any play equipment, outdoor furniture

Management of building interiors

At 1 week, the contribution to the total individual dose from contamination on indoor surfaces is relatively high. However, the level of activity is comparatively low (versus outdoor surfaces) and the relatively high contribution to dose is largely due to the amount of time an individual spends inside their home and the fact that there is little to no reduction in the dose rate due to materials being present that provide shielding. The relative contribution from indoor surfaces decreases more sharply with time as regular cleaning routines steadily remove contamination. Furthermore, contamination indoors is likely to be highly variable across buildings and would be very difficult to predict without direct measurements. It would seem prudent to wait until all of the remediation work is completed outdoors before monitoring the interior of the school. At this point a decision can be made on whether any additional protective actions would be justified.

Step 5 – Make decisions

By working through Step 3 (Identify options) and Step 4 (Evaluate options), it is possible to propose a shortlist of protective actions suitable for inclusion in a remediation strategy for Buckleton that focus primarily on the school and sports ground. For the remainder of Buckleton, it is unlikely that any large scale remedial protective actions would be required.

Management of the population

- Prohibit public access (school and sports ground)
- Temporary relocation (school only)

Open spaces at the school and sports ground

- Remove grass after cutting
- Remove plant material (school only)
- Remove topsoil (and turf) (with temporary tie down in place)

Roads and paved areas (school only)

- High pressure washing including water jetting
- Vacuum cleaning (indoor and outdoor)

Buildings external (roofs and garden furniture, play equipment)

- Tie down (temporary) (roofs)
- High pressure washing including water jetting (roofs)
- Reactive liquids (domestic chemicals) (garden furniture and children's play equipment)
- Water-based cleaning (garden furniture and children's play equipment)

Buildings (internal)

- Internal surfaces at the school would be subject to monitoring once remediation of outdoor areas had been completed. Only then would it be possible to make decisions on implementation of further protective actions

In terms of timing, temporary relocation and prohibiting of public access would be implemented first to allow other actions to be carried out more easily. Tie down of contamination on roofs and outdoor areas would be implemented as early as possible, until high pressure washing or water jetting of roofs and remediation of those other surfaces can be implemented. Since some of the contamination on roofs can be transferred to lower surroundings during washing, it would be most effective to implement other actions (relating to plants, grass, roads and paved areas and garden furniture) after cleaning of roofs has been completed (assuming roof cleaning can be arranged without much delay).

In a real situation, stakeholders and representatives from the local community would be very much involved in any decisions on the remediation strategy.

5 Food production systems – green vegetables

The following steps walk through the decision-aiding process to select remedial protective actions that could be applied to commercial production of green vegetables.

Step 1 – Define the situation

The release and subsequent dispersion of radioactive material occurred over a period of approximately 24 hours. The period of notification of the release was insufficient to allow any preventive actions (that is, closing air intakes in greenhouses and food processing plants, and protecting harvested crops from deposition) to be carried out. Radioactivity was deposited over large areas of farmland, and shortly after this was confirmed by field measurements. A decision was made during the emergency phase to restrict the commercial sale of green vegetables grown in the affected area as a food product by use of a FEPA (Food and Environment Protection Act) order.

Step 2 – Assess impacts

Through a combination of measurements and modelling, activity concentrations in leafy green vegetables (for example, lettuce) and legumes (hereafter collectively referred to as “green vegetables”) are predicted to exceed maximum permitted levels (MPLs) in food over a growing area of approximately 54 km^2. The scale and duration of the predicted restrictions is shown in Table 3. Without any other protective actions, it is estimated that in total approximately 4,400 tonnes of green vegetables would be prevented from being sold to market over the lifetime of restrictions and would therefore need to be managed as a waste product.

Table 3. Scale of restrictions on green vegetables

Duration of restriction	Area affected (km^2) [note 1]	Maximum distance (km)	Mass of food needing disposal (tonnes)
1 day – 30 days	29	220	1,500
30 days – 90 days	25	130	2,900
90 days – 1 year	< 1	4	26
1 year – 3 years	0	0	0
>3 years	0	0	0

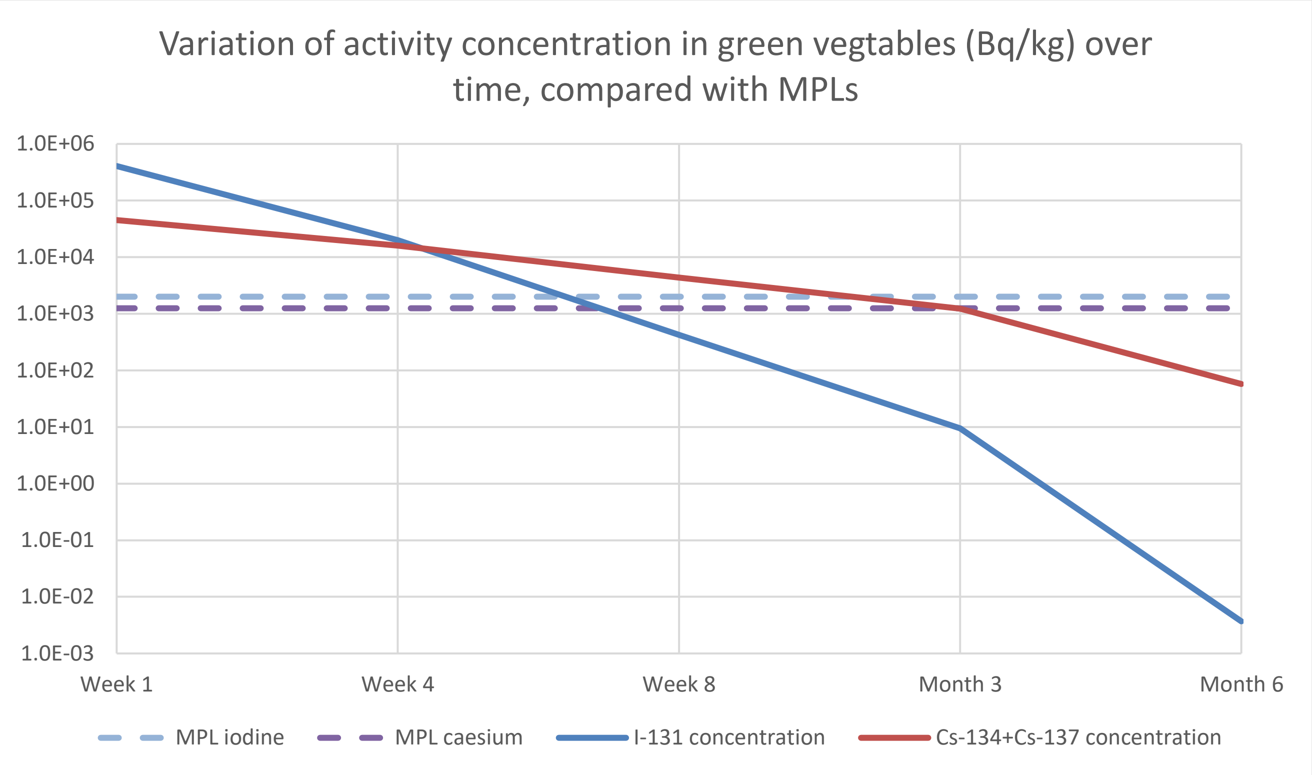
Notes

[note 1] Area of land used for green vegetable production.

A small proportion of the crops affected (~ 25%) is lettuce which needs to be harvested by the end of June. The rest (~ 75%) are peas and beans which need to be harvested by October.

The durations for which MPLs are exceeded depend on the levels of deposition at a given location but also vary between radionuclide groups. For illustration, Figure 3 shows how the total activity concentrations of different radionuclides (^{131}I, ^{134}Cs and ^{137}Cs) in green vegetables produced at a farm 2 km downwind from the release vary with time with respect to the associated MPL.

Figure 3. Activity concentrations in green vegetables compared with maximum permitted levels (MPLs) at a farm 2 km downwind from the release



Modelling indicates that initially the concentration of ^{131}I in green vegetables exceeds the MPL by a greater margin than the combined concentration of radiocaesium isotopes exceeds the corresponding MPL. However, after ~ 6 weeks, the concentration of ^{131}I in green vegetables falls below the MPL (mainly due to the short half-life of ^{131}I) whereas the combined caesium radionuclide concentration continues to exceed the relevant MPL for up to ~ 3 months.

Step 3 – Identify options

A remediation strategy for green vegetable growing areas can be formed by considering protective actions applicable to this food product.

Consult the look-up table on food types (Table 22 of the handbook) to determine which of the 24 protective actions listed are applicable to green vegetables (crops and grassland). In this scenario, 14 potential protective actions can be eliminated because they are not applicable to commercial production of green vegetables. A further 2 options (‘close air intake in greenhouses and food processing plants’ and ‘protect harvested crops from deposition’) can be eliminated since they must be implemented before arrival of the plume to be effective, and in this scenario the period of notification was insufficient for any actions to be carried out in that time.

Options for green vegetables (commercial production) (n=8)

Restricting/preventing/reducing consumption of contaminated food

- Processing and storage (commercial)
- Product withdrawal and recall
- Restrictions on terrestrial or aquatic foods (FEPA orders)
- Select alternative land use (non-edible products)

Monitoring and dose/risk assessment

- Natural attenuation with monitoring

Land management

- Application of nitrate, phosphate and potassium (NPK) fertilisers and/or lime to soils
- Ploughing options
- Remove topsoil

Step 4 – Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclides of concern in this scenario are ^{131}I, ^{134}Cs and ^{137}Cs.

Consult the look-up table on radionuclide applicability (Table 23 of the handbook) to determine applicability of each option for ^{131}I, ^{134}Cs and ^{137}Cs. Since there is a mixture of short- and long-lived radionuclides present and, in many areas, the MPLs are exceeded by the long-lived caesium radionuclides even after the short-lived ^{131}I has largely decayed away, it is not possible to eliminate any options solely on the basis that they are applicable only to short- or long-lived radionuclides (while they might not be useful for ^{131}I, they could still be useful for ^{134}Cs and ^{137}Cs). Therefore, the list of options remaining is unchanged from that in Step 3.

Consider key constraints that will influence applicability of each protective action

There are constraints such as waste generation, effectiveness in reducing dose, doses to implementers, technical limitations, time constraints, weather, time of year and cost, that may reduce the applicability of a protective action according to the circumstances under consideration.

Consult the look-up table on constraints (Table 24 of the handbook) to identify if the major or moderate constraints of any of the protective actions are relevant for the current scenario.

<u>Options for green vegetables (commerical production)</u>

There are 8 protective actions to consider, split over 3 categories.

Restricting/preventing/reducing consumption of contaminated food

- Processing and storage (commercial)
- Product withdrawal and recall
- Restrictions on terrestrial or aquatic foods (FEPA orders)
- Select alternative land use (non-edible products)

Restrictions on the entry of green vegetables into the foodchain, where activity concentrations exceed the MPLs for ^{131}I, ^{134}Cs and ^{137}Cs, would be enforceable by the placing of FEPA orders which are legally binding, irrespective of any constraints. Where there is uncertainty that contaminated products may have entered the foodchain before restrictions had been put in place, product withdrawal and recall is a possible option. This and the placing of restrictions can lead to large volumes of waste, requiring disposal.

Processing and storage of leafy green vegetables and legumes, for example, by methods such as removal of inedible outer leaves and pods, washing, freezing or canning can be a useful alternative to disposal provided suitable facilities are available, an available market, and that the final product is monitored before entering the foodchain.

Selection of an alternative land use is generally an expensive, last resort option that would only be considered once it was decided that the land couldn't support food production due to high levels of contamination leading to food restrictions over many years. This is not the case here and as less radical protective actions are available, the selection of an alternative land use can be eliminated.

Conclusion:

- **Eliminate**: 'select alternative land use (non-edible products)'
- **Retain**: 'processing and storage (commercial)', 'product withdrawal and recall', 'restrictions on terrestrial or aquatic foods (FEPA orders)'

Monitoring and dose/risk assessment

- Natural attenuation with monitoring

Natural attenuation with monitoring may be a useful option for some varieties of green vegetables still growing in the contaminated area which are predicted to have activity concentrations of ^{134}Cs and ^{137}Cs less than the MPL at the time of harvest. It may also be useful for areas where late crops would be grown but have not yet been sown/transplanted to outdoor soil.

Conclusion

- **Retain**: 'natural attenuation with monitoring'

Land management

- Application of NPK fertilisers and/or lime to soils
- Ploughing options
- Remove topsoil

Application of NPK fertilisers and/or lime is only applicable where the soil has a low pH or calcium status, which is extremely unlikely in this scenario where prime agricultural land has been contaminated, so this option can be eliminated. Shallow ploughing of the land after removal of the crop is normal agricultural practice and may reduce radionuclide uptake to subsequent crops by up to 50%. Deep ploughing is more effective but may impact soil fertility so, if chosen, may require additional soil treatments. Given the relatively short expected duration of the restrictions (~ 3 months), deep ploughing would not represent an optimised strategy. Therefore, ploughing options (shallow ploughing only) should be retained, recognising that this may be carried out as part of normal agricultural practice anyway.

The removal of topsoil is an expensive and radical protective action that produces significant volumes of contaminated waste that would require disposal. It also leads to a reduction in soil fertility. The steady decrease in the level of soil and plant contamination (expected duration of food restrictions ~ 3 months) in this scenario means application of this option is unlikely to represent an optimsed use of resources. Therefore, the remove topsoil option can be eliminated.

Conclusion:

- **Eliminate:** ‘application of NPK fertilisers and/or lime to soils’, ‘remove topsoil’
- **Retain**: ‘ploughing options (shallow ploughing only)’

Step 5 – Make decisions

By working through Step 3 (Identify options) and Step 4 (Evaluate options), it is possible to propose a remediation strategy for green vegetables as follows:

Early-medium phase

- Processing and storage (commercial)
- Product withdrawal and recall
- Restrictions on terrestrial or aquatic foods (FEPA orders)

Medium-long-term phase

- Natural attenuation with monitoring
- Ploughing options (shallow ploughing only, as part of normal agricultural practice, before planting of new crop)

In a real situation, stakeholders and representatives from the local community would be very much involved in any decisions on the remediation strategy.

6 Food production systems – beef

The following sections step through the decision-aiding process to select remedial protective actions that could be applied to commercial production of beef.

Step 1 – Define the situation

The release and subsequent dispersion of radioactive material occurred over a period of approximately 24 hours. The period of notification of the release was insufficient to allow any preventive actions (that is, closing air intakes in food processing plants; and sheltering livestock) to be carried out. Radioactivity was deposited over large areas of farmland, and shortly after this was confirmed by field measurements. A decision was made during the emergency phase to restrict the commercial sale of beef from cows living on farms in the affected area by use of a FEPA order.

Step 2 – Assess impacts

Through a combination of measurements and modelling, activity concentrations in beef from livestock living on pasture are predicted to exceed maximum permitted levels (MPLs) in food over an area of approximately 800 km^2. The scale and duration of the predicted restrictions is shown in Table 4. Without any other protective actions, it is estimated that in total approximately 4,800 tonnes of beef would be prevented from going to market over the lifetime of the restrictions and would therefore need to be managed as a waste product.

Table 4. Scale of restrictions on beef

<table>
<tr><th>Duration of restriction</th><th>Area affected (km^2) [note 1]</th><th>Maximum distance (km)</th><th>Mass of beef needing disposal (tonnes)</th></tr>
<tr><td>1 day – 30 days</td><td>2</td><td>20</td><td rowspan="2">540</td></tr>
<tr><td>30 days – 90 days</td><td>290</td><td>160</td></tr>
<tr><td>90 days – 1 year</td><td>470</td><td>150</td><td>3,500</td></tr>
<tr><td>1 year – 3 years</td><td>32</td><td>29</td><td rowspan="2">720</td></tr>
<tr><td>>3 years</td><td>0.02</td><td><0.5</td></tr>
</table>

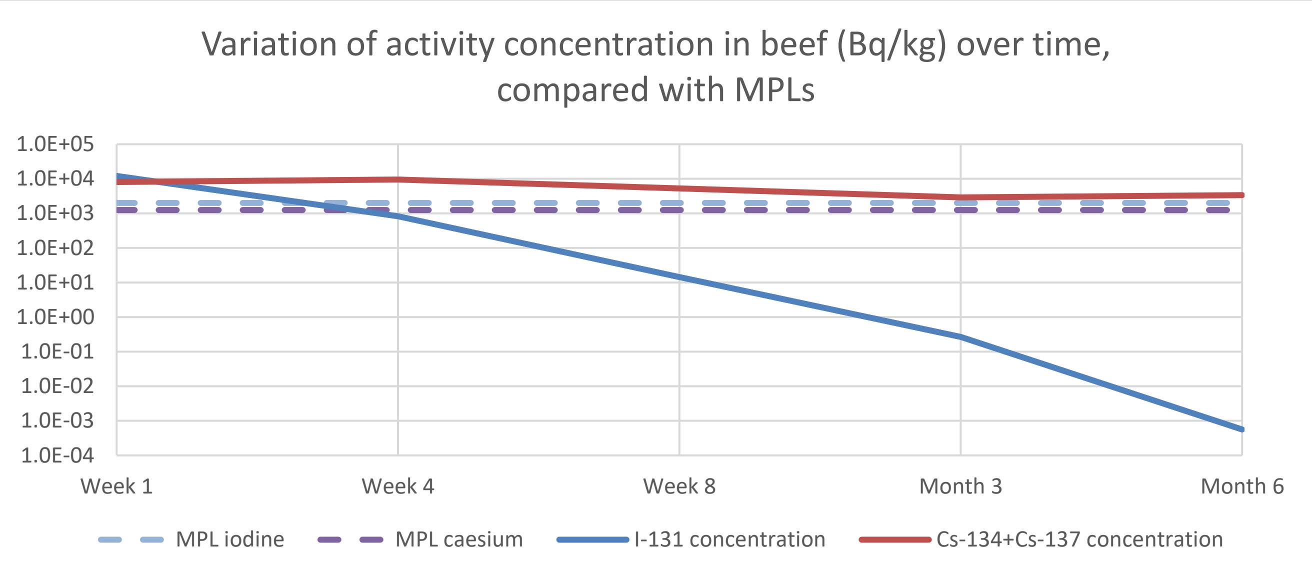
Notes

[note 1] Area of land used for beef production.

The beef cattle within the affected area are a range of ages. At the time of the accident, almost half of the animals are due to be slaughtered within the next 6 months.

The durations for which MPLs are exceeded depend on the levels of deposition at a given location but also vary between radionuclide groups. For illustration, Figure 4 shows how the total activity concentrations of different radionuclides (^{131}I, ^{134}Cs and ^{137}Cs) in beef produced on a farm 20 km downwind from the release vary with time with respect to the appropriate MPL. For this scenario it was assumed that, following normal farming practices, animals would be housed inside after month 3. Once housed inside those animals would be fed contaminated fodder due to most of that feed being harvested during late summer after deposition occurred. The impact of this practice can be seen in Figure 4 where a small increase in the activity concentration of radiocaesium in beef is observed after month 3.

Figure 4. Activity concentrations in beef compared with maximum permitted levels (MPLs)



Modelling indicates that in the first month, both the concentration of ^{131}I and the combined concentration of radiocaesium isotopes exceed the corresponding MPL. However, after ~ 4 weeks, the concentration of ^{131}I in beef falls below the MPL (mainly due to the short half-life of ^{131}I) whereas the combined caesium radionuclide concentration continues to exceed the relevant MPL for significantly longer, until beyond 6 months.

Step 3 – Identify options

A remediation strategy for beef production areas can be formed by considering protective actions applicable to this food product.

Consult the look-up table on food types (Table 22 of the handbook) to determine which of the 24 protective actions listed are applicable to beef (meat intensive). In this scenario, 8 potential protective actions can be eliminated because they are not applicable to beef. A further 2 options (‘close air intake in greenhouses and food processing plants’ and ‘shelter livestock’) can be eliminated since they must be implemented before arrival of the plume to be effective, and in this scenario the period of notification was insufficient for any actions to be carried out in that time.

Options for beef (commercial production) (n=14)

Restricting/preventing/reducing consumption of contaminated food:

- Processing and storage (commercial)
- Product withdrawal and recall

- Restrictions on terrestrial or aquatic foods (FEPA orders)
- Select alternative land use (non-edible products)
- Slaughter and supress lactation

Monitoring and dose/risk assessment:

- Derestriction surveys and dose assessment
- Live monitoring (Mark and Release)
- Natural attenuation with monitoring

Livestock management:

- Addition of ammonium iron hexacyanoferrate (AFCF) to concentrate ration
- Addition of calcium to concentrate ration
- Addition of clay minerals to concentrate ration
- Clean feeding
- Manipulate slaughter times
- Selective grazing

Step 4 – Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclides of concern in this scenario are ^{131}I, ^{134}Cs and ^{137}Cs.

Consult the look-up table on radionuclide applicability (Table 23 of the handbook) to determine applicability of each option for ^{131}I, ^{134}Cs and ^{137}Cs. Since there is a mixture of short- and long-lived radionuclides present and, in many areas, the MPLs are exceeded by the long-lived caesium radionuclides even after the short-lived ^{131}I has largely decayed away, it is not possible to eliminate any options on the basis that they are applicable only to short- or long-lived radionuclides (while they might not be useful for ^{131}I, they could still be useful for ^{134}Cs and ^{137}Cs). Nevertheless, one option, addition of calcium to feed, can be eliminated because it is specific for radionuclides in Group II of the periodic table which does not include either iodine or caesium. This leaves 13 options remaining.

Consider key constraints that will influence applicability of each protective action

There are constraints such as waste generation, effectiveness in reducing dose, doses to implementers, technical limitations, time constraints, weather, time of year and cost that may reduce the applicability of a protective action according to the circumstances under consideration.

Consult the look-up table on constraints (Table 24 of the handbook) to identify if the major or moderate constraints of any of the protective actions are relevant for the current scenario.

<u>Options for beef (commercial production)</u>

There are 13 protective actions to consider, split over 3 categories.

Restricting/preventing/reducing consumption of contaminated food:

- Processing and storage (commercial)
- Product withdrawal and recall
- Restrictions on terrestrial or aquatic foods (FEPA orders)
- Select alternative land use (non-edible products)
- Slaughter and supress lactation

Restrictions on the entry of beef into the foodchain, where activity concentrations exceed the MPLs for ^{131}I, ^{134}Cs and ^{137}Cs, would be enforceable by the placing of FEPA orders which are legally binding, irrespective of any constraints. Where there is uncertainty that contaminated products may have entered the food chain before restrictions had been put in place, product withdrawal and recall is a possible option. This and the placing of restrictions can lead to large volumes of waste, requiring disposal.

Processing and storage of meat, for example, by methods such as boiling or salting/marinating can be useful, although the resulting reduction in activity concentration is low (reductions of less than a factor of 2) and unlikely to reduce levels in meat products sufficiently so that they could enter the food chain, and so would probably not be part of an optimised strategy. Alternative land use and slaughtering of animals are both expensive, radical options that, given the availability of other protective actions (see options for livestock management below), would not be applicable. Therefore, ‘processing and storage’, ‘select alternative land use (non-edible products)’ and ‘slaughter and supress lactation’ can be eliminated.

Conclusion:

- **Eliminate:** ‘processing and storage (commercial)’, ‘select alternative land use (non-edible products)’, ’slaughter and supress lactation’
- **Retain:** ‘product withdrawal and recall’, ‘restrictions on terrestrial or aquatic foods (FEPA orders)’

Monitoring and dose/risk assessment:

- Derestriction surveys and dose assessment
- Live monitoring (Mark and Release)
- Natural attenuation with monitoring

Given that a large proportion of the contamination in meat products over the duration of the restrictions is from ^{134}Cs and ^{137}Cs, natural attenuation is unlikely to lead to significant reduction in contamination levels on the timescales required for beef production (that is, livestock would still need to be slaughtered and disposed of) so this option can be eliminated.

Live monitoring can provide valuable information on the effectiveness of other actions (see options for livestock management below) and so is likely to be an important part of any strategy to reduce activity concentrations in meat products. Availability of resources (equipment and trained personnel) are likely to be limiting factors on how quickly live monitoring can be implemented at scale, making it an option for the medium-long term.

Derestriction surveys are carried out where routine monitoring indicates that activity concentrations of gamma emitting radionuclides in grazing livestock have decreased and are no longer exceeding the MPLs; they are used as evidence that FEPA orders and associated restrictions can be removed and would likely be required in this case.

Conclusion:

- **Eliminate:** ‘natural attenuation with monitoring’
- **Retain:** ‘derestriction surveys and dose assessment’, ‘live monitoring (Mark and Release)’

Livestock management:

- Addition of AFCF to concentrate ration
- Addition of clay minerals to concentrate ration
- Clean feeding
- Manipulation of slaughter times
- Selective grazing

The addition of ammonium-ferric hexacyano-ferrate (AFCF) or clay minerals to feed can significantly reduce the uptake of caesium radionuclides in the cow gut, resulting in reduced concentration of those radionuclides in the meat. The need to secure supplies of sufficient quantities of these additives would mean this is more likely to be retained as a medium to long term option only, if the combination of other options is not adequate.

Clean feeding of livestock in the period leading up to slaughter, possibly for up to a few months depending on the activity present in individual animals, would help to reduce activity concentrations in the meat to below the MPL. Suitable housing should not be an issue since livestock in the east of England are typically brought indoors during the winter. However, there may be limited supplies of alternative clean feed as winter supplies would have been depleted and the first cut of silage may not be ready. This can be remedied by the purchase of clean feed from outside the contaminated area.

Manipulation of slaughter time is a viable option, either by slaughtering early to prevent radionuclide uptake to meat (limited capacity), or by adopting a longer finishing period during which clean feed is provided.

Selective grazing requires the availability of less contaminated pasture nearby but, in this scenario, contamination is assumed to be sufficiently widespread that costs associated with the transportation of livestock would not be justified, particularly when other more practicable options are available. Therefore, the selective grazing option can be eliminated.

Conclusion:

- **Eliminate:** ‘selective grazing’
- **Retain:** ‘addition of AFCF to concentrate ration’, ‘addition of clay minerals to concentrate ration’, ‘clean feeding’, ‘manipulate slaughter times’

Step 5 – Make decisions

By working through Step 3 (Identify options) and Step 4 (Evaluate options), it is possible to propose a remediation strategy for beef production as follows:

Early-medium phase

- Restrictions on terrestrial or aquatic foods (FEPA orders)
- Product withdrawal and recall

Medium-long-term phase

- Derestriction surveys and dose assessment (in order for FEPA Orders to be removed)
- Live monitoring (Mark and Release) (to show effectiveness of other protective actions)
- Clean feeding
- Manipulate slaughter times (delayed slaughter)

In reserve (these options may be considered for implementation in the medium- to long-term if the above options do not adequately address the situation)

- Addition of AFCF to concentrate ration
- Addition of clay minerals to concentrate ration

In a real situation, stakeholders and representatives from the local community would be very much involved in any decisions on the remediation strategy.

7 Food production systems – domestic produce

The following steps walk through the decision-aiding process to select remedial protective actions that could be applied to domestic produce grown on allotments.

Within urban areas, food is mainly produced in either allotments or gardens. Although the following text discusses application of the UKRHRIv5 to allotments, since for most people who eat domestic produce a larger fraction of their food would come from such areas compared to gardens, similar arguments would apply to garden produce. Since statutory restrictions, including the use of maximum permitted levels (MPLs), do not apply to domestically produced foods, and protective actions are not enforceable, provision of advice to members of the public would be the primary aim of responsible authorities.

Step 1 – Define the situation

The release and subsequent dispersion of radioactive material occurred over a period of approximately 24 hours. Radioactivity was deposited over urban areas and rural settlements, including land used as allotments by the local population. At the time of contamination, the vast majority of crops growing were a range of green vegetables and root vegetables.

Step 2 – Assess impacts

Although statutory restrictions, including the use of maximum permitted levels (MPLs), do not apply to domestically produced foods, MPLs will be referenced in this discussion as a guide for when contamination present in domestically produced foods may represent an unacceptable level of risk. In a real situation, food contamination levels of concern would be determined by use of a specific risk assessment. For illustration, Figure 3 shows how the total activity concentration of different radionuclides (^{131}I, ^{134}Cs and ^{137}Cs) in green vegetables produced 2 km downwind from the release vary with time with respect to the associated MPL. It can be seen that at this location, MPLs would be expected to be exceeded in green vegetables for up to 6 months. Assuming standard growing conditions, activity concentrations in other domestic foods (for example, root vegetables) will be considerably lower than in green vegetables, especially in the first year.

Step 3 – Identify options

A remediation strategy for food produce grown on allotments can be formed by considering protective actions applicable to this production type.

Consult the look-up table on food type (Table 22 in the handbook) to determine which of the 24 protective actions listed are applicable to domestic production. In this scenario, all except 3 protective actions can be eliminated.

Options for domestic produce (allotments) (n=3)

Restricting/preventing/reducing consumption of contaminated food:

- Dietary advice, including culinary preparation

Monitoring and dose/risk assessment:

- Consumer access to monitoring equipment

Land management:

- Remove topsoil

Step 4 – Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclides of concern in this scenario are ^{131}I, ^{134}Cs and ^{137}Cs.

Consult the look-up table on radionuclide applicability (Table 23 of the handbook) to determine applicability of each option for ^{131}I, ^{134}Cs and ^{137}Cs. Since there is a mixture of short- and long-lived radionuclides present and, in many areas, the MPLs are exceeded by the long-lived caesium radionuclides even after the short-lived ^{131}I has largely decayed away, it is not possible to eliminate any options solely on the basis that they are applicable only to short- or long-lived radionuclides (while they might not be useful for ^{131}I, they could still be useful for ^{134}Cs and ^{137}Cs). Therefore, the list of options remaining is unchanged from that in Step 3.

Consider key constraints that will influence applicability of each protective action

There are constraints such as waste generation, effectiveness in reducing dose, doses to implementers, technical limitations, time constraints, weather, time of year and cost that may reduce the applicability of a protective action according to the circumstances under consideration.

Consult the look-up table on constraints (Table 24 of the handbook) to identify if the major or moderate constraints of any of the protective actions are relevant for the current scenario.

<u>Options for domestic produce (allotments)</u>

There are 3 protective actions to consider, split over 3 categories.

Restricting/preventing/reducing consumption of contaminated food

- Dietary advice, including culinary preparation

Monitoring and dose/risk assessment

- Consumer access to monitoring equipment

Land management

- Remove topsoil

Dietary advice includes provision of information on activity concentrations in a range of domestic produce in conjunction with advice on the risks of consuming contaminated produce and options for reducing radionuclide intake from consuming the produce. Culinary preparation includes standard techniques such as washing, blanching, removal of outer leaves, peeling and shelling. Dietary advice and culinary preparation are together an effective protective action for domestic produce and should be retained.

In the medium to long term, monitoring equipment can be made available to consumers for them to better control their own radiological situation.

Whilst removal of topsoil may be considered for allotments, significant quantities of waste are generated, and the overall cost is high. In this scenario, where risks to health from eating contaminated foods without any protective actions may not be unacceptable after the first 6 months, removal of topsoil is unlikely to represent an optimised solution.

Conclusion:

- **Eliminate**: ‘remove topsoil’
- **Retain**: ‘dietary advice, including culinary preparation’, ‘consumer access to monitoring equipment’

Step 5 – Make decisions

By working through Step 3 (Identify options) and Step 4 (Evaluate options), it is possible to propose a remediation strategy for domestic produce grown on allotments, as follows:

Early-medium phase

- Dietary advice, including culinary preparation

Medium-long-term phase

- Consumer access to monitoring equipment

In a real situation, stakeholders and representatives from the local community would be very much involved in any decisions on the remediation strategy.

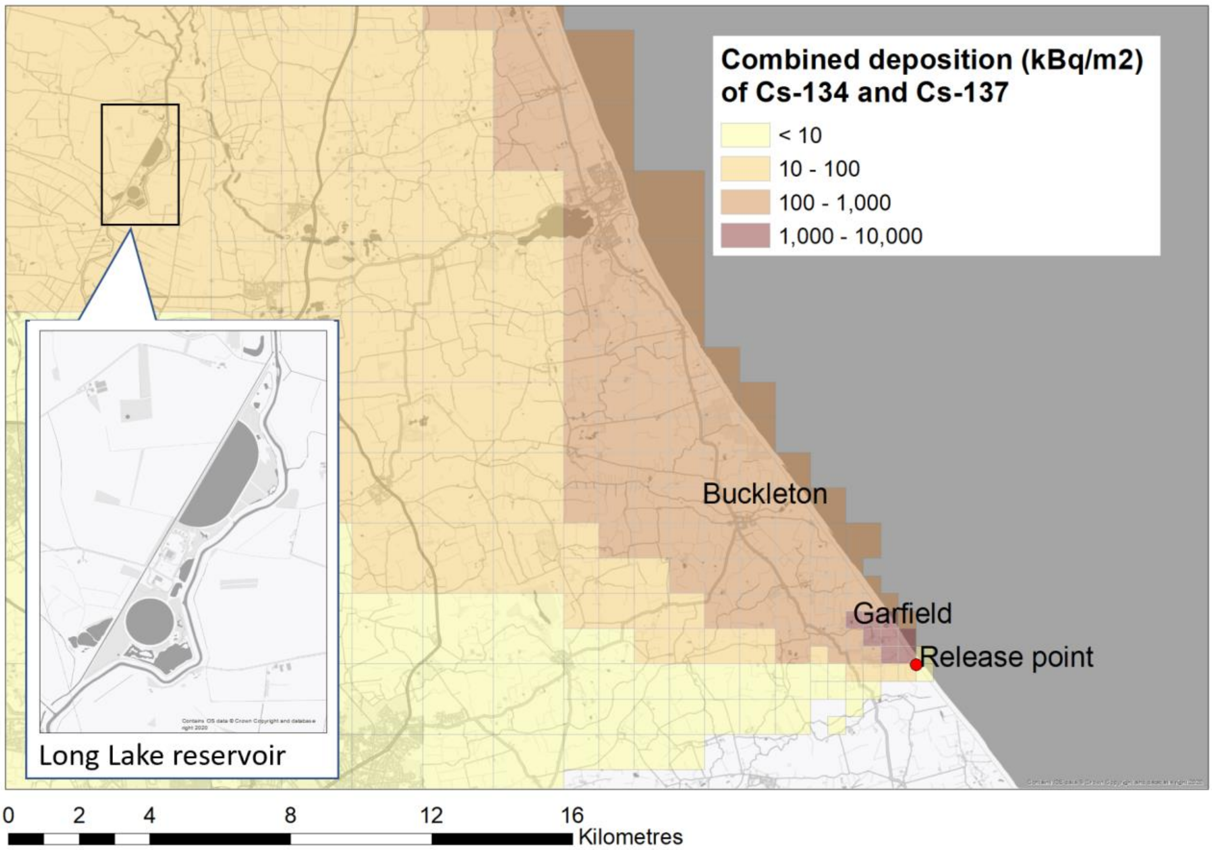
8 Drinking water supply – water reservoir

The following steps walk through the decision-aiding process to select remedial protective actions that could be applied to drinking water, focussing on water sourced from a reservoir.

Step 1 – Define the situation

The release and subsequent dispersion of radioactive material occurred over a period of approximately 24 hours. Radioactivity was deposited over a large area, including Long Lake reservoir (Figure 5), which lies 25 km northwest of the power plant. The reservoir is a source of potable water and has an abstraction system and water processing plant attached to it which feeds into the public supply. During the airborne dispersion of the radioactive material, significant deposition of radioactivity onto the reservoir occurred: 500 kBq/m^2 of ^{131}I, 40 kBq/m^2 of ^{134}Cs and 15 kBq/m^2 of ^{137}Cs.

Figure 5. Location of reservoir with combined deposition of caesium radionuclides



No private water supplies are known to be contaminated as a result of the accident.

Step 2 – Assess impacts

Through a combination of measurements and modelling, it is estimated that in the first 7 days after deposition, the average activity concentrations in abstracted water prior to treatment will be approximately 2,700 Bq/l of ^{131}I, 400 Bq/l of ^{134}Cs and 150 Bq/l of ^{137}Cs. These activity concentrations exceed the UK drinking water action level for isotopes of iodine (500 Bq/l) but not for isotopes of radiocaesium (1,000 Bq/l). Over time, it is anticipated that the activity concentration of all radionuclides in the reservoir will decrease due to increasing dilution in the reservoir and radioactive decay. As a result of these processes, it is predicted that by day 30, the activity concentration in abstracted water, prior to treatment, will be 35 Bq/l of ^{131}I, 39 Bq/l of ^{134}Cs and 15 Bq/l of ^{137}Cs, that is, all below the action levels.

Since the action levels are derived based on individuals drinking contaminated water for a full year, the risk to health from drinking water above those action levels for only a few weeks will be very low. When deciding on a remediation strategy it is therefore important that consideration is given to whether protective actions are required for the period of time until monitoring shows the average activity concentrations are below the action levels for all radionuclides (estimated to be 2-3 weeks following deposition).

Step 3 – Identify options

A remediation strategy for public drinking water supplies can be formed by considering protective actions applicable in this scenario.

Consult the look-up table on supply type (Table 25 of the handbook) to determine which of the 5 protective actions listed are applicable to public water supplies. All 5 options are applicable to the current scenario on the basis of supply type.

Options for public drinking water supply (n=5)

- Alternative drinking water supply
- Changes to water abstraction point
- Controlled blending
- Continue normal water treatment
- Flush distribution system

Step 4 – Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclide of concern in this scenario is ^{131}I (concentrations of ^{134}Cs and ^{137}Cs do not exceed the action levels).

Consult the look-up table on radionuclide applicability (Table 26 of the handbook) to determine applicability of each option for ^{131}I. Since ^{131}I has a comparatively short radiological half-life relative to the timescale required to either change the water abstraction point or carry out controlled blending, both of these options can be eliminated.

Conclusion:

- **Eliminate**: 'changes to water abstraction point', 'controlled blending'
- **Retain:** 'alternative drinking water supply', 'continue normal water treatment', 'flush distribution system'

Consider key constraints that will influence applicability of each protective action

There are constraints such as waste generation, effectiveness in reducing dose, doses to implementers, technical limitations, time constraints and cost, that may reduce the applicability of a protective action according to the circumstances under consideration.

Consult the look-up table on constraints (Table 27 of the handbook) to identify if the major or moderate constraints of any of the protective actions are relevant for the current scenario.

Options for public drinking water supply

There are 3 protective actions to consider:

- Alternative drinking water supply
- Continue normal water treatment
- Flush distribution system

There are no major constraints affecting the provision of an alternative water supply as water companies in the UK have experience in providing water using tankers or bowsers in emergency situations involving other contaminants and natural disasters (for example, floods). There are also extensive bottled water resources in the UK. Given the short half-life of radioiodine and the overall levels of contamination, the duration of time for which an alternative supply would be required should not cause significant problems with supply.

Normal water treatment involves processes such as flocculation, coagulation, slow and rapid filtration, ion exchange and activated carbon. The effectiveness of some of these treatments for ^{131}I is low (that is, less than 50% activity is removed). Normal water treatment will hasten the removal of ^{131}I from drinking water supplies and reduce the duration for which alternative supplies may need to be provided (reducing the time in which activity concentrations fall below the action level from about 3 weeks to about 2 weeks). Short-term changes to working practices may be required at the water treatment plant at Long Lake reservoir to minimise doses to operatives from handling contaminated filter media and sludge. More frequent cleaning of storage tanks and replenishment of filters and resins will help prevent high concentrations of radioactive material building up in the waste.

The flushing of the distribution system can be a major undertaking for widespread contamination. Given that a large proportion of the radioactive material is short-lived and that water treatment will further reduce activity concentrations in the distribution network post treatment, flushing would likely not be worthwhile in this case; this option can therefore be eliminated.

Conclusion:

- **Eliminate:** 'flush distribution system'
- **Retain:** 'alternative drinking water supply', 'continue normal water treatment'

Step 5 – Make decisions

By working through Step 3 (Identify options) and Step 4 (Evaluate options), it is possible to propose a remediation strategy for public drinking water supplies, as follows:

Early phase:

- Continue normal water treatment
- Alternative drinking water supply (in affected area for first few weeks until activity concentrations in mains water are below action levels)

In a real situation, stakeholders and representatives from the local community would be very much involved in any decisions on the remediation strategy.

9 References

1. UKHSA (2024). 'UK Recovery Handbook for Radiation Incidents 2024: version 5'
UK recovery handbook for radiation incidents 2024 – GOV.UK (www.gov.uk)

Annex A Decision-aiding look-up tables

The navigation and look-up tables from the UKRHRIv5 are included here for ease of reference when stepping through the examples in this document. The original table numbers from the UKRHRIv5 are included in brackets in the table headers and it is these numbers that are referred to in the main text. A breakdown of the tables included in this annex is given in Table A1.

Table A1 (UKRHRIv5 Table 21). Navigation to look-up tables

Elimination criteria	Food	Drinking water	Inhabited area
Types or surfaces	Table A2 (UKRHRIv5 Table 22)	Table A5 (UKRHRIv5 Table 25)	Table A8 (UKRHRIv5 Table 28)
Radionuclides	Table A3 (UKRHRIv5 Table 23)	Table A6 (UKRHRIv5 Table 26)	Table A9 (UKRHRIv5 Table 29)
Constraints	Table A4 (UKRHRIv5 Table 24)	Table A7 (UKRHRIv5 Table 27)	Table A10 (UKRHRIv5 Table 30)

Table A2 (UKRHRIv5 Table 22). Food production systems: protective actions by food type (commercial and non-commercial production)

In this table white cells indicate ‘Applicable’, cells shaded dark grey indicate ‘Not applicable’.

Category or option	Commercial					Non-commercial	
	Milk	**Meat intensive**	**Meat extensive**	**Fish and other aquatic foods**	**Crops and grassland**	**Domestic**	**Foraging, hunting or fishing**
Preventing contamination of food before release							
Close air intake in greenhouses and food processing plants							
Protect harvested crops from deposition							
Shelter livestock							
Restricting, preventing or reducing consumption of contaminated food							
Dietary advice, including culinary preparation							
Processing and storage (commercial)							
Product withdrawal and recall							
Restrictions on hunting and fishing							
Restrictions on terrestrial or aquatic foods (FEPA orders)							
Select alternative land use (non-edible products)							
Slaughter and suppress lactation							
Monitoring and dose or risk assessment							
Consumer access to monitoring equipment							

Category or option	**Commercial**					**Non-commercial**	
	Milk	**Meat intensive**	**Meat extensive**	**Fish and other aquatic foods**	**Crops and grassland**	**Domestic**	**Foraging, hunting or fishing**
Derestriction surveys and dose assessment							
Live monitoring (Mark and Release)							
Natural attenuation with monitoring							
Land management							
Application of NPK fertilisers and/or lime to soils							
Ploughing options							
Remove topsoil							
Livestock management							
Addition of AFCF to concentrate ration							
Addition of calcium to concentrate ration							
Addition of clay minerals to concentrate ration							
Administer AFCF boli to ruminants							
Clean feeding							
Manipulate slaughter times							
Selective grazing							

Table A3 (UKRHRIv5 Table 23). Applicability of protective actions for food production systems according to radionuclide

In this table white cells indicate 'Applicable', cells shaded dark grey indicate 'Not applicable'. A key to the reasons options are not applicable (cells containing letters) is provided below the table.

Category or options	^{60}Co	^{75}Se	^{90}Sr/^{90}Y	^{106}Ru	^{131}I	^{134}Cs	^{137}Cs	^{192}Ir	^{235}U	^{239}Pu	^{241}Am
Preventing contamination of food before release											
Close air intake in greenhouses and food processing plants											
Protect harvested crops from deposition											
Shelter livestock											
Restricting, preventing or reducing consumption of contaminated food											
Dietary advice, including culinary prep.											
Processing and storage of food (commercial)	a			a					b, c	c	c
Product withdrawal and recall											
Restrictions on hunting and fishing											
Restrictions on terrestrial or aquatic foods											
Select alternative land use		d		d	d			d	b	b	b
Slaughter and suppress lactation					d				b	b	b
Monitoring and dose or risk assessment											
Consumer access to monitoring equipment			e						b	b	

Category or options	^{60}Co	^{75}Se	^{90}Sr/^{90}Y	^{106}Ru	^{131}I	^{134}Cs	^{137}Cs	^{192}Ir	^{235}U	^{239}Pu	^{241}Am
Derestriction surveys and dose assessment			e						b	b	
Live monitoring or mark and release			e						b	b	
Natural attenuation with monitoring			e			c	c	c	b, c	c	c
Land management											
Application of NPK fertilisers and/or lime to soils	Lime only	f, g	Lime only	Lime only	f	NPK only	NPK only	NPK only	Lime only	Lime only	NPK only
Ploughing options					d				g		
Removal of topsoil					d						
Livestock management											
Addition of AFCF to concentrate ration	f	f	f	f	f			f	f	f	f
Addition of calcium to concentrate ration	h	h		h	h	h	h	h	h	h	h
Addition of clay minerals to concentrate ration	f	f	f	f	f			f	f	f	f
Administration of AFCF boli to ruminants	f	f	f	f	f			f	f	f	f
Clean feeding											
Manipulate slaughter times	b			b				b	b	b	b
Selective grazing	b			b	d				b	b	b

Key to Table A3

a - No evidence that it would be effective.

b - Radionuclide either has low feed-to-meat or milk transfer, or low soil-to-plant transfer making this rather disruptive protective action inappropriate.

c - Protective action only effective for short-lived radionuclides, that is, protective action must have a short timescale for implementation.

d - Comparatively short physical half-life of radionuclide relative to timescale of implementation of the protective action, that is, the radionuclide may have decayed to levels where action is no longer justified.

e - No easily detectable radiations emitted, precludes protective actions relying on detection.

f - Protective action specific for Cs.

g - Protective action increases mobility of some radionuclides in soil (that is, pH effect of applying lime or ploughing).

h - Protective action specific for radionuclides in Group 2 of the periodic table.

Table A4 (UKRHRIv5 Table 24). Details of major and moderate constraints of protective actions for food production systems

Category or option	Major constraints	Moderate constraints
Preventing contamination of food before release		
Close air intake in greenhouses and food processing plants	**Time** • a decision needs to be made quickly as this option would need to be implemented as soon as the possibility of a release is identified • there needs to be enough time between notification of the release and arrival of the contamination to travel to sites to switch off ventilation systems	**Doses to implementers** • when closing air intake or ventilation system, no exposure if completed before arrival of the contaminated air; otherwise, potential for external exposure from the plume, external exposure to deposited contamination and inhalation of contaminated air
Protect harvested crops	**Time** • a decision needs to be made quickly as this option would need to be implemented as soon as the possibility of a release is identified • there needs to be enough time between notification of the release and arrival of the contamination, to travel to, and then cover harvested crops; cannot be done in areas where population is advised to shelter	**Technical** • availability of covering materials and means to secure them • high winds can affect implementation **Doses to implementers (farmers)** • when applying covering materials, no exposure if completed before the arrival of the contaminated air; otherwise, potential for external exposure from the plume, external exposure to deposited contamination and inhalation of contaminated air • when removing covering materials, external exposure from contamination. Depending on how the cover is removed and weather conditions, resuspension of dusts may occur so inhalation or ingestion can be important

Category or option	Major constraints	Moderate constraints
Shelter livestock	**Time** • a decision needs to be made quickly as this option would need to be implemented as soon as the possibility of a release is identified • there needs to be enough time between notification of the release and arrival of the contamination, for farmers to gather and shelter livestock; cannot be done in areas where population is advised to shelter **Technical** • distance between pastures and shelters • availability of suitable housing with water supply and stored feed • availability of farm workers to look after housed livestock	**Doses to implementers (farmers)** • when bringing livestock indoors, no exposure if completed before arrival of contaminated air; otherwise, potential for external exposure from the plume, external exposure to deposited contamination and inhalation of contaminated air
Restricting, preventing or reducing consumption of contaminated food		
Dietary advice, including culinary preparation	None	**Technical** • availability of appropriate lines of communication **Timing** • Washing, removal of outer leaves or peeling are most effective if carried out soon after deposition **Effectiveness** • blanching, boiling and de-boning have low effectiveness with reductions in activity concentrations of less than a factor of 2

Category or option	Major constraints	Moderate constraints
Processing and storage of food (commercial)	**Technical** • availability of equipment as it may be in use all year (and acceptability to implementors)	**Cost** • decontamination of equipment **Doses to implementers** • external exposure at processing plants, where radionuclides are concentrated in waste **Effectiveness** • highly variable depending on half-life of radionuclide, mode of contamination, processing method and storage time • for techniques such as boiling and salting, effectiveness is low with reductions in contamination of less than a factor of 2
Product withdrawal and recall	None	**Technical** • efficiency of tracking mechanism, methods of communication and clarity of information **Waste** • recalled food products will require disposal **Effectiveness** • withdrawal can be highly effective. Recall can be less effective as it is difficult for the recall message to reach all purchasers of affected batches. Consumption of some food above MPLs not likely to have any significant effects on health
Restrictions on hunting and fishing	None	**Technical** • ability to predict times during the season when radionuclide levels will be below MPLs

Category or option	Major constraints	Moderate constraints
		• availability of appropriate lines of communication **Effectiveness** • highly variable, depending on availability of contaminated foodstuffs (for example, mushrooms) before and during hunting season (varies by year, time, and location) and willingness of individuals to comply with restrictions
Restrictions on terrestrial or aquatic foods (FEPA orders)	**Time** • needs to be enforced as soon as possible **Waste** • there may be significant amounts of contaminated food products that will require disposal	**Technical** • requirement to establish a monitoring and surveillance programme **Effectiveness** • variable for foods gathered from the wild, depending on how well the message is communicated and compliance by consumers
Select alternative land use	**Technical** • expertise in cultivation of alternative products **Cost** • availability of a market for alternative products and investment in specialist equipment • likely to require financial support and compensation	**Doses to implementers** • variable, depending on alternative practices (for example, processing plant operative: external exposure to non-food crop; operative at wood burning power plants (from coppice) – external exposure from fly-ash

Category or option	Major constraints	Moderate constraints
Slaughter and suppress lactation	**Time** • slaughter of livestock may be considered in the early phase if farmers have been evacuated **Technical** • availability of slaughtering equipment and licensed slaughter persons in early phase	**Waste** • livestock carcasses considered unfit for the food chain will require further action (that is, rendering, incineration, landfill, or burial) **Effectiveness** • for dairy animals contaminated milk will be produced until lactation is suppressed – this milk will require disposal **Cost** • Expensive when carried out on a large scale
Monitoring and dose or risk assessment		
Consumer access to monitoring equipment	**Time** • time will be required to manufacture and calibrate monitoring kits and train personnel	**Technical** • provision of information about results and their interpretation
Derestriction surveys and dose assessment	None	**Time** • to gather livestock and to carry out surveys **Technical** • availability of suitable dose assessment models, particularly probabilistic models **Doses to implementers (monitoring operatives)** • external exposure while working in a contaminated area (terrestrial); external irradiation from radionuclides in sediment (aquatic)
Live monitoring or mark and release	**Time** • time will be required to manufacture and calibrate monitoring kits and train personnel	**Technical** • availability of suitable detectors (for example, sodium iodide) and trained personnel

Category or option	Major constraints	Moderate constraints
		Doses to implementers (monitoring operatives) • external exposure from land and livestock while working in a contaminated area
Natural attenuation with monitoring	**Time** • it may take an unacceptably long time given land use or stakeholder concerns before decrease in activity levels from radioactive decay and weathering has reduced doses to acceptable levels	**Technical** • monitoring equipment and trained personnel are required to take measurements and samples **Effectiveness** • relies on radioactive decay, so best suited to short-lived radionuclides. Physical and chemical processes also affect availability and uptake **Doses to implementers (monitoring operatives)** • external exposure while working in a contaminated area, inhalation of material resuspended by the wind
Land management		
Application of NPK fertilisers and/or lime to soils	**Technical (lime)** • only applicable if soil has low pH or calcium status **Technical (potassium)** • only applicable if soil has low potassium status	**Technical lime)** • may increase mobility of some radionuclides and induce micronutrient deficiencies **Technical (lime and NPK)** • restrictions may be imposed in areas designated as nitrate vulnerable zones or affected by environmental protection schemes (for example, special areas of conservation, special protection areas) **Effectiveness** • potassium is most effective when exchangeable potassium status is less than 0.5 milli equivalents per

Category or option	Major constraints	Moderate constraints
		100 grams of soil, that is, 0.5 meq per 100 g soil (not a condition common in UK) • liming of soils with pH greater than 7 has no effect. Application of lime increases the mobility of ^{75}Se, ^{134}Cs, ^{137}Cs due to change in soil pH **Doses to implementers** • from external exposure and, to a lesser extent, inadvertent ingestion and inhalation while spreading or ploughing
Ploughing options	**Technical** • not applicable if soil is very wet, sandy, frozen, stony, or on a steep slope • not applicable if crop is present • for deep ploughing, a soil depth of more than 0.5 m is required; must be implemented before normal ploughing has been undertaken	**Technical (shallow and deep ploughing)** • restrictions may be imposed in areas designated as nitrate vulnerable zones or affected by environmental protection schemes (for example, special areas of conservation, special protection areas) • complicates the removal of contaminated soil in the future; contamination is moved closer to the ground water • deep ploughing affects soil fertility **Effectiveness** • shallow ploughing reduces plant uptake by less than a factor of 2; deep ploughing is more effective than shallow ploughing; good reductions in external doses from all ploughing options **Doses to implementers** • from external exposure and, to a lesser extent, inadvertent ingestion and inhalation while ploughing

Category or option	Major constraints	Moderate constraints
Removal of topsoil	**Technical** • not applicable if crop is present or if soil is shallow, stony, uneven **Waste** • there may be significant volumes of contaminated soil requiring disposal **Cost** • may be high, considering: ○ equipment ○ personnel ○ size of the affected area and volume of topsoil requiring disposal	**Technical** • restrictions may be imposed in areas designated as nitrate vulnerable zones or affected by environmental protection schemes (for example, special areas of conservation, special protection areas) • soil fertility may be affected, depending on depth removed **Doses to implementers (when removing soil)** • external exposure from contamination in topsoil; inadvertent ingestion of contaminated soil; inhalation of resuspended soil
Livestock management		
Addition of AFCF to concentrate ration	**Technical** • availability of AFCF and identification of feed manufacturing plants that will add AFCF to feed pellets	**Technical** • implications for farms with ‘organic’ status **Time** • a period of adaptation may be required for livestock

Category or option	Major constraints	Moderate constraints
Addition of calcium to concentrate ration	None	**Technical** • availability of calcium supplements, or pelleted concentrates with enriched levels of calcium **Effectiveness** • doubling of calcium intake results in reductions of approximately 50% (that is, by around a factor of 2) in the transfer of radiostrontium to milk; larger reductions are achievable in animals with low dietary calcium status prior to supplementation
Addition of clay minerals to concentrate ration	None	**Technical** • may be limited availability of clay minerals or infrastructure (that is, feed manufacturing plants) to add clay minerals to feed (clay mineral needs to be compliant with animal feed legislation) • may have implications for farms with ‘organic’ status **Time** • a period of adaptation may be required for livestock
Administration of AFCF boli to ruminants	**Technical** • availability of AFCF and identification of manufacturing plants that can produce AFCF boli	**Technical** • implications for farms with ‘organic’ status **Doses to implementers (farmer)** • external exposure while collecting livestock from pasture
Clean feeding	**Technical** • availability of suitable housing with water, power supply, straw for bedding and	**Doses to implementers (farmers)** • external exposure from gamma-emitting radionuclides during gathering of livestock

Category or option	Major constraints	Moderate constraints
	ventilation; availability of alternative clean feed	**Cost** • may be high, considering: ○ number of affected animals ○ consumables (that is, clean feed)
Manipulate slaughter times	**Technical** • if immediate slaughter is ordered, availability of abattoir or on-farm slaughtering equipment	**Technical** • if prolonged slaughter, availability of additional feed and any implications for animal welfare **Doses to implementers (farmers and slaughter workers)** • external exposure from gamma-emitting radionuclides during gathering and slaughtering on farm in the early phase
Selective grazing	**Technical** • availability of less contaminated pasture in the area	**Doses to implementers (farmers)** • external exposure from gamma-emitting radionuclides while collecting or moving livestock to less contaminated pasture **Time** • to transport animals to less contaminated pasture

Table A5 (UKRHRIv5 Table 25). Drinking water supplies: protective actions by supply type

In this table white cells indicate ‘Applicable’, cells shaded dark grey indicate ‘Not applicable’. A key to further information for some options (cells containing letters) is provided below the table.

Category or option	Public supply	Private supply
Alternative drinking water supply		
Changes to water abstraction point		
Controlled blending		
Continue normal water treatment		a
Flush distribution system		b

Key to Table A5

a - Some private drinking water supplies may include treatment that would reduce levels of radioactivity, for example, membrane plants, sand filtration, or cartridge filters.

b - May be viable for larger private water supplies if sufficient water available for flushing or else an alternative supply may be pumped from a tanker into a private distribution network to flush the system.

Table A6 (UKRHRIv5 Table 26). Applicability of protective actions for drinking water supplies according to radionuclide

In this table white cells indicate ‘Applicable’, ‘a’ on a grey background indicates that comparatively short physical half-life of radionuclide relative to timescale of implementation of the protective action, that is, the radionuclide may have decayed to levels where action is no longer justified.

Category or option	^{60}Co	^{75}Se	^{90}Sr/^{90}Y	^{106}Ru	^{131}I	^{134}Cs	^{137}Cs	^{192}Ir	^{235}U	^{239}Pu	^{241}Am
Alternative drinking water supply											
Changes to abstraction point					a						
Controlled blending					a						
Continue normal water treatment											
Flush distribution system											

Table A7 (UKRHRIv5 Table 27). Details of major and moderate constraints of protective actions for drinking water supplies

Option	Major constraints	Moderate constraints
Alternative drinking water supply	None	**Technical** • if bowsers are used, there is a requirement to sample the water in them every 48 hours and analyse for a full suite of contaminants or to refresh the water on a regular basis; this would involve a number of personnel and significant resources in the laboratory depending on the number of bowsers or tanks required and tankering requirements • there may also be a limit on the number of tankers or bowsers available, especially if large area affected • suitable road networks required for distribution via large vehicles or tankers **Cost** • may be high, considering: vehicle hire (tankers and bowsers); consumables (fuel, bottles, or containers for transporting water); personnel (that is, travelling time for drivers, possibly unsocial hours, as well as costs associated with sampling and analysis)
Changes to abstraction point	**Technical** • widespread contamination or water shortages during periods of drought could result in fewer opportunities for changing abstraction points or water sources • it may not be feasible to provide an alternative abstraction point without significant engineering	**Effectiveness** • depends on the availability of alternative ‘clean’ abstraction points. Where surface water has been contaminated, then the effectiveness of switching could be low **Time** • it takes time to identify, monitor and organise connection to an alternative abstraction point; ideally, this would be done as soon as possible to be effective

Option	Major constraints	Moderate constraints
Controlled blending	**Technical** • depends on whether it is technically feasible to blend several water supplies (pipework connectivity issues); widespread contamination or water shortages during periods of drought could result in fewer opportunities for blending	**Effectiveness** • depends on the availability of alternative 'clean' water supplies. Where the area of contamination is large and the supplies come from surface water, then the effectiveness of blending could be low **Time** • it takes time to identify, monitor and organise connection to an alternative supply for the purposes of blending; ideally, this would be done as soon as possible to be effective
Continue normal water treatment	**Effectiveness** • some treatments (flocculation, coagulation, slow and rapid filtration, activated carbon) have low effectiveness for radiocaesium, strontium and iodine nuclides (that is, less than 50% activity is removed) **Doses to implementers** • changes to working practices may be required to minimise doses to operatives at the treatment works; in particular the sludge handling tasks can give rise to high doses from external exposure and inhalation of resuspended material	**Waste** • contaminated material from filter or resin beds, wastewater or sludge may be concentrated in certain waste streams or sludges; this may necessitate more frequent cleaning of storage tanks and replenishment of filters and resins to prevent high concentrations of radioactive waste arising and potential recontamination of water

Option	Major constraints	Moderate constraints
Flush distribution system	**Technical** • major undertaking for large distribution networks with widespread contamination; usually used for clearance of local contamination in a distribution system: there also needs to be a good understanding of the distribution network and access points	**Waste** • contaminated water from flushing the network; disposal to the sewer system would move the contamination into the wastewater treatment process; disposal to environment (that is, river) may contaminate another drinking water source

Table A8 (UKRHRIv5 Table 28). Inhabited areas: protective actions by surface type

In this table white cells indicate ‘Applicable’, cells shaded dark grey indicate ‘Not applicable’. A key to further information for some options (cells containing letters) is provided below the table.

Category or option	Building (external)	Building (internal)	Roads and paved	Open green spaces
No active remediation				
Natural attenuation with monitoring				
Restrict access				
Prohibit public access				
Temporary relocation				
Shielding				
Cover contaminated soil and grass				
Ploughing methods and mechanical digging techniques				
Store and cover personal and precious objects				
Tie down				
Physical removal				
High pressure washing including water jetting		a		
Remove and replace road and paved surfaces				
Remove building surfaces		a		
Remove grass after cutting				
Remove plant material				
Remove topsoil (and turf)				
Strippable coatings				
Vacuum cleaning (indoor and outdoor)				

Category or option	Building (external)	Building (internal)	Roads and paved	Open green spaces
Chemical removal				
Reactive liquids (domestic chemicals)	b			
Water-based cleaning	b			

Key to Table A8

a - Large buildings only.

b - Only applicable to some exterior metal, glass, and wooden surfaces, for example, fences, benches.

Table A9 (UKRHRIv5 Table 29). Applicability of protective actions for inhabited areas according to radionuclide

In this table white cells indicate ‘Applicable’, cells shaded dark grey indicate ‘Not applicable’. A key to the reasons options are not applicable (cells containing letters) is provided below the table.

Category or option	^{60}Co	^{75}Se	^{90}Sr/^{90}Y	^{106}Ru	^{131}I	^{134}Cs	^{137}Cs	^{192}Ir	^{235}U	^{239}Pu	^{241}Am
No active remediation											
Natural attenuation (with monitoring)	a		a, b	a, b		a	a		a, b	a, b	a, b
Restrict access											
Prohibit public access											
Temporary relocation											
Shielding											
Cover contaminated soil and grass					c			c			
Ploughing and mechanical digging techniques	a		a				a		a	a	a
Store and cover personal and precious objects	a		a				a		a	a	a
Tie down											
Physical removal											
High pressure washing including water jetting											
Remove and replace road and paved surfaces					c			c			
Remove building surfaces					c			c			
Remove grass after cutting											
Remove plant material											
Remove topsoil (and turf)					c			c			
Strippable coatings					c			c			
Vacuum cleaning (indoor and outdoor)											
Chemical removal											

Category or option	^{60}Co	^{75}Se	^{90}Sr/^{90}Y	^{106}Ru	^{131}I	^{134}Cs	^{137}Cs	^{192}Ir	^{235}U	^{239}Pu	^{241}Am
Reactive liquids (domestic chemicals)									d	d	d
Water-based cleaning											

Key to Table A9

a - Protective action more suitable for short-lived radionuclides.

b - No easily detectable radiations emitted.

c - Protective action more suitable for long-lived radionuclides.

d - Potential for undesirable consequences in terms of waste management.

Table A10 (UKRHRIv5 Table 30). Details of major and moderate constraints of protective actions for inhabited areas

Category or option	Major constraints	Moderate constraints
No active remediation		
Natural attenuation (with monitoring)	**Time** • it may take an unacceptably long time before decrease in activity levels from radioactive decay and weathering has reduced doses to acceptable levels	**Effectiveness** • more effective for radionuclides with short half-lives, or where weathering rates are high **Technical** • monitoring equipment and skilled personnel are required to take measurements and samples to build confidence with the public **Doses to implementers** • external exposure to monitoring and sampling teams from deposited radionuclides
Restrict access		
Prohibit public access	**Time** • this option should be implemented as soon as a contaminated area is identified; the option will be in place until the doses have been assessed and options for managing doses have been agreed	**Technical** • large areas will require extensive fencing and signage **Doses to implementers** • external exposure from deposited radionuclides to people erecting signage and security guards
Temporary relocation	**Technical** • availability of alternative accommodation (hotels, bed and breakfast, self-catering, hostels and so on) • availability of drivers and transport to aid relocation, especially for those unable to drive themselves	**Doses to implementers** • external exposure to drivers with potential for inhalation of resuspended material from vehicles used for relocation

Category or option	Major constraints	Moderate constraints
	• disruptive to people affected	**Cost** • this measure can prove to be expensive for local authorities responsible for relocating residents **Time** • the maximum period that temporary relocation could be tolerated, for example, impact on mental health and psychosocial well-being
Shielding		
Cover contaminated soil and grass	**Technical** • can only be implemented on a small scale as very large quantities of shielding materials are required • affects aesthetics of gardens and may impact landscape	**Technical** • restricts future land use, so needs careful targeting • cannot be applied on steep slopes, or to surfaces covered in standing water; trees and shrubs may need felling • leaching to or from water courses • contamination remains in place which may cause anxiety **Doses to implementers** • external exposure from deposited radionuclides
Ploughing and mechanical digging techniques	**Technical** • soil depth and presence of buried pipes, roots and so on may restrict where ploughing or digging can be carried out	**Technical** • complicates subsequent options for removal of contaminated soil. In some cases, contamination is moved closer to groundwater • cannot be done on steep slopes, or where surfaces are covered in standing water

Category or option	Major constraints	Moderate constraints
		• contamination remains in place which may cause anxiety **Doses to implementers** • external exposure from deposited radionuclides; potential for inhalation of resuspended material while ploughing or digging, so use of tie-down recommended
Store and cover personal and precious objects	**Time** • particularly suitable for short-lived radionuclides (that is, 2 years or less)	**Technical** • availability of storage locations, including logging, tracking, transportation and return of items
Tie down	**Time** • the maximum benefit, in terms of dose reduction and prevention of secondary contamination, can be achieved when applied early **Technical** • some techniques may be adversely affected by cold and wet weather, high temperatures and high humidity and uneven surfaces	**Doses to implementers** • external exposure from deposited radionuclides **Time** • depending on choice of coating, longevity of the option could be one month to one year
Physical removal		
High pressure washing including water jetting	**Time** • needs to be implemented soon after deposition **Waste** • pressure washers may produce large volumes of effluent and wastewater; to prevent run off, the effluent may be collected in tanks or temporary bunded areas for subsequent disposal	**Technical** • walls and roofs must be waterproof and resistant to water at high pressure; the technique cannot be carried out in severe cold weather • use on listed and historic building may be restricted

Category or option	Major constraints	Moderate constraints
		Doses to implementers • external exposure from deposited radionuclides. Potential for inhalation of resuspended material as dust or spray
Remove and replace road and paved surfaces	**Time** • maximum benefit if carried out soon after deposition **Waste** • large quantities of contaminated tarmac or concrete will be produced **Cost** • expensive depending on the area removed and replaced so use likely to be restricted to the most contaminated areas or areas of high use	**Technical** • uneven surface and road camber can make surface removal difficult • tie-down may be needed to suppress resuspension, including contamination of new surfaces from contamination present in surrounding environment • other actions may be needed to prevent run-off and contamination of surroundings **Doses to implementers** • external exposure from deposited radionuclides. Potential for inhalation of resuspended material as dust or spray, so use of tie-down recommended
Remove building surfaces	**Technical** • methods intended for large areas with simple geometry. Unsuited to complex or undulating surfaces **Waste** • depends on technology used; sandblasting will produce the most waste and creates a significant secondary contamination potential	**Technical** • each method requires some supporting infrastructure, access equipment and facilities for waste capture and packaging • use on listed and historic building may be restricted • potentially damaging **Doses to implementers** • external exposure from deposited radionuclides. Potential for inhalation of resuspended material

Category or option	Major constraints	Moderate constraints
		as dust or spray, so use of tie-down recommended
Remove grass after cutting	**Time** • maximum benefit if carried out soon after deposition **Waste** • large volumes of putrescible material **Effectiveness** • minimum benefit after rain	**Technical** • uneven, rocky ground may be unsuitable for mowing. Soft underlying soils may prevent use of heavy machinery **Effectiveness** • reduces activity concentrations by less than a factor of 2 **Doses to implementers** • external exposure from deposited radionuclides. Potential for inhalation of resuspended material as dust, so a light dampening of the surface may be required beforehand
Remove plant material	**Time** • maximum benefit if carried out soon after deposition and before rain; for deciduous trees, leaves should be removed soon after they fall **Waste** • volumes can be large, so options for chipping, shredding, and composting should be considered	**Technical** • steep slopes, densely packed woodland, waterlogged soils restrict access for heavy machinery **Doses to implementers** • external exposure from deposited radionuclides; potential for inhalation of resuspended material
Remove topsoil (and turf)	**Waste** • large quantities of contaminated soil and vegetation	**Technical** • rocky, uneven, frozen, and waterlogged soils restrict machinery

Category or option	Major constraints	Moderate constraints
		• for turf to be removed, grassed area must be mature, that is, with an established root mat **Doses to implementers** • external exposure from deposited radionuclides; potential for inhalation of resuspended material as dust or spray, so use of tie-down recommended
Strippable coatings	**Time** • maximum benefit if carried out soon after deposition when contamination is still on the surface **Technical** • strippable coatings are temporary (under 12 months) before there are signs of physical degradation; other non-strippable coatings can be used, for example paints for longer term	**Technical** • can be a cost-effective option • cannot be applied in wet or cold weather (less than 4°C) • cannot be applied to fragile surfaces due to potential for damage if or when peeled off, surfaces need to be robust • with increasing surface roughness or complexity, strippable coatings become more difficult to remove without a thicker coat and increased cost **Doses to implementers** • external exposure from deposited radionuclides. Potential for inhalation of resuspended material
Vacuum cleaning (indoor and outdoor)	**Time** • maximum benefit if carried out soon after deposition when maximum contamination is on surfaces **Technical** • only of value for loose particulates or dusty contamination	**Waste** • potential for high levels of contamination on indoor vacuum cleaner filters (low volume); larger volumes of dust and sludge from outdoor vacuuming

Category or option	Major constraints	Moderate constraints
	• outdoor vacuuming of large areas requires specialist equipment	**Effectiveness** • highly variable, depending on the nature and condition of the surface • use on concrete and other porous surfaces must be evaluated to prevent 'soaking' contamination into the substrate **Doses to implementers** • external exposure from deposited radionuclides; potential for inhalation of resuspended material
Chemical removal		
Reactive liquids (domestic chemicals)	**Time** • 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	**Technical** • most effective on non-porous surfaces and there must be a good understanding of the chemical form of the deposition and radionuclide mix **Effectiveness** • highly variable, according to porosity of substrate and physical-chemical form of the radionuclides **Waste** • liquid waste may require treatment to remove chemicals prior to release into the environment; if radioactivity levels are high, specialist on- or off-site treatment may be required using more aggressive chemical options **Doses to implementers**

Category or option	Major constraints	Moderate constraints
		• external exposure from deposited radionuclides; potential for inhalation of resuspended material as dust or spray
Water-based cleaning	**Time** • maximum benefit if carried out within a few days of deposition when maximum contamination remains on surfaces and before natural weathering or 'traffic' can disperse contamination throughout the environment	**Effectiveness** • likely to be much lower for rough exterior surfaces such as concrete, stone and brick surfaces and rough indoor surfaces such as carpets, rugs, and upholstery; low for difficult to reach surfaces • highly variable, according to porosity of substrate and physical-chemical form of the radionuclides **Waste** • if radioactivity levels are high, specialist on- or off-site treatment may be required **Doses to implementers** • external exposure from deposited radionuclides; potential for inhalation of resuspended material as dust or spray

About the UK Health Security Agency

UKHSA is responsible for protecting every member of every community from the impact of infectious diseases, chemical, biological, radiological and nuclear incidents and other health threats. We provide intellectual, scientific and operational leadership at national and local level, as well as on the global stage, to make the nation health secure.

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